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ESSAYS ON ENVIRONMENTAL ECONOMICS AND POLICY

Mehdi Nemati

University of Kentucky, mehdi.nemati@uky.edu
Author ORCID Identifier:
https://orcid.org/0000-0002-4736-7489
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ESSAYS ON ENVIRONMENTAL ECONOMICS AND POLICY

DISSERTATION

A dissertation submitted in partial
fulfillment of the requirements for the
degree of Doctor of Philosophy in the
College of Agriculture, Food and
Environment at the University of Kentucky

By

Mehdi Nemati
Lexington, Kentucky

Co-Directors: Dr. Steven C. Buck, Assistant Professor of Agricultural Economics
and   Dr. Wuyang Hu, Professor of Agricultural Economics

Lexington, Kentucky

ABSTRACT OF DISSERTATION

ESSAYS ON ENVIRONMENTAL ECONOMICS AND POLICY

Environmental goals such as urban water conservation and pollution control regulations are typically achieved through price and non-price methods. This dissertation offers an analysis of the non-price approaches, including the rationing of water for particular users, installation of particular technologies, and adoption of particular certifications to achieve environmental goals. To begin, an analysis of California's 2015 urban water conservation mandate was performed. Results indicate that the average welfare loss of the mandate is $6,107 per acre-foot of restriction in Northern California and $2,757 per acre-foot of restriction in Southern California. In terms of monthly household-level willingness-to-pay (WTP) to avoid the mandate, results illustrate that households have a WTP between $5 and $200 per month. Northern Californian utilities were generally in compliance with their mandated conservation targets, while Southern Californian utilities tended to fall short. The second essay focuses on analyzing how web-based Home Water Use Reports (HWURs) affect household-level water consumption in Folsom City, California. The HWURs under study, offered by the company Dropcountr (DC), share social comparisons, consumption analytics, and conservation information to residential accounts, primarily through digital communications. We found that there is a 7.8% reduction in average daily household water consumption for a typical household under treatment of the DC program. Results suggest that the effect of DC varies by the baseline consumption quintile, the number of months in the program, the day of the week, message type, and enrollment wave. Furthermore, we find that indicate these responses to DC program likely come from the information channel rather than moral suasion. The final essay studies the effectiveness of ISO-14001 on pollution reduction as a non-price pollution control approach. Manufacturers have been increasingly relying on environmental management systems (such as ISO 14001 based ones) to comply with government regulations and reduce waste. In this essay, we investigated the impact of ISO 14001 certification on manufacturers' toxic release by release level. Results show that ISO 14001 had a negative and statistically significant effect on the top 10% manufacturing sites regarding the on-site toxic release, but it did not reduce off-site toxic release. Therefore, one should not expect ISO 14001 to have a uniform impact on manufacturing sites' environmental performance. For large firms, encouraging voluntary adoption of ISO 14001 might be an effective government strategy to reduce on-site pollution.

KEYWORDS: Non-price environmental policy, Water Conservation, Automated Meters, Mandate, ISO-14001.

Mehdi Nemati

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June 4, 2018

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ESSAYS ON ENVIRONMENTAL ECONOMICS AND POLICY

By

Mehdi Nemati

Dr. Steven Buck

Co-Director of Dissertation

Dr. Wuyang Hu

Co-Director of Dissertation

Dr. Carl Dillon

Director of Graduate Studies

June 4, 2018

To my beautiful wife Samane and my precious daughter Isla

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Chapter 1.   INTRODUCTION

1.1 Background

Policymakers have two broad types of instruments for meeting environmental goals. They can use non-price methods including regulatory—command and control-- and voluntary approaches, or they can use market-based approaches that rely on market forces. Despite the popularity of non-price approaches, empirical work is credibly identifying both the effectiveness and consequences of these policies as well as the heterogeneous effects of these policies among different groups remains in its infancy. My dissertation focuses on the development of empirical methods to investigate the non-price approaches in addressing environmental issues as well as exploring the heterogenous implications of these policies.

These questions are important not only as a justification for using non-price approaches to achieve environmental goals and evaluating alternative options but also for understanding how heterogenous effects may shape the design and implementation of these policies. For example, a general problem with the regulatory approaches, such as urban water mandates, is that they are associated with consumer or producer welfare losses. It is important to assess these losses because it improves our understanding of the cost of these policies which is maybe to some policymakers is not so tangible. Also, estimating welfare cost of such policies is useful for evaluating alternative policy options including market-based approaches. A general problem with voluntary actions to reduce environmental externalities, such as reducing water consumption or pollution level, is that it is empirically difficult to assess the success of these programs. However, given the

number of voluntary approaches being implemented in the United States as a way to achieve the environmental goals, measuring the effectiveness of these programs has become increasingly important. My dissertation investigates these questions in the context of programs and policies that are important in their own right. Chapter 2 of my dissertation explores the welfare costs associated with the recent environmental regulatory program in the United States, California's 2015 urban water mandate. Chapters 3 and 4 examine the effectiveness of voluntary policies in the context of water conservation technology adoption and pollution reduction certification adoption. My dissertation remains unified in both its subject matter and methodological approach – using unique sources of data and sound research designs to understand important issues in environmental policy.

Furthermore, both welfare losses of regulatory approaches and effectiveness of voluntary approaches are potentially different among different groups of consumers or producers, for example, depending on the income, consumption or production level, firm size or other demographics Understanding heterogeneous effects of these policies will allow targeting groups that are most responsive, which will be a cost-effective strategy (Djebbari and Smith 2008, Ferraro and Miranda 2013, Heckman, Smith, and Clements 1997). Also, investigating heterogeneous effects by subgroups helps researchers understand generalizability of the result to other populations and places (Ferraro and Miranda 2013, Imai and Ratkovic 2013, Manski 2004). In all three essays, I examine the heterogeneity of the results and evaluate the implications of these heterogeneities.

1.2 Objectives and Structure

The purpose of this dissertation is to improve our understanding of regulatory and

voluntary approaches as an environmental policy. The primary focuses are on understanding welfare effects of regulatory policies, the effectiveness of voluntary approaches and heterogeneity of these effects. To achieve these goals, we focus on three programs in the United States. First, we examine the recent regulatory policy that has been implemented in California. In April 2015, governor of California, Jerry Brown, issued an executive order mandating a statewide reduction in urban water use by 25% because of a multi-year drought. We estimate the welfare losses due to California's 2015 water conservation mandate as a regulatory approach. Second, we examine the effectiveness of a voluntary water consumption analytics program to reduce water consumption. Finally, we study the effectiveness of voluntary adoption of ISO-14001 certification by manufacturing facilities on pollution reduction.

In the second chapter, we measure the welfare consequences of the 2015 California drought mandate. In response to the severe California drought, in April 2015 Governor Jerry Brown issued an executive order mandating a statewide reduction in water use. The mandate aims to reduce the amount of water consumed statewide in urban areas by 25% from 2013 levels. The State Water Resources Control Board (SWRCB) proposed regulatory instructions that grouped urban water suppliers into nine tiers, with conservation standards ranging from 8% to 36%. In this chapter, we evaluate welfare losses due to this mandate. Understanding the proposed regulation's welfare losses requires estimating water demand. Using a fixed effect model and data from 2004 to 2009 on 111 urban water utilities an annual demand curve is estimated. The estimated demand elasticity is between -0.61 and -0.1 which is heterogeneous across the regions. In the second step, we use estimated annual demand function to recover price elasticities in

a sample of 53 urban water utilities in California which provide water for more than 20 million customers. We calculate the average welfare loss of the mandate to be $6,107 per acre-foot of restriction in Northern California and $2,757 per acre-foot of restriction in Southern California. In terms of monthly household-level willingness-to-pay (WTP) to avoid the mandate, we find households have a WTP between $5 and $200 per month. Northern Californian utilities were generally in compliance with their mandated conservation targets, while Southern Californian utilities tended to fall short. In addition, using data on changes in actual consumption during the drought we estimate welfare losses under imperfect compliance with the mandate.

The second essay (chapter three) focuses on understanding heterogeneous effects of consumption analytics on residential water consumption. This essay estimates how web-based Home Water Use Reports (HWURs) affect household-level water consumption in Folsom City, California. The HWURs under study, offered by the company Dropcountr (DC), share social comparisons, consumption analytics, and conservation information to residential accounts, primarily through digital communications. The data utilized in this essay is a daily panel tracking single-family residential households from January-2013 to May-2017. We found that there is a 7.8% reduction in average daily household water consumption for a typical household who enrolled in DC program. Results suggest that the effect of DC varies by the baseline consumption quintile, the number of months in the program, the day of the week, quartile of the year, message type, and enrollment wave. We also conduct empirical tests to evaluate the channels through which DC may act to reduce consumption. Results indicate these responses to DC program likely come from the information

channel rather than moral suasion. Furthermore, our results indicate that providing consumption and pricing information may not improve the effectiveness of non-linear pricing.

Chapter 4 details the third essay, with a focus on voluntary action to reduce pollution. In this essay, we evaluate the effect of the ISO-14001 standard on firms' environmental performance. Manufacturers have been increasingly relying on environmental management systems (such as ISO 14001 based ones) to comply with government regulations and reduce waste. In this essay, we investigated the impact of ISO 14001 certification as a voluntary approach to manufacturers' toxic release by release level. Our theoretical model suggests that ISO 14001 effect on pollution is mixed depending on the initial pollution levels. In the empirical section of this essay, we applied the censored quantile instrumental variable estimator (CQIV) to data on the U.S. transportation equipment manufacturing subsector facilities. Results show that ISO 14001 had a negative and statistically significant effect on the top 10% manufacturing sites regarding the on-site toxic release, but it did not reduce off-site toxic release. Therefore, one should not expect ISO 14001 to have a uniform impact on manufacturing sites' environmental performance. For large firms, encouraging voluntary adoption of ISO 14001 might be an effective government strategy to reduce on-site pollution. However, for small firms and to reduce off-site pollution, other economic incentives or regulations are warranted.

From a broader perspective, these papers shed light on the non-price approaches as an environmental policy. We examine welfare consequences and effectiveness of regulatory and voluntary approaches and how these effects could be heterogeneous

among different subgroups. Chapter 5 summarizes the collective findings and provides

some discussion of potential implications.

Chapter 2.   WELFARE CONSEQUENCES OF CALIFORNIA'S 2015 DROUGHT
   WATER CONSERVATION MANDATE

Abstract

In April 2015, California Governor Jerry Brown issued an executive order mandating a statewide reduction in water use by 25% in urban areas because of a multi-year drought. We estimate the mandate's effect on consumer welfare losses using a novel panel dataset of price and monthly water consumption data on 111 water utilities to estimate utility-specific demand curves. We calculate the average welfare loss of the mandate to be $6,107 per acre-foot of restriction in Northern California and $2,757 per acre-foot of restriction in Southern California. Regarding monthly household-level willingness-to-pay (WTP) to avoid the mandate, we find households have a WTP between $5 and $200 per month. Northern Californian utilities were generally in compliance with their mandated conservation targets, while Southern Californian utilities tended to fall short. Also, using data on changes in actual consumption during the drought we estimate welfare losses under imperfect compliance with the mandate.

Keywords: California, demand, government policy, urban water utilities, water supply restriction

2.1 Introduction

The recent California drought, which began with an abnormally dry period in late 2011 and was declared over in April 2017, was one of the most extreme on record, characterized by low precipitation and high temperatures (Shukla et al. 2015). The drought impacted local communities, ecosystems, and the economy in a multitude of ways; for instance, during this period there was a rapid drawdown of groundwater reserves (Famiglietti 2014, Harter and Dahlke 2014) and an increase in agricultural land fallowing (Howitt et al. 2014). In response to these drought conditions, in April 2015, Governor Jerry Brown issued an executive order mandating a 25% reduction in urban water use effective between June 2015 and February 2016. This reduction was projected to save approximately 1.3 million acre-feet of water over the 9-month period.

The California State Water Resources Control Board (SWRCB), the state agency responsible for the implementation of the order, initially proposed a relatively uniform set of restrictions across water utilities. The final regulation, however, departed from that approach, setting the highest percentage reductions on those utilities with the highest water use regarding gallons per capita per day (GPCD). Under the SWRCB's adopted regulation, only urban water utilities serving more than 3,000 customers or delivering more than 3,000 acre-feet (AF) of water per year were required to reduce their customers' water consumption, with restrictions ranging from 4% to 36% of baseline usage (the adopted schedule defines nine conservation standards based on the per capita water usage during 2014 summer months; see Table 2-1 for the schedule). According to the SWRCB, the 411 urban water utilities subject to this mandate provide more than 90% of urban water supplies in California.[1] In this paper, we quantify the welfare consequences of

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[1] A large number of very small suppliers serving less than 3,000 customers exist in California.

these restrictions for residential consumers in Northern and Southern California.[2] We compare our predicted welfare losses, which assume perfect implementation of the restrictions, to estimates of actual welfare losses based on realized reductions in consumption.

Restricting urban water use is a common drought management strategy in many parts of the United States. Most urban water restrictions focus on the single-family residential sector (Mansur and Olmstead 2012) because it is generally considered to have lower value use than the multi-family residential, commercial, and industrial sectors. Moreover, reducing residential consumption is generally expected to result in fewer job losses and output effects than restricting commercial and industrial water use. In California, the residential sector accounts for one-half to two-thirds of urban water use in a typical community. Thus, the largest costs of restrictions are consumer welfare losses resulting from reduced water consumption. As demonstrated by Buck et al. (2016), because water rates are often more than marginal supply costs, the consumer welfare loss from mandatory conservation can be significantly higher than the loss evaluated using standard consumer surplus measures of welfare.

Our preferred estimates suggest that the predicted consumer welfare losses experienced as a consequence of utility-specific water restrictions were approximately $875 million across the utilities in our sample. Not surprisingly, predicted welfare losses under a uniform restriction of 25% across all utilities are larger—welfare losses under such a scenario are estimated to be under $1.20 billion. While the bulk of the welfare

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[2] Urban locations in Northern California include the City and County of San Francisco and their wholesale customers. Urban locations in Southern California include those serviced by the Metropolitan Water District of Southern California—these are the greater Los Angeles and San Diego regions.

losses were experienced in Southern California where the population is larger, per-household losses are larger in Northern California. Average welfare losses in Southern California are approximately $2,800 per acre-foot of reduced consumption, while they are $6,100 per acre-foot in Northern California. Our estimates suggest that the household willingness-to-pay (WTP) to avoid the 2015 mandatory restrictions is $26 per month in Southern California and $24 per month in Northern California under typical consumption levels.

Water utilities do not have complete control over their customers, so it is not surprising that actual changes in consumption did not perfectly match the mandated reductions for each utility. We also calculate welfare losses under actual changes in consumption. The welfare results for observed changes in consumption differ somewhat from those which assumed reductions in consumption equal to mandated levels. In general, consumers in Northern California met or exceeded their conservation targets, while consumers in Southern California often fell short.

2.2 Welfare Loss Framework

We determine welfare losses in the residential sector using a measure of consumers' WTP to avoid water supply restriction, which is similar to other recent works (Brozović, Sunding, and Zilberman 2007, Buck et al. 2016). Notably, among water utilities in California, and the United States more broadly, volumetric water rates reflect both variable and fixed costs. Often the fixed cost component of price is considerable; thus, the consumer surplus triangle can underestimate losses experienced by consumers. Buck et al. (2016) provide evidence of average cost pricing among public water utilities in California. Consistent with this, we measure welfare losses as the area under the demand

curve and above the marginal costs curve. We assume a constant elasticity of demand and estimate the single-family residential water demand elasticities for each urban water utility using the functional form:

$$P_i = A_i Q_i^{\frac{1}{\varepsilon_i}} \quad (i = 1,2,3,\dots,n) \quad (1)$$

where, A_i is a constant and ε_i is the elasticity of water demand in utility i. We denote price and quantity of water consumption by households in urban water utility service area i prior to the mandatory supply restriction as P_i^* and Q_i^*, respectively.

Let $Q_i(r_{it})$ indicate available water supply for urban water utility i under a restriction for utility i at time t; assume $Q_i(r_{it}) < Q_i^*$. We define available supply under a restriction as:

$$Q_i(r_{it}) = (1 - r_{it})Q_i^* \quad (2)$$

Using equations (1) and (2), we can estimate consumers' willingness-to-pay to avoid a supply restriction r_{it} by integrating under the isoelastic demand curve between baseline consumption Q_i^* and consumption under the restriction, $Q_i(r_{it})$. This is demonstrated with the equalities below:

$$W_i(r_{it}) = \int_{Q_i(r_{it})}^{Q_i^*} P_i(Q)dQ = \int_{Q_i(r_{it})}^{Q_i^*} A_i Q_i^{\frac{1}{\varepsilon_i}} dQ = \frac{\varepsilon_i}{1 + \varepsilon_i} P_i^* Q_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}} \right] \quad (3)$$

Note that an urban water utility's total cost of service is the sum of fixed cost (e.g., infrastructure costs, repair, and maintenance, administrative expenses, etc.) and variable cost (e.g., energy and chemical costs of treating water), with the latter depending on the amount of water delivered to customers. Supply restrictions reduce variable costs simply because the urban water utility i supplies less water, recall that $Q_i(r_{it}) < Q_i^*$. The

measure of WTP to avoid a restriction – indicated in equation (3) – does not account for

the avoided costs of service delivery when there is a supply restriction; therefore,

equation (3) is not a correct measure of welfare losses.

Assuming the marginal cost of service delivery is C_i , equation (3) becomes as

follows:

$$W_i(r_{it}) = \frac{\varepsilon_i}{1 + \varepsilon_i} P_i^* Q_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}} \right] - \int_{Q_i(r_{it})}^{Q_i^*} C_i(x)dx \quad (4)$$

Assuming a flat marginal cost curve, we can re-write the welfare loss function as

follows:

$$W_i(r_{it}) = \frac{\varepsilon_i}{1 + \varepsilon_i} P_i^* Q_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}} \right] - r_{it} Q_i^* C_i \quad (5)$$

Under the assumption of a flat marginal cost curve, the average loss per unit of

restriction is:

$$W_i/Q_i^* r_{it} = \frac{\varepsilon_i}{1 + \varepsilon_i} P_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}} \right] / r_{it} - C_i \quad (6)$$

Based on equation (6), the average welfare loss resulting from a supply restriction

is a function of the elasticity of demand in service area *i*, the initial water price before the

supply restriction in water utility *i* at time *t*, and the variable cost of service in water

utility *i*.

2.3 Residential Water Demand Estimation

Accurate price elasticity of water demand is essential for measuring consumer welfare

losses associated with California's 2015 restrictions. Arbués, Garcıa-Valiñas, and

Martınez-Espiñeira (2003) overview methodologies for estimation of water demand by

analyzing different specifications of water demand models, functional forms, different

data sets, selection of variables, and type of price specification. Additional examples of

water demand estimation and associated issues are described in several works in the

United States (Gaudin 2006, Hewitt and Hanemann 1995, Olmstead, Hanemann, and

Stavins 2007, Pint 1999, Renwick and Green 2000) and around the world (e.g., in France,

Nauges and Thomas (2003); in Germany, Schleich and Hillenbrand (2009); in Italy,

Mazzanti and Montini (2006); in Spain, Martinez-Espineira (2007)). We use these studies

to frame our empirical demand model regarding specification, functional form, and

choice of control variables.

Water consumption is measured as the average household consumption for each

utility and month in the dataset. In terms of functional form, the log-log model is used,

where all continuous variables enter into the regression equation in logarithmic form.

This functional form has frequently been used in previous studies (Frondel and Messner

2008, Mazzanti and Montini 2006, Olmstead, Hanemann, and Stavins 2007). An

attractive feature of this form is that the coefficient on price can be interpreted as the

price elasticity of demand.

One potential issue is whether the estimator for this coefficient suffers from

simultaneity bias. Consistent with other similar settings (Buck et al. 2016, Olmstead and

Stavins 2009), water rates are set by local government, rather than the market supply and

demand equilibrium; this should break possible simultaneity bias. Despite this, the cross-

sectional analysis is still vulnerable to omitted variable bias, which can arise from a

variety of unobserved factors (Billings and Agthe 1980, Gaudin 2006, Martínez-Espiñeira

2002). To address bias resulting from omitted time-invariant demand factors, utility fixed

effects are included in the preferred demand specification.

2.3.1 Econometric specification & data

We use a fixed effects estimator with utility and year fixed effects. The base equation we estimate is reported in equation (7):

$$\ln(q_{imt}) = \beta_1 \ln(P_{imt}) + \beta_2 \ln(W_{imt}) + \mu_i + \theta_t + u_{imt} \quad (7)$$

where q_{imt} is the average single family residential consumption in utility service area i in month m and year t; P_{imt} is the marginal price per hundred cubic foot (CCF) on the median tier of the price schedule; W_{imt} is a vector of precipitation and temperature measures; μ_i is a utility service area fixed effect; θ_t is a year fixed effect; and u_{imt} captures all unobserved factors affecting the dependent variable. Spatial heterogeneity is modeled by interacting price with median household income and a region indicator variable; see Reiss and White (2005) for a commonly cited example of this interaction.

The residential demand estimation uses utility-level panel data on average monthly water consumption and annual price, between January 2004 and December 2009, for single-family residential consumers in California. One of the advantages of using monthly data is that we can tailor our analysis to the mandate period (June 2015 – February-2016). Thus, we estimate the elasticity of water demand using the relevant period and drop observations from March, April, and May 2015. The dataset includes 90 urban water utilities in the Metropolitan Water District of Southern California (MWD) and 21 utilities in the San Francisco Bay Area. Consumption and price data for water utilities in the San Francisco Bay Area were obtained from the Bay Area & Water Supply Conservation Agency Annual Surveys from 2004-2009; similar data for water utilities in the MWD service area were obtained by directly contacting each water utility.

We measure utility-level average monthly water consumption per household in hundreds of cubic feet (CCF). Table 2-2 provides descriptive statistics for water consumption by region and season in 2009. Water consumption in sample utilities located in Southern California is, on average, 1.6 times higher than water consumption in sample utilities located in Northern California. This pattern reflects somewhat lower densities and drier conditions in Southern California, which leads to more outdoor water use and higher overall consumption. Not surprisingly, there is an even larger gap in residential consumption between Southern and Northern California during the summer months, when landscape irrigation is more common.

We use Census tract data from the year 2000 to obtain information on median household income and household size. The measure of lot size is derived from data collected by DataQuick. Utility-specific measures of these variables are generated using the intersection between utility-specific borders and Census tract borders. This allows us to generate a weighted-average of these variables that reflect the population of single-family residential households for each specific utility. In addition, we include weather drivers of residential demand (precipitation and temperature), which are obtained from PRISM (Parameter-elevation Regressions on Independent Slopes Model) group data.

2.3.2   Estimation results

The results of the residential water demand estimation are presented in Table 2-3. Column (1) of Table 2-3 presents the baseline fixed effects model corresponding to Equation (7). The estimated price elasticity of demand is -0.198. In Column (2), we add weather variables (average daily maximum temperature and monthly precipitation) and month of year fixed effects to control for seasonality. Since neither the year-to-year

variation in weather nor the month of year fixed effects is correlated with price, we do not expect the point estimate to change much. Consistent with this, we obtain an estimated price elasticity of demand of -0.207. The primary objective of adding these additional controls is to explain variation in consumption, and by doing so, reduce the standard error for the coefficient on our price measure. Notably, the within R-squared increases from 0.021 to 0.543 and precision improves, though not by a significant degree (t-stat increases from 2.07 to 2.19). One concern with the specifications in the first two columns is that they are vulnerable to bias resulting from omitted time-variant variables related to both price and consumption. To address this concern, in Column (3) we estimate a model that includes county-specific linear and quadratic time trends. These variables control for time-variant county level unobservables that share a common trend within a county. An example is conservation efforts since water utilities in the same county generally share common conservation programs. Under this specification, we observe an estimated price elasticity of -0.23.

To demonstrate the utility of using monthly, instead of annual water consumption data, Column (4) of Table 2-3 presents demand estimation results in which annual data has been used to estimate the price elasticity of demand. The elasticity point estimate using annual data is -0.184; we cannot reject the null hypothesis that the point estimates in Column (3) and Column (4) are identical.

In the final specification presented in Table 2-3, we add interaction between price and income. This interaction term captures how price responses vary by household income level. Because the price elasticity of demand is negative, a positive coefficient on the interaction term indicates a decrease in the price response as income increases—

thereby implying less elastic demand. Results for this specification are reported in

Column (5) of Table 2-3 and indicate that the price elasticity of water demand in an urban

water utility with a median household income of $65,000 would be -0.19. Moving

forward, we use this specification to estimate elasticities for the welfare loss calculations.

2.4 Welfare Analysis

Welfare losses resulting from restrictions on residential water consumption in Northern

and Southern California are quantified using equation (5) and consumption data from the

year 2013 (the baseline period according to the SWRCB regulation) encompassing 53

urban water utilities in California, including 27 utilities in the San Francisco Bay Area of

Northern California and 26 utilities in the Los Angeles and San Diego regions of

Southern California. The mandate affects the entire residential sector, both single and

multi-family residential consumers. The econometric analysis in the preceding section

focused on the single-family residential sector because comparable data is not available

for the multi-family residential sector. Therefore, in the subsequent welfare analysis, we

assume single and multi-family sectors have identical elasticities. This is a simplifying

assumption which acts to under-estimate losses for at least two reasons. First, the multi-

family residential sector mainly consists of indoor water consumption, so these users

have fewer margins on which to reduce water consumption compared to consumers in the

single-family residential sector. This suggests more inelastic demand for the multi-family

residential sector. Second, precisely because the two sectors' demand curves are

different, the efficient distribution of restrictions across the two sectors would not be

proportional. Grouping them with an identical elasticity implicitly assumes proportional

rationing across the single and multi-family residential demand sectors. In this case,

proportional rationing is inefficient because it does not account for the more elastic

demand in the single-family residential sector. By combining these sectors, we are

implicitly avoiding any incremental losses that would result from an inefficient allocation

of restrictions between these different sectors. Therefore, these assumptions may result in

reduced estimates for the consumer welfare consequences of the mandate.

2.4.1 Data for calculation of welfare losses

From equation (5), the calculation of welfare losses requires data on baseline price,

baseline quantity demanded, the percentage of use restricted, the price elasticity of

demand, and the marginal cost of service delivery.[3]

We use consumption data from the year 2013 as our baseline, or pre-drought,

quantity-demanded. Data were obtained from the SWRCB, which calculates an estimate

of residential water consumption by month for approximately 400 water utilities in

California. For the Northern California utilities that belong to Bay Area Water Supply &

Conservation Agency (BAWSCA), the price data comes from median tier price reported

in the BAWSCA survey for the year 2014. Prices for the other utilities were obtained

from their website or through a telephone interview. In the case of wholesale utilities,

including many of the utilities that belong to the MWD, no single median tier price exists

because they sell their water to multiple local utilities that set their rates. Thus, for each

wholesale utility, we collect rate information on every local utility within the wholesale

utility and then generate a quantity-weighted average of the median tier price. Figure 2-1

presents the range of median tier prices (converted to price per acre-foot of water) for

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[3] For the marginal cost of service delivery we use $193 per acre-foot based of previous
work by Buck *et al.* (2016), which relies on financial documents from California utilities.

these 53 urban water utilities. The mean, minimum and maximum prices per acre-foot in Northern California are $2,513, $1,446, and $4,217, respectively. The mean, minimum and maximum prices per acre-foot in Southern California are $1,526, $674, and $2,943, respectively.

The demand estimation result presented in Column (5) of Table 2-3 suggests that the price elasticity of water is significantly different across utilities throughout California, according to median household income levels. The distributions of elasticities implied from this result for the Northern and Southern California utilities of interest are displayed in Figure 2-2.[4] Estimated mean, minimum and maximum price elasticities in Northern California utilities are -0.16, -0.32, and -0.1, respectively. Estimated mean, minimum and maximum price elasticities in Southern California utilities are -0.29, -0.50, and -0.1, respectively.[5] This suggests that consumers in Southern California may be able to accommodate water restrictions than consumers in Northern California more easily. This is consistent with the pattern of cut-backs ultimately adopted by the SWRCB, in which Southern California faced more stringent requirements than Northern California. These primary observations suggest there are likely efficiency gains from the SWRCB conservation program relative to uniform restrictions across utilities.

Welfare losses for two regulatory scenarios are estimated to examine whether there are welfare improvements from choosing the SWRCB restrictions instead of a uniform cut-back across utilities. In the first scenario, we assume a uniform percentage restriction (25%) relative to baseline consumption during the year 2013 (less consumption during

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[4] We construct measures of median household income for each of the 53 utilities based on data from the American Community Survey.
[5] For utilities with a GPCPD greater than 150.

March, April, and May, which are excluded under the SWRCB regulation). This scenario is representative of a naïve policy option in which policymakers do not differentiate requirements based on variation in the values for the marginal unit of water across utilities. For example, under this policy, utilities with high and low outdoor water consumption will face the same percentage cut-backs. In the second scenario, we assume utility-specific restrictions based on the SWRCB utility-level conservation standards (henceforth, this scenario is referenced as the SWRCB conservation program). Under the SWRCB conservation program, urban water utilities are assigned to reduce their total consumption from June 2015 through February 2016 at rates between 4% and 36% based on historical consumption levels. In the case of wholesale utilities, no single conservation standard exists because they sell their water to multiple local utilities, which have their conservation standard from SWRCB. Thus, for each wholesale utility, we collect conservation standard information on every local utility within the wholesale utility and use this information to calculate a household-weighted average conservation standard.

Figure 2-3 shows the distribution of mandatory conservation percentages (i.e., restriction percentages) by region. Utilities in Northern California are mostly in tiers 2, 3, and 4 of the SWRCB conservation program with a weighted average restriction of 16.2%. Utilities in Southern California are in higher tiers (6, 7, 8, and 9) with a weighted average restriction of 22.5%.

2.4.2   Estimated welfare losses forecasted under perfect compliance
In Table 2-5 we present estimates of average forecasted welfare losses per acre-foot of restriction under perfect compliance with a uniform restriction (25%) and the SWRCB conservation program. The average welfare loss per acre-foot due to a uniform 25%

restriction is $5,094, which represents an aggregate loss for the metropolitan regions of Northern and Southern California of $1.20 billion. Under the SWRCB conservation program, the average welfare loss per acre-foot is $3,846, which represents an aggregate loss of $875 million. For these two metropolitan regions, we observe lower aggregate welfare losses under the SWRCB conservation program than under a uniform restriction policy. However, these figures are difficult to compare since, in consumption terms, the SWRCB conservation program is less than a 25% restriction, at least for those utilities in the study sample. This is because utilities outside of the metropolitan regions we considered were generally assigned percentage restrictions through the SWRCB conservation program that were greater than 25%. For the utilities included in our analysis, total water saved by single-family households, assuming perfect compliance, is 373,000 acre-feet under the 25% uniform restriction, but only 336,000 acre-feet under the SWRCB conservation program. The aggregate percentage restriction from the SWRCB conservation program is just under 20% in the urban areas under study.

Next, we assess efficiency advantages of these policies and evaluate important regional differences in the relative incidence of losses under each policy. Table 2-5 presents the results of forecasted welfare loss calculations for Northern and Southern California under perfect compliance with a uniform 25% restriction and the SWRCB conservation program. In Northern California, forecasted welfare losses are estimated to be $182 million under a 25% uniform restriction and $106 million under the SWRCB conservation program. In Southern California, forecasted welfare losses are estimated to be $1.01 billion under a 25% uniform restriction and $769 million under the SWRCB conservation program. Larger total losses in Southern California relative to Northern

California are due to the larger population. In Northern California, a comparison of the uniform restriction (25%) and the SWRCB conservation program indicates average welfare losses per acre-foot of $6,726 and $6,107, respectively. In Southern California, average welfare loss per acre-foot of restriction is $2,832 under the 25% uniform restriction and $2,757 under the SWRCB conservation program.

However, to effectively evaluate efficiency, we require a different comparison for Northern and Southern California since, under the SWRCB conservation program, Northern and Southern California would reduce residential urban consumption by less than 25%. To this end, Column (3) of Table 2-5 presents welfare analysis corresponding to a hypothetical uniform restriction policy that achieves the same level of cutbacks as the SWRCB conservation program for each of the regions: Northern California (16.2% overall restriction) and Southern California (22.5% overall restriction). In Northern California, the average welfare loss per-acre foot under a uniform restriction of 16.2% is $3,983. In Southern California, the average welfare loss per-acre foot under a uniform restriction of 22.5% is $2,654. In both cases, average losses are lower under the adjusted uniform restriction compared to the SWRCB conservation program. This finding is surprising because uniform restrictions on service areas with heterogeneous elasticities tend to be inefficient. The utility-specific restrictions under the SWRCB conservation program were not assigned according to an efficient allocation scheme.

Besides inefficiency, another argument against a uniform percentage restriction is inequity. Under the SWRCB program, restrictions are monotonically increasing according to baseline consumption, which works to tighten the distribution of household level consumption across service areas. Further, there is a strong positive relationship

between consumption in the residential sector and household income; thus, cut-backs are generally larger under the SWRCB conservation program for households in wealthier services areas (e.g., Hillsborough in Northern California and Beverly Hills in Southern California) than for households in poorer service areas. Therefore, by its very construction, the SWRCB program is more equitable than a uniform cut-back.

The second and fourth rows of Table 2-5 indicate the 95% confidence interval for each estimate. These confidence intervals reflect the estimated variability in the price elasticities of demand recovered from the regression analysis. Due to the non-linearity of price elasticity in the expression of welfare losses, confidence intervals for welfare estimates are bootstrapped by cluster (urban water utility), they are not based on analytic standard errors.

Our data also provides some insight into the magnitude of estimated welfare effects in terms of implied household WTP measures. The fifth row of each panel illustrates the average household's WTP under each scenario. Estimated monthly WTP per household to avoid the 25% restriction is $42 in Northern California and $34 in Southern California, while under the SWRCB conservation program, households estimated monthly WTP is $24 in Northern California and $26 in Southern California. Consistent with previous results, the higher WTP to avoid the uniform 25% cut-back demonstrates that households find the 25% uniform cut-back more harmful than the SWRCB conservation program. Again, this is driven by the fact that the SWRCB conservation program conserves less water in the urban areas included in this study. The third column displays the WTP to avoid a uniform policy achieving the same aggregate water reduction as the SWRCB conservation program. We observe that the average household WTP to avoid such a uniform percentage cut-back is less than the WTP to

avoid the SWRCB conservation program. Overall, these households' WTP measures are not as large as some might fear, though they are sizeable when compared to baseline household water expenditures.

The last row of both panels illustrates households' WTP measure regarding the percentage increase in expenditures on the volumetric rate component of the households' monthly water bills. Households in Northern California have a WTP in terms of increase in monthly water bills between 28% and 75%, depending on the scenario. Households in Southern California have a WTP regarding percentage increase in the monthly bills between 31% and 41%.

Table 2-6's presentation of average outcomes for large metropolitan areas masks the high degree of variation within the Northern and Southern California regions. Figure 2-4 illustrates the heterogeneity in average welfare loss per acre-foot of restriction for urban water utilities within each region. We observe average welfare losses per acre-foot ranging from approximately $800 to $15,000. Relative to Southern California, the distribution in Northern California is shifted to the right and is more disperse. This figure reflects that households have more inelastic demand in the San Francisco Bay Area than in Southern California. Further, the wider range of average welfare losses per acre-foot of restriction in the San Francisco Bay Area reflects its greater variability in incomes, which coincides with household landscaping choices in the region. When comparing these distributions of average welfare losses for a uniform restriction versus utility-specific restrictions, we observe somewhat contrasting patterns in Northern versus Southern California. In Northern California, the distribution of average welfare losses for the uniform restriction is flatter than and shifted to the right of the distribution for the utility-

specific restrictions, while in Southern California, the distribution for the uniform

restriction has more mass to the left and a smaller right tail than the distribution for the

utility-specific restrictions. The distributions of average welfare losses for both Northern

and Southern California provide visual evidence that there is significant heterogeneity in

welfare impacts across the state.

Overall, the anticipated welfare losses under perfect compliance with the SWRCB

conservation program suggest aggregate losses of $106 million for the 27 agencies we

consider in Northern California and $769 million for the 26 agencies we consider in

Southern California.

2.4.3 Actual welfare losses under observed imperfect compliance

We calculate actual welfare losses, based on imperfect compliance with the SWRCB

conservation program since some utilities did not meet their conservation standard, while

others exceeded them. Tables 2-6 and 2-7 present estimated average monthly R-GPCD[6]

for both June-February 2013 and the mandate period (June 2015 to February 2016), by

the utility. These tables also present both the mandated percentage cut-back and the

observed percentage cut-back.[7] The final two columns in the tables compare predicted

average welfare losses under perfect compliance with the SWRCB conservation program

and estimates of actual average welfare losses observed under imperfect compliance with

the SWRCB conservation program.

The numbers in the first two columns of both tables 2-6 and 2-7 confirm that average

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[6] R-GPCD= Residential Gallons per Capita Day.
[7] For more information visit:
http://www.waterboards.ca.gov/water_issues/programs/conservation_portal/conservation
_reporting.shtml

consumption decreased in the mandate period for all of the utilities in Northern and

Southern California, compared to the base year 2013. However, the magnitudes and

spatial distribution of actual reductions are not consistent with the SWRCB conservation

program. For example, the SWRCB conservation program imposed a 32% restriction on

Beverly Hills, but they only achieved a 19% reduction in water consumption.

Columns (3) and (4) of Table 2-6 summarize the restrictions from the SWRCB

conservation program, and the corresponding observed percentage reductions relative to

2013, for utilities in Northern California. Recorded consumption for utilities in Northern

California (with reported data) shows that 23 of 24 utilities considered actually exceeded

the required consumption cut-backs. California Water Service-Bear Gulch is the only

utility that did not to meet its cut-back standard, though the target was only missed by

one percentage point. On average, utilities in Northern California reduced water usage by

seven percentage points more than was required by the SWRCB conservation program.

The same columns in Table 2-7 show these restrictions and observed percentage

reductions for utilities in Southern California. Compared to the results from Northern

California, only 8 of 25 utilities met their conservation standard, and 9 of the 17 utilities

that missed their standards did so by more than 5 percentage points. Overall, Table 2-7

demonstrates a mismatch in the spatial distribution of assigned versus observed cut-backs

in Southern California.[8] For example, while Beverly Hills missed their conservation

target, San Diego exceeded their target of 16%, achieving a 19% reduction. On average,

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[8] In the case of wholesale utilities, such as many of the utilities belonging to MWD, no single observed reduction exists because they sell their water to multiple local utilities who have their own reductions. Thus, for each wholesale utility, we collected observed reduction information on every single local utility within the wholesale utility, and a household-weighted average reduction was calculated.

utilities in Southern California reduced their water usage by approximately three percentage points less than what was required by the SWRCB conservation program.

The difference in compliance between Northern and Southern California is striking, though it is difficult to attribute to a single factor. A natural driver of compliance may be the value of restricted water units. For example, Beverly Hills' anticipated average welfare loss per acre-foot due to their mandated 32% restriction would be over $11,000 per acre-foot. Thus, their incentive to comply was considerably less than other utilities in Southern California (the majority of utilities had anticipated average welfare losses per acre-foot below $3,000). However, other utilities with anticipated average welfare losses above $11,000 per acre-foot managed to comply with the mandate. Another important feature of the SWRCB conservation program was that individual utilities were charged with determining how mandated conservation targets would be met. For instance, the City of Hillsborough, which had large anticipated average welfare losses, imposed stringent prohibitions on certain categories of water-use. Wichman (2016) showed that prohibitions on categories of water-use (e.g., landscape irrigation) result in larger reductions than other conservation strategies (e.g., conservation pricing), especially among high income, high volume users. Wichman's results on conservation pricing are consistent with the residential [isoelastic] demand estimation presented in the previous section showing that high-income households are more inelastic. A general takeaway from Wichman, Taylor, and Von Haefen (2016) is that conservation response will depend on a utility's conservation strategy; thus, differences in compliance may be attributed to each utility's method for achieving the SWRCB conservation standards. While individual utilities under the SWRCB conservation plan are given flexibility regarding how to meet

assigned conservation standards, the SWRCB program also defined a $10,000 a day fine on water utilities for not meeting the assigned targets. Thus, income levels and the size of the customer base for a utility's service area could also affect compliance, since high-income communities with a sizable customer base may not be responsive to fines assessed at the utility level.

Utility-level conservation encouragement may also explain the pattern of compliance across California, although encouragement could affect compliance through distinct channels. A common form of conservation encouragement is to offer rebates for water efficient appliances. At the state-level, the California Energy Commission has offered rebate programs to replace inefficient showerheads, faucet heads, older appliances with newer, water-efficient models, and water-intensive lawns with turf or brownscaping (SWRCB, 2015). In addition to state programs, many urban water utilities support participation in state-sponsored programs or augment the state programs with local rebate offers. Historical participation in rebate programs may lead to demand hardening; after initial conservation efforts, there may be few margins on which to further reduce consumption. This highlights the fact that the base year of 2013 that was used to determine utility-specific conservation standards is an arbitrary base period which penalized utilities that achieved significant conservation in the years immediately before 2013 (or favored microclimatic regions that had an unseasonably dry, warm year in 2013). For these reasons, historical conservation may partially explain compliance.

Participation in rebate programming in response to the mandate, or in the years immediately preceding it (but after the base year of 2013), would support compliance with restrictions. For example, city utilities, such as Menlo Park in Northern California,

had attractive rebate programs during the mandate period for lawn replacement and offered a subsidized consultation on how to design drought-tolerant landscaping. Naturally, these types of recent conservation efforts at the utility level may also explain the pattern of compliance across utilities.

A separate channel through which encouragement may explain compliance with the SWRCB conservation standards is moral suasion through conservation messaging and local social norms. Hollis (2016) documents how urban water consumption covaries over time during MWD's multi-faceted conservation messaging program, which uses roadside billboards and freeway signs, radio messages, and TV advertisements. Other water conservation messaging includes a host of interviews, op-ed pieces, news stories and public service messages. In addition to the MWD, urban water utilities conducted their public information campaigns—8 of 10 Southern Californians reported having recently heard conservation-related messages (Hollis, 2016). Evidence on the effectiveness of such conservation messaging is mixed and may depend on factors such as local green-ness. Therefore, differential responses to conservation messaging in Northern and Southern California may also explain the divergence in compliance with the SWRCB's conservation program.

Another potential determinant of compliance is water supply storage. In Southern California, utilities have made significant investments in storage. For example, when the mandated restrictions were announced in the year 2015, MWD had approximately one million acre-feet of dry-year storage, a significant amount to report after three years of intense drought. To put this in perspective, MWD generally provides less than two million acre-feet of water annually; thus, their dry-year reserves at the end of a three-year

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drought were capable of servicing over half of their historical annual demand quantity. While protecting dry-year storage supplies is an important consideration, utilities in Southern California may have determined that they have sufficient storage to weather the drought without enforcing the SWRCB conservation program restrictions.

While the pattern of compliance seems somewhat unexpected, one simple observation is worth pointing out. The mandated restrictions in Northern California compared to Southern California were significantly less in both percentage terms (16.2% versus 22.5% reduction) and absolute terms (12 R-GPCD versus 24 R-GPCD reductions). Given these facts alone, we might anticipate more compliance in Northern California, though there are likely other drivers.

We conclude this section by presenting welfare loss results under observed imperfect compliance, as opposed to hypothetical perfect compliance, with mandated restrictions. In the Northern California region, estimates of average welfare losses per acre-foot from actual reductions over the course of the mandate range from $2,702 to $15,710. In the Southern California region, estimates of welfare losses from actual reductions range from $890 to $7,349. The difference between average welfare losses calculated from estimates of actual reductions in Northern and Southern California ($7,375 - $2,537 = $4,838) is considerably larger than the difference between the predicted average welfare losses calculated assuming perfect compliance ($4,717 - $2,974 = $1,743). This makes sense since utilities in Northern California, which have more inelastic demands than utilities in Southern California, tended to exceed their conservation standards, while those in Southern California tended to miss their standards.

Putting these numbers in perspective, the per household, per month results suggest

that households in Northern California would have been willing to pay between $12 and $468 per month to avoid the conservation efforts that were actually implemented in response to the mandate; the median household would have been willing to pay $39 per month. In Southern California, the results suggest that households would have been willing to pay between $5 and $177 per month to avoid the conservation efforts they implemented in response to the mandate and the median household would have been willing to pay $26 per month. Residential water demand in Northern California tends to be more inelastic than in Southern California, resulting in higher welfare losses for a given percentage reduction in water use.

2.5 Concluding Remarks

Californians experienced a severe drought between late 2011 through early 2017, perhaps the worst in California's history regarding its economic impacts on urban users. According to the U.S. Drought Monitor, more than 50% of the state was in an "extreme" drought event with more than 30% in an "exceptional" drought event.[9] This drought has had a widespread, but unevenly distributed, impact on different sectors and water users, including farmers, industry, cities, and natural ecosystems that depend on water quantity, quality, and timing of flows (Gleick 2016).[10] To mitigate the adverse impacts of drought, in April 2015 Governor Jerry Brown issued an executive order mandating statewide reductions in water use by 25% in urban areas, which generally targeted residential water-use. We calculate one component of the mandate's impacts by assessing its effect

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[9] For more information, see:
http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA.
[10] For more detail information about 1987-1992 drought consequences see Gleick and Nash 1991; and Nash 1993, the 2007-2009 drought see Christian-Smith et al. 2011, and the current 2012-2015 drought see Cooley et al. 2015; and Gleick 2015.

on residential ratepayers in urban areas of Northern and Southern California.

We construct a utility-level panel of monthly consumption data from 2004-2009 for 111 utilities to estimate residential urban water demand. The demand estimation results provide price elasticities that are used to calculate the welfare consequences of the 2015 drought mandate. Estimated elasticities for the sample utilities in Northern California are between -0.32 and -0.1; for the sample utilities in Southern California, estimated elasticities are between -0.50 and -0.1. Our empirical results indicate significant variation in the value of water across urban space.

Two different policy options were defined and analyzed to estimate welfare losses experienced due to water restrictions, including (i) a 25% uniform cut-back across utilities during the mandate period (June 2015- February 2016), and (ii) utility-specific cut-backs based on the SWRCB program during the same mandate period. According to the estimated results, welfare losses per acre-foot are lowest under the SWRCB conservation program in Southern California and highest under the 25% uniform cut-back in Northern California. We also calculate welfare results for a uniform restriction that achieves the same aggregate level of rationing as the SWRCB conservation program. This uniform policy is more efficient than the utility-specific restrictions imposed by the SWRCB conservation program. These results suggest that the SWRCB conservation program targets equity, rather than efficiency. Further, the efficiency losses are not so substantial, relative to the uniform policy. Based on the work of Buck et al. (2016), an efficient allocation of restrictions across utilities based on the marginal value of water for the last unit restricted, would not likely yield significant efficiency gains.

The aggregate cost of the governor's mandate in terms of lost consumer welfare is an

estimated $875 million. The cost to implement the water conservation mandate is $106 million in the San Francisco Bay area and $769 million in Southern California. In other words, Northern California households have a WTP of $24 per month to avoid the conservation mandate. Put differently; these households are willing to see an increase in their water rates of 44% to avoid the conservation requirements. Households in Southern California have a WTP of $26 per month to avoid this mandate; they are willing to see a 31% increase in their water rate to avoid the mandated cutbacks.

The pattern of compliance with the SWRCB's conservation program presents a puzzle. The data indicate that Northern and Southern California households reduced their water usage by a similar percentage: 23.3% in the Bay Area of Northern California and 21.4% in Southern California. However, conservation targets in the Bay Area were significantly lower than in Southern California in both absolute and percentage terms. On average, consumers in Northern California over-complied with the conservation mandate, while those in Southern California slightly under-complied. Future research may help to better explain patterns of actual conservation during a drought and may shed light on whether the state was justified in setting such different percentage conservation targets for consumers in different regions.

2.6 Figures and Tables
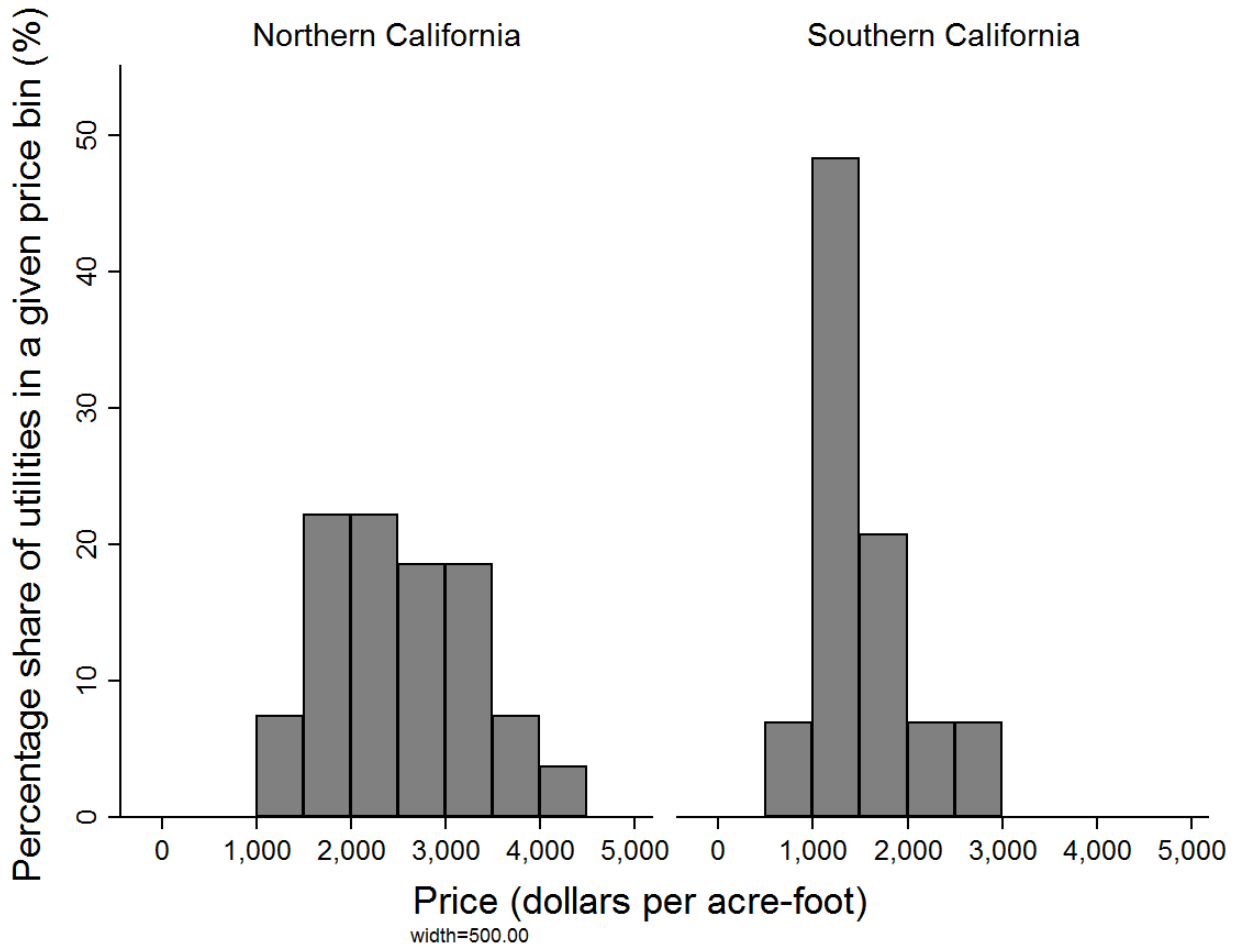
Figure 2-1 Prices Per Acre-Foot by Utility in the Northern and Southern California

Notes: Vertical axis in this figure shows the share of utilities in a given price bin. For example, approximately 50% of utilities in Southern California are in $1,000-$1,500 price bin. However, only 8% of utilities in Northern California are in the same price bin. It is noted that 27 utilities are used from Northern California; 26 utilities are from Southern. Mean, minimum, and maximum price per acre-foot in Northern California utilities are $2,513, $1,446, and, $4,217, respectively. These summary statistics for Southern California utilities are $1,526, $674, and $2,943, respectively.
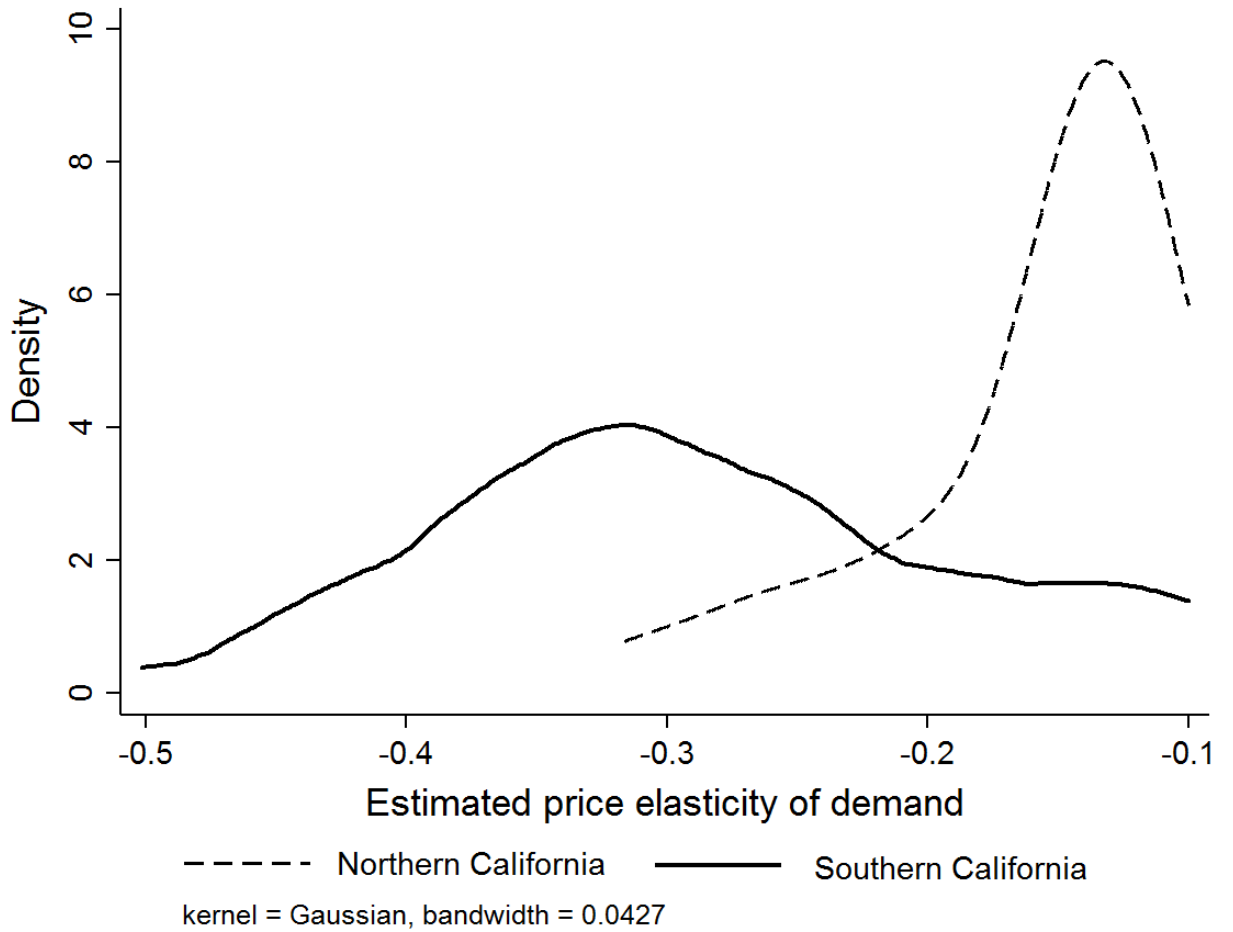
Figure 2-2 Distribution of Estimated Price Elasticity of Water Demand by Region

Notes: Elasticities are based on results reported in Column (5) of Table 2-3. The mean, minimum and maximum estimated price elasticities in Northern California utilities are -0.16, -0.32, and -0.1; in Southern California utilities are -0.29, -0.50, and -0.1. Estimated price elasticities are truncated at -0.1.
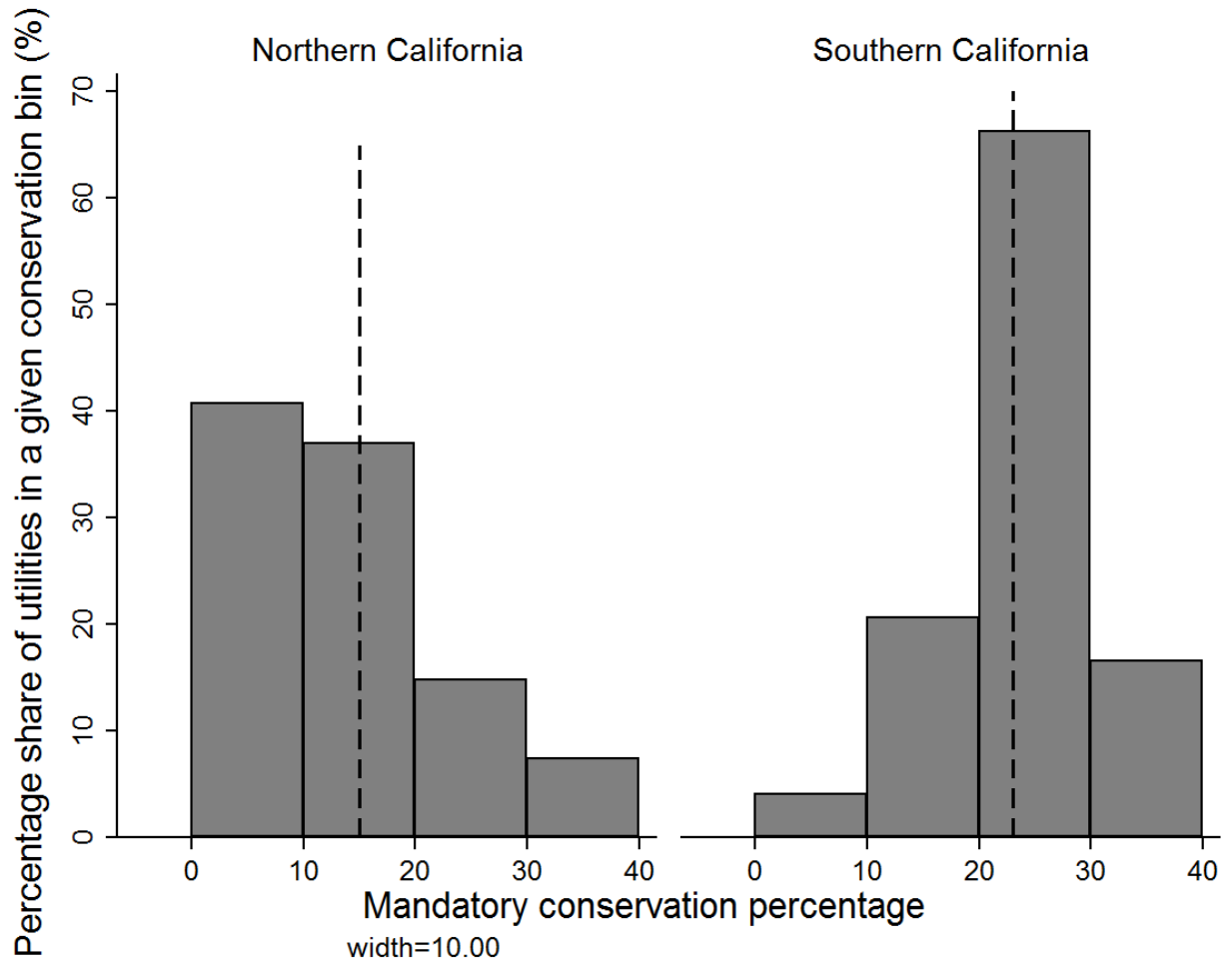
Figure 2-3 Distribution of Mandated Conservation Across Utilities in Northern and Southern California

Notes: Vertical axis in this figure shows percentage share of utilities in a given mandatory conservation standard bin. For example, approximately 40% of utilities in Northern California are required to conserve less than 10%. However, only approximately 4% of utilities in Southern California are required to conserve the same amount. The vertical dashed line indicates average mandatory cut-back in the sample utilities. Utilities in the Northern California (27 utilities) were required to cut-back water usage by 16.2%. Minimum and maximum cut-back for these utilities respectively are 8% and 36%. Utilities in the Southern California (26 utilities) were required to cut-back water usage by 22.5%. Minimum and maximum cutbacks for these utilities respectively are 8% and 36%.
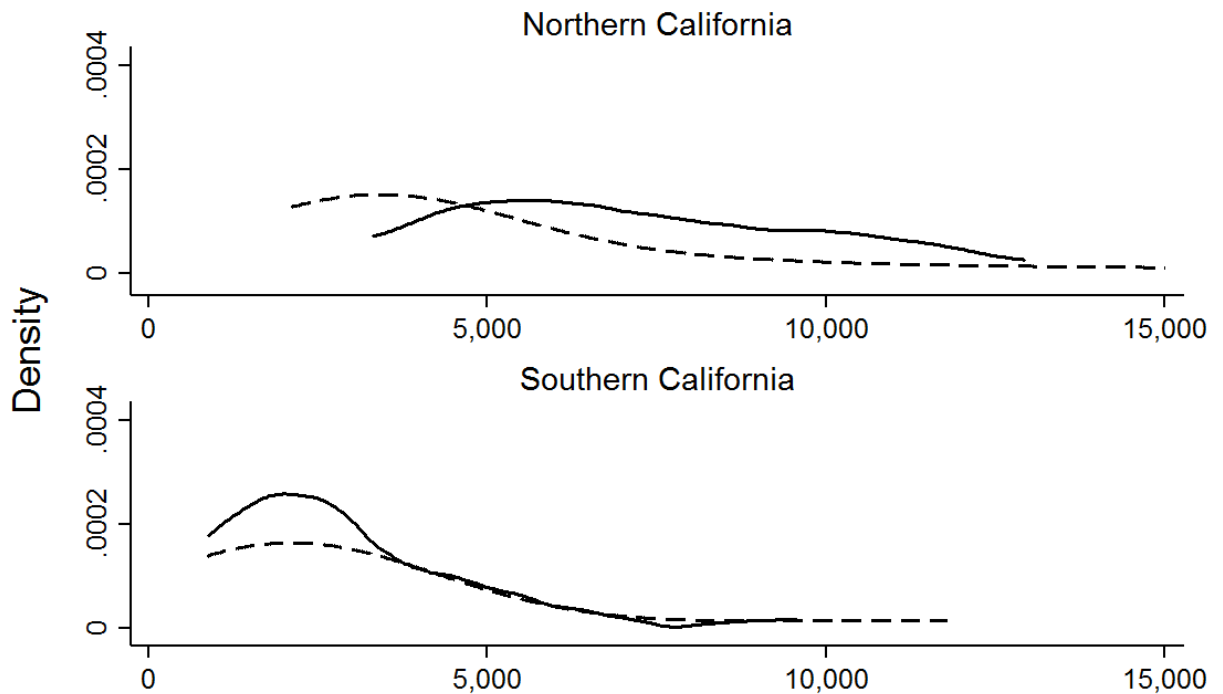
Figure 2-4 Heterogeneity in Welfare Losses for Urban Water Utilities Located in Northern and Southern California.

Notes: For the study sample, utility-specific restrictions result in an overall cutback of 16.2% in Northern California and 22.5% in Southern California. Per acre-foot welfare loss under 25% uniform restriction lies between $3,318 and $12,926 in Northern California. For southern California, this number lies between $883 and $9,569. Under utility-specific restrictions per acre-foot welfare loss in Northern California lies between $2,111 and $15,028 and in Southern California, this range is between $859 and $11,808.

Table 2-1 Urban Water Utilities Conservation Tiers and Count of the Utilities in each Tier

Tier	R-GPCD Range		# of Suppliers in Range	Conservation Standard
	From	To		
1			4	4%
2	0	64.99	27	8%
3	65	79.99	23	12%
4	80	94.99	42	16%
5	95	109.99	61	20%
6	110	129.99	45	24%
7	130	169.99	81	28%
8	170	214.99	61	32%
9	215	612.00	67	36%

Notes: The mandate aim is to reduce the amount of water consumed statewide in urban areas by 25% relative to 2013 levels – roughly 1.3 million acre-foot of water. A total of 411 urban water utilities are required to reduce water supply (sum of Column (4) in Table 2-1).
R-GPCD: Residential Gallons Per Capita Day

Table 2-2 Average Monthly Household Water Consumption In 2009 From Regression Dataset (Unit: CCF/Month)

Region	Variable	Mean	S.D.	Min.	Max.
Total utilities in the sample	Average monthly	17.50	8.40	4.06	52.87
	Arid season	23.40	11.57	0.43	68.95
	Wet season	17.58	8.73	0.25	69.51
Sample utilities in the Northern California	Average monthly	11.98	7.97	4.063	52.87
	Arid season	16.55	10.41	0.44	66.02
	Wet season	11.72	6.27	0.25	52.87
Sample utilities in the Southern California	Average monthly	19.07	7.83	7.74	52.80
	Arid season	25.30	11.16	4.73	68.95
	Wet season	19.17	8.61	2.88	69.51

Notes: Average monthly household water consumption on a CCF basis lies between 5 to 15 CCF in Northern California and between 12 and 25 in Southern California.

CCF: hundred cubic feet
S.D: Standard deviation

Table 2-3 Monthly Residential Water Demand Estimation

	(1)	(2)	(3)	(4)	(5)
Ln(Price)	-0.198**	-0.207**	-0.23*	-0.184*	-2.100**
	(0.0992)	(0.100)	(0.105)	(0.103)	(1.087)
Ln(Price) X Ln(Income)	-	-	-	-	0.458*
					(0.268)
Observations	4,176	4,176	4,104	468	4,104
R-squared	0.021	0.543	0.543	0.282	0.543
Year Fixed Effects (Y=6)	Yes	Yes	Yes	Yes	Yes
Utility Fixed Effects (U=111)	Yes	Yes	Yes	Yes	Yes
Weather Controls	No	Yes	Yes	Yes	Yes
Month Fixed Effects (M=9)	No	Yes	Yes	No	Yes
County Specific t, t2 (C=9)	No	No	Yes	Yes	Yes

Notes: Huber-White standard errors estimated using the Huber-White method and reported in parentheses; multi-way clustered standard errors are approximately the same as Huber-White standard errors. Multi-way clustered standard errors are clustered by year and utility. Implied price elasticity using Column (5) specification indicates that own price elasticity in an urban water utility with a median household income of $65,000 would be -0.19. Note that $65,000 is the weighted median income by using an average number of households in each utility service area as a weight.

*** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

Table 2-4 Average Forecasted Welfare Losses Per Acre-Foot of Restriction by Scenario

Scenario	Average welfare loss per acre-foot
Scenario 1: Uniform restriction (25%)	$5,094 [$3,138]
Scenario 2: Utility-specific restrictions (State Water Resources Control Board Conservation Program)	$3,846 [$3,004]

Notes: The standard deviation for mean welfare losses per acre-foot across 53 urban water utilities is reported in square brackets. The numbers reported in the square brackets are not standard errors; instead, they are the standard deviations associated with the calculation of mean welfare loss per acre-foot for the 53 urban water utilities. Marginal loss per acre-foot is truncated at $20,000.

Table 2-5 Welfare Losses Under Uniform Restriction (25%) and Utility-Specific Restrictions from the SWRCB Conservation Program

Panel A: Northern California Utilities

Policy restriction scenario:	Uniform Restriction (25%)	Utility-specific Restrictions (resulting overall cut-back of 16.2%)	Uniform Restriction (16.2%)
Total loss ($ millions)	$182	$106	$69
[95% Bootstrapped C.I.]	[$160-$230]	[$100-$109]	43[$56-$80]
Average loss ($/AF)	$6,726	$6,107	$3,983
[95% Bootstrapped C.I.]	[$5,914-$8,471]	[$5,773-$6,263]	[$3,238-$4,626]
Household WTP($/Month) *	42	24	16
% increases in expenditures*	75	44	28

Panel B: Southern California Utilities

Policy restriction scenario:	Uniform Restriction (25%)	Utility-specific Restrictions (resulting overall cut-back of 22.5%)	Uniform Restriction (22.5%)
Total loss ($ millions)	$1,010	$769	$872
[95% Bootstrapped C.I.]	[$759-$2,098]	[$600-$1,435]	[$668-$1,685]
Average loss ($/AF)	$2,832	$2,757	$2,654
[95% Bootstrapped C.I.]	[$2,126-$5,875]	[$2,154-$5,150]	[$2,032-$5,128]
Household WTP($/month)	34	26	29
% increases in expenditures	41	31	36

Notes: For Northern California Utilities in the panel the quantity-weighted average price is $2,236 ($/AF), the household-weighted average price elasticity of demand is -0.17, total residential demand from June-February in 2013 is 108,457 (AF), and a total number of single-family residential households is 485,892. In Southern California Utilities the quantity-weighted average price is $1,709 ($/AF), the household-weighted average elasticity is -0.29, total residential demand from June-February is 1,428,380 (AF), and a total number of single-family residential households is 3,314,653. Square brackets report 95% confidence intervals for estimates of total welfare losses and average welfare losses per acre-foot of supply restriction. Because the elasticity estimates enter non-linearly into the welfare expression, these are bootstrapped confidence intervals with bootstrapping clustered at water utility level. The household WTP measure divides the total loss reported in the first row by the total number of single-family residential households in the region. The % increase in expenditures uses the welfare loss estimates to calculate how much households would be willing to increase their existing expenditures in percentage terms to avoid the percent restriction identified at the top of the corresponding column. WTP and percentage increases in expenditures are calculated only for the single-family residential sector. Marginal losses are truncated at $20,000.

Table 2-6 Average Predicted and Actual Welfare Losses ($/AF) in Northern California

Northern California	Estimated average R-GPCD[11,12] (y2013)	Estimated average R-GPCD[13] (y2015)	Mandatory restriction relative to y2013 (%)	Observed reduction relative to y2013 (%)	Predicted welfare loss ($/AF)	Actual welfare loss ($/AF)
CWS So. SF	49	40	8%	*20%*	2,111	2,998
East Palo Alto	57	44	8%	*24%*	2,320	3,248
Estero MID	67	57	12%	*15%*	2,322	2,702
Alameda CWD	90	65	16%	*28%*	2,574	4,887
SFPUC	48	41	8%	*15%*	2,730	3,232
Milpitas*	NA	59	12%	NA	2,731	2,731
Santa Clara	79	62	16%	*22%*	2,973	4,047
Hayward	63	48	8%	*23%*	3,016	4,262
Menlo Park MWD	109	65	16%	*42%*	3,120	10,938
Redwood	73	56	8%	*24%*	3,268	7,380
Westborough	58	44	8%	*26%*	3,584	10,328
CWS Mid-Peninsula	77	57	16%	*26%*	3,683	6,564
Daly City	61	54	8%	*12%*	3,689	4,191
San Jose MWS	97	70	20%	*28%*	3,709	6,455
San Bruno	56	43	8%	*24%*	3,752	6,508
Mountain View	81	56	16%	*31%*	3,893	8,642
North Coast CWD	55	42	8%	*24%*	4,073	8,786
Millbrae	80	61	16%	*23%*	4,075	5,789
Sunnyvale	79	56	16%	*28%*	4,648	9,675
Coastside CWD	69	54	8%	*21%*	4,924	9,861
Burlingame	83	59	16%	*29%*	7,263	12,284
Mid-Peninsula	96	70	20%	*26%*	7,441	10,022
Palo Alto	105	75	24%	*31%*	9,277	11,703
CWS Bear Gulch	174	113	36%	35%	11,729	11,432
Hillsborough	260	148	36%	*42%*	15,028	15,710
Average	74.2	57.0	16.2%	23.3%	4,717	7,375
Aggregate Welfare Loss ($ millions)	-	-	-	-	129	265

Notes: Utilities that exceed the mandatory conservation requirement are indicated with italics. MID = Municipal Improvement District; CWD = County Water District; MWD = Metropolitan Water District; CWS = California Water Service. * indicates no data available. Brisbane and Purissima Hills are not required to cut-back. All welfare loss calculations capped marginal welfare loss per acre-foot at $20,000.

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11 R-GPCD= Residential Gallons Per Capita Day.
12 Monthly R-GPCD for 9-month (June-February) of 2013 is calculated using monthly RGPCD and monthly percent saved data which is publicly available on the State Water Resources Control Board (SWRCB) website.
13 The SWRCB monthly R-GPCD data is averaged over the period of June 2015 and February 2016.

Table 2-7 Average Predicted and Actual Welfare Losses ($/AF) in Southern California.

Southern California	Estimated average R-GPCD[14,15] (y2013)	Estimated average R-GPCD[16] (y2015)	Mandatory restriction relative to y2013 (%)	Observed reduction relative to y2013 (%)	Predicted welfare loss ($)	Actual welfare loss ($)
Burbank	117	87	24%	*25%*	859	890
Compton	61	54	8%	*12%*	1,170	1,235
Anaheim	96	75	20%	*22%*	1,292	1,356
Long Beach	74	63	16%	15%	1,302	1,284
USGV MWD*	119	92	32%	27%	1,353	1,273
Santa Ana	71	79	12%	*17%*	1,407	1,531
San Fernando	108	86	24%	20%	1,422	1,330
Glendale	102	80	20%	*21%*	1,655	1,701
Fullerton	116	93	28%	20%	1,738	1,376
IEUA*	131	100	28%	23%	1,757	1,534
Central Basin MWD*	64	52	16%	*18%*	2,050	2,087
Eastern MWD	112	92	28%	18%	2,080	1,722
Western MWD*	150	115	32%	23%	2,223	1,781
Pasadena	123	99	28%	21%	2,262	1,910
Three Valleys MWD*	121	96	28%	24%	2,408	2,049
MWD Orange County*	106	82	24%	23%	2,451	2,380
Torrance	98	77	20%	20%	2,761	2,761
West Basin MWD*	121	98	20%	15%	2,845	2,454
San Diego CWA*	106	80	16%	*19%*	3,087	3,177
Santa Monica	90	71	20%	*21%*	3,433	3,498
Calleguas MWD*	141	103	21%	20%	3,433	3,313
Los Angeles	85	72	16%	16%	3,515	3,496
Foothill MWD*	214	160	24%	*26%*	6,121	5,300
Las Virgenes MWD	211	155	36%	29%	9,914	7,349
Beverly Hills	178	144	32%	19%	11,808	6,638
Average	107.4	84.4	22.5%	21.4%	2,974	2,537
Aggregate Welfare Loss ($ millions)	-	-	-	-	916	794

Notes: Utilities that exceed the mandatory conservation requirement are indicated with italics. MWD = Metropolitan Water District; IEUA = Inland Empire Utilities Agency; USGV = Upper San Gabriel Valley; * For each wholesale utility we collect required information on every local utility within the wholesale utility and calculate an average. San Marino is not required to reduce consumption. All welfare loss calculations cap marginal welfare loss per acre-foot at $20,000.

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14 R-GPCD= Residential Gallons Per Capita Day.
15 R-GPCD for 9-month (June-February) of 2013 is calculated using monthly RGPCD and monthly percent saved data which is publicly available on the State Water Resources Control Board (SWRCB) website.
16 The SWRCB monthly R-GPCD data is averaged over the period of June 2015 and February 2016.

Chapter 3.   HETEROGENEOUS EFFECTS OF REAL-TIME CONSUMPTION
ANALYTICS ON RESIDENTIAL WATER CONSUMPTION

Abstract

This paper estimates how web-based Home Water Use Reports (HWURs)
affect household-level water consumption in Folsom City, California. The HWURs under
study, offered by the company Dropcountr (DC), share social comparisons, consumption
analytics, and conservation information to residential accounts, primarily through digital
communications. The data utilized in this paper is a daily panel tracking single-family
residential households from January-2013 to May-2017. We found that there is a 7.8%
reduction in average daily household water consumption for a typical household who
enrolled in DC program. Results suggest that the effect of DC varies by the baseline
consumption quintile, the number of months in the program, the day of the week, quartile
of the year, message type, and enrollment wave. We also conduct empirical tests to
evaluate the channels through which DC may act to reduce consumption. Results indicate
these responses to DC program likely come from the information channel rather than
moral suasion. Furthermore, our results indicate that providing consumption and pricing
information may not improve the effectiveness of non-linear pricing.

Keywords: Automated meters, Non-price conservation, Social-norms, Urban water
demand, moral suasion, marginal pricing

3.1 Introduction

Public utilities in arid regions struggle to balance supply and demand of water resources both in the short-term and long-term. Most of California's water suppliers in 2015, for example, were required to reduce water use to achieve a 25 percent mandatory reduction level[17]. In addition to these short-term policies, water suppliers are required to comply with longer-term policies, such as the California Water Action Plan(CWAP)[18]. Specifically, the CWAP provides strategies for enhancing water use efficiency and conservation. One of its objectives is to "strengthen water conservation programs to a level comparable to those of energy utilities." In addition to CWAP, California's 20x2020 Water Conservation Plan of 2008[19] requires utilities to make 20 percent reductions in water use by 2020. The primary reason for consideration of conservation is financial; conservation reduces water consumption in a cost-effective and less politically sensitive manner than developing new supplies or reallocating from agriculture to the urban sector (Kenney 2014, Kenney, Mazzone, and Bedingfield 2010).

Utilities use a variety of tools to meet conservation goals-- including price adjustments, outdoor water use restrictions, and efficient appliances rebate programs (Olmstead 2010). Relying on price adjustments to reduce household water demand results in uncertainty in revenue forecasting for utilities and stirs political rancor due to equity concerns for this essential good. Rebate programs may not be cost-effective (Bennear et al. 2013, Brent, Cook, and Olsen 2015) and water use restrictions are costly. For instance,

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[17]http://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/docs/040115_executive_order.pdf
[18]http://resources.ca.gov/california_water_action_plan
[19] http://www.water.ca.gov/wateruseefficiency/sb7/docs/20x2020plan.pdf

Buck, Nemati, and Sunding (2016b) find that California's mandatory restriction in 2015-2016, resulted in economic losses of over $1 billion and cost households an average of $25 per month.

The most appealing non-pecuniary conservation programs are "social-norm-based" ones. These programs seek to alter households' decisions by providing consumption information -- which often includes the households' consumption behavior and comparison to their neighbors. Although there is limited academic evidence available as to whether these programs cost-effectively reduce water consumption, initial research suggests significant potential. Moreover, debate persists in the academic literature as to the significance of and the type of (average versus marginal) price effects on consumption decisions. Generating frequent and highly granular micro-level household data through partnerships between a digital social comparison product and water service providers will improve academic and policy-maker information around decision-making over residential water demand management programming. Well-designed experiments and partnerships have the potential to reduce consumption, while also providing more precise estimates about how various price and non-price management tools, as well as household characteristics, determine water consumption. Additionally, such information could be leveraged not only to direct more effective and efficient water management strategies but also to enable improved forecasting of future water demand, which is necessary for determining optimal state and regional regulatory and infrastructure choices. Hence, this type of research is important in developing solutions to water resource challenges that are impactful, cost-effective, and efficient.

This paper will contribute to a substantial body of similar research in the energy sector

and growing but less advanced work in social comparison programs for the water sector. Experimental designs in numerous markets with *Opower*, an information sharing, and social comparison tool used in residential electricity management programming, have allowed for a multitude of research questions to be explored on residential energy consumption. In general, these findings show an economically and statistically significant average treatment effect, with evidence of heterogeneous impacts and advantages over other programs in reducing energy consumption in a cost-effective manner (Allcott 2011, Allcott and Rogers 2014, Allcott and Taubinsky 2015, Ayres, Raseman, and Shih 2013, Costa and Kahn 2013). Other social norm-based programs in the electricity sector also found similar results (Pellerano et al. 2017). Limited academic analysis has been generated in the water sector, however; the authors are aware of only a few analyses published in peer-reviewed academic journals, which examined the effect of *WaterSmart* services in three Californian utilities (Brent, Cook, and Olsen 2015), a single program in Cobb County, Georgia (Bernedo, Ferraro, and Price 2014, Ferraro and Miranda 2013, Ferraro, Miranda, and Price 2011, Ferraro and Price 2013), and a program in San Diego (Schultz et al. 2014). Shortly, we discuss results of all these experiments— including *Opower*, *WaterSmart*, and Cobb County- in greater detail.

In this paper, we examine the effect of a social-norm-based conservation program on households' water usage. The program under study is administered by Dropcountr (DC), a mobile and web application that informs customers of their water consumption, relative to their neighbors. Specifically, DC provides (i) current water usage, (ii) a comparison to previous usage, (iii) comparison to similar nearby households, and (iv) the efficient budget for households. Also, it also provides tips about where households can

save water and connects them to existing water utility rebate programs on water saving appliances. DC also monitors households' hourly water usage data to identify possible leaks in their water system. They use unexpected boosts in water consumption as a signal of a leak in the households' water system and send an email message or phone alert to the customer. Hence, DC is designed to motivate households to reduce their water use by changing their behavior, adopting water efficient technologies or finding leaks. DC differs from other similar programs in the water sector because of their emphasis on leveraging digital communication platforms, rather than paper reports, which allows for greater flexibility in message content and more frequent and varied content. Also, the DC platform is connected to the households' Smart meter. This option allows DC to provide real-time information to customers.

We analyze the effect of DC program on water consumption in the City of Folsom, CA. The data utilized for this analysis includes two years of historical daily consumption, along with 29 months of data under the DC pilot program, spanning January 2013 through May 2017. DC designed this program as an opt-in program. Therefore, analysis of a treatment effect is challenged by this non-experimental design. However, various statistical tools will be explored to minimize the challenges of interpreting results.

To preview the results, we find evidence that DC has a statistically and economically significant conserving effect on water consumption at the household level for customers who enrolled in the service. The estimated Average Treatment Effect Under Treated (ATOT) is a 7.8% reduction in daily consumption. Given the overall price

elasticity for the single-family residential sector is around -0.23[20], 7.8% reduction in daily

consumption is comparable to an almost 34% increases in prices. There appears to be a

stronger effect for those households identified as high-water consumers in the summer of

the baseline period. This paper also finds evidence of a "boomerang effect"' (i.e., an

increase in average water use) for those households in the lower portion of baseline

distribution. We also find evidence of heterogeneity in the effect of DC by day of the

week, message type, etc. These results are for the City of Folsom, CA with opt-in

program design. The precise magnitude of a DC effect on household water consumption

will vary both by location, experimental design and by time-specific conditions, such as

weather conditions and variations in other determinants of water use that correlate with

time and location.

This paper proceeds as follows: Section two discusses relevant academic

literature; Section three offers an overview of the DC business model and description of

services; Section four describes data; Section five describes empirical method and results;

the paper concludes with a discussion, summary, and policy implications in Section six.

3.2 Relevant Literature

This paper has relevance to existing literature in two particular areas: estimating the

effect of social comparison on consumption decisions, in general, and understanding the

determinants of residential water demand, in particular. Price response in household

water consumption has been studied extensively in the academic literature. Debate

persists in how decision-makers are affected by both the qualitative aspects of price

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[20] This elasticity is reported in (Buck, Nemati, and Sunding 2016b). This is one elasticity
from the literature and is not from our sample

(block rates versus uniform pricing and average versus marginal) and the quantitative

changes (estimating elasticities) (Dalhuisen et al. 2003, Ito 2014, Olmstead, Hanemann,

and Stavins 2007). However, price instruments to reduce residential demand are

considered a political liability, complicate revenue estimation for utilities, and inspire

concerns over the impacts to lower-income households (Agthe and Billings 1987).

Additionally, it is widely understood that other factors determine residential water

demand, such as income, household size, lot size, landscaping, and weather. Buck,

Soldati, and Sunding (2015) use a data-driven process to identify model performance in

predicting residential water demand, which reveals that price is not necessarily the most

important determinant.

Consistent with this, utilities often employ non-price demand-side management

(DSM) strategies to influence household water consumption. Renwick and Green (2000)

estimate the effects of six different categories of non-price DSM policies, which include

information and rebate opportunities. Not surprisingly, they find that mandatory policies

result in larger demand reductions, relative to voluntary programs. They also identify

areas where more research is needed, including the effect of household characteristics

and multiple, simultaneous policy tools on aggregate demand. Services, such as DC,

which have the technological flexibility to vary signals, can amass frequent, granular data

that can be used to fill knowledge gaps. Additionally, recent research has estimated

household willingness-to-pay to avoid water service disruptions for some California

utilities (Buck et al. 2016, Buck, Nemati, and Sunding 2016a). These estimates may help

utilities evaluate the possible conservation benefits through various categories of

messaging, including social norms, information, and pro-social language

Social comparison of household consumption began in the residential electricity sector. The leading figure in this movement has been *Opower*, which partners with utilities to create content with the objective of reducing household electricity demand and improving efficiency and conservation. A growing collection of research in this field has provided estimates of program effectiveness, as well as evaluating the persistence of treatment and examining site selection bias (Allcott 2015, Allcott and Rogers 2014, Ayres, Raseman, and Shih 2013). These analyses estimate treatment effects in the range of 1.2 -3.3%, which varies according to location and program implementation but appears to persist over time. Research on heterogeneous effects suggests that targeted content that considers sub-population attributes improves messaging response (Costa and Kahn 2013). Allcott (2015) identifies a problem in site and population selection bias, where program evaluation of early-adopting utilities overstates the treatment effect, relative to implementation across less environmentally progressive regions and populations.

This business model of combining social, behavior, and data science to impact household decision-making is being replicated in the water sector. *WaterSmart* Software has been building partnerships with water utilities in California, as well as other states, for the past several years. In one analysis, this service has been shown to cause a 5% reduction in average consumption for two California markets, with no statistically significant effect in a third (Brent, Cook, and Olsen 2015). A 2007 randomized experiment in Cobb County, Georgia found strong evidence that social comparison messages had a substantially larger impact than pro-social content and technical recommendations (Ferraro and Price 2013). They find an estimated 4.8% effect when treatment combines social comparison, pro-social messaging, and technical suggestions.

Both the *WaterSmart* program and Georgia study find significant heterogeneity in treatment effect across household types, while only the *WaterSmart* analysis observes stable persistence in treatment effect over time. DC differs from both of these programs for their emphasis on leveraging digital communication platforms, rather than paper reports, which allows for greater flexibility in message content, more frequent and varied content, and the option to survey customer feedback.

We analyze the effect of enrollment in DC service on daily water consumption in the City of Folsom, CA. We provide evidence that the DC effect in the water sector is comparable to and even larger than, *Opower*'s effect in the energy sector. Also, we examine the heterogeneity in the treatment effect. Understanding variation in treatment effects of DC helps target subgroups in a cost-effective manner. Also, this result helps researchers understand the generalizability of the treatment effects to different populations and places (Djebbari and Smith 2008, Ferraro and Miranda 2013, Heckman, Smith, and Clements 1997, Imai and Ratkovic 2013, Manski 2004).

3.3 Overview of Dropcountr Services

DC users have access to water usage and other information anytime via their mobile devices (iOS and Android) or by logging into their account on the web. In addition, DC sends users a monthly email summary of their water use, including contextual comparisons and water utility announcements. While DC can and does work with utilities, who read their meters monthly or bi-monthly, DC is especially well suited for utilities who have migrated to smart metering.

Users who have downloaded the mobile application receive ``push'' notifications to their mobile devices. These notifications can alert households when they may be

approaching the next tier for a block-pricing utility, an indication of leaks, rebate opportunities or other tips. The web platform allows customers to access their DC account, where they can explore their monthly report in more detail and access similar information that may be generated through the mobile alerts. Additionally, DC will produce and mail paper water use reports for utilities that request it.

The "Your Water" interface on both mobile and web apps includes four main features: summary statistics of usage, which includes reference to an individualized "goal"; comparison of usage to "similar" and "efficient" households; and conservation tips tailored to their account characteristics. An example of this interface can be found in Figure 3-1.

The top portion provides statistics on monthly and average daily consumption, along with a graphical representation of their historical consumption over the previous 12-month period. Also, this portion of the report evaluates the households' performance in achieving their "goal" water usage. A goal is an account-specific value and represents the amount of water required by the account each month of the year. The goal is the sum of an indoor budget, primarily determined by household occupancy, and an outdoor budget, which based on parcel size, irrigable area and local weather and other climate factors, such as local evapotranspiration constants. The industry standard and baseline assumption is that 50% of parcel area is irrigated; households may update this irrigation profile, along with other household features, in their DC account.

The social comparison component informs customers how their usage compares to "similar" or "nearby" households and "efficient" households. A "similar/nearby" household lies within a specified radius of the given account and is comparable in

features, such as lot size and household occupancy. Households with consumption below a certain percentile of the distribution are labeled "efficient" by DC. DC also provides "Relevant water saving tips" portion as a part of the report that encourages water savings by suggesting two conservation tips per the report, out of over 100 recommendations, which are tailored to that particular household's profile and past use. Finally, customers are encouraged to log into their online account, where they may explore their report in greater detail and receive further conservation information.

3.4 Data Sources and Description

3.4.1   Enrollment process and enrollment definition

In mid-December of 2014, all account holders in the City of Folsom water utility service area were offered the option of participating in the DC pilot program on a "first come, first served" basis. The offer of service came as a paper advertisement, on city letterhead, with a monthly bill and included a market insert that illustrated the look and style of the DC web and mobile platforms. The utility contracted for a maximum of 5,000 accounts, with a current enrollment of just over 3,350 accounts. The City of Folsom water utility initiated their DC program in December 2014, and enrollment in the program has increased over time.

Progression of DC enrollment over the post-DC period is presented in Figure 3-2. The initial pulse of enrollment was spurred, in part, by direct email when the program was first rolled out. Beyond the initial email, the DC program has been promoted continually on the website of the utility. Households can sign up for DC through the DC website or use the DC mobile application from the Apple or Android app stores.

For this analysis, households who participated in the DC service offer at any point during the study period will be referred to as ``treated'' households, while those who do not are "control" households. The first full month after which a household has received their first DC report is considered the first treatment month. Therefore, since enrollment began in December 2014, the first reports were generated in January 2015, which makes January 2015 the first possible treatment month. This approach is consistent in defining treatment for both *Opower* and *WaterSmart* program analysis. The rate of enrollment, using this definition of treatment, is represented in Figure 3-2.

3.4.2   Summary statistics

Summary statistics for the data used in this analysis is presented in Table 3-1. The average in the baseline period is 589.54 gallons per day. The enrolled group includes 3,353 households, and the never enrolled group includes 16,171 households. Balance in observable variables in the pre-DC period between never enrolled and enrolled group is prerequisite to investigate DC effect using the Difference-in-Differences method. Because of data limitation on demographic information of control households in the study we only use water consumption in the pre-DC period to check for the balance. As shown in Table 3-1, the difference between average consumption of enrolled and never enrolled groups is -1.79 gallons per day. A simple t-test shows that mean pre-DC consumption values are not statistically different between these two groups.

Further investigation of the pre-trends between never enrolled and enrolled groups is analyzed using graphical analysis. Panel (a) in Figure 3-3 presents average water consumption (gallons per day) in the enrolled and never enrolled groups with a vertical dashed line which indicates the DC start time. This graph illustrates that, despite

differences in average consumption across the treated and control groups before DC, there exists a visually distinct increase in this difference in average monthly consumption between treated and control households, following the introduction of DC service (indicated by the vertical dashed line). In other words, we observe graphical evidence that there is a larger difference in average water usage after DC between those households that enrolled in DC and those that did not enroll.

We observe this difference more clearly by plotting the difference in average monthly consumption as a percent difference between the two groups across the sample time horizon. Panel (b) Figure 3-3 illustrates how this percent difference changes across the sample period. Reflecting the pattern observed in panel (a) of the same figure we see that there is a significant increase in the difference in average consumption as a percent between the pre-period, before the availability of DC services, and the post-period, with households under DC treatment. In the pre-period, we observe that enrolled and never enrolled households consume approximately the same water on average. Whereas, in the post-period, households who are in the enrolled group consumed about 6% less water, on average.

Figure 3-4 illustrates how the difference between treated and control groups changes across households with different baseline consumption levels. For this figure, quintiles of consumption are defined based on the average baseline summer usage. Quintiles thresholds, in average gallons per day, are 401.00 and lower as the first quintile, between 401.00 and 646.32 as the second, between 646.32 and 797.92 as the third, between 797.92 and 1,077.19 as the fourth, and higher than 1,077.19 as the fifth quintile. This figure illustrates that there are larger increases in the difference in average monthly

consumption between treated and control households, following the introduction of DC service, for the higher quintiles.

In addition to this graphical evidence of parallel trends, various fixed effects are employed to account for weekly, seasonal, annual, and household invariant factors that may determine consumption. Given the extensive amount of baseline data and number of observations, these fixed effects can explain a significant amount of variation that could otherwise bias the results. For regression analysis purpose, we organize a panel dataset of household-level daily water consumption in the City of Folsom water utility service area. City of Folsom panel begins January-2013 and ends in May-2017, this period includes the start date of the DC service (December-2014). The regression results measure the effect of DC, taking into account household characteristics that also affect consumption (e.g., lot size) as well as any seasonal or year-specific effects on consumption. The average effect of DC enrollment on water consumption is estimated by defining two groups; households who enrolled in DC (treated households) and households who did not enroll in DC (control households).

3.5 Empirical Method and Results
The figures and tables presented in the previous section motivate the empirical strategy for this paper. Table 3-2 provides the basic double difference results and indicates that water consumption in treated households was reduced on average by 32.04 gallons per day, which is equivalent to 6.65% of average daily usage.

Note that in the double difference method with no additional controls, we assume that enrollment in DC is randomly assigned. This assumption means that our estimation result is not suffering from omitted variable bias. However, this assumption is naïve. For

instance, in this estimation, we are omitting household-specific characteristics, like environmental consciousness, that are related to both enrollments in DC program and water consumption. The goal is to estimate the causal effect of enrollment in DC program on water consumption. The primary challenges to estimating this effect are that many observable and unobservable factors affect enrollment in DC program and water consumption which -- if unaccounted for-- could lead to omitted variable bias in estimates of the DC effect on water consumption. Identifying this effect is challenging because the program is voluntary.

Diagnostics that we used to address this challenge include balance in pre-DC usage conditional on controls. Smart water meters which record hourly water consumption gives us the opportunity to explore DC effect using high-frequency data. Rich data set of household level daily water consumption allows us to include various fixed effects and control for unobservable factors. Specifically, in our preferred specification, we estimate the following equation:

$$log(q_{hymd}) = \alpha_1 . Dropcountr_{hd} + \gamma_{hm} + \mu_{my} + \delta_d + \varepsilon_{hymd} \quad (1)$$

In equation (1), the outcome of interest is the log of the household h water consumption in year y, month m, and day d ($log(q_{hymd})$). The variable of interest is *Dropcountr* which denotes whether a household observation is in the enrolled group during the post period in which DC was active. γ_{hm} indicates household-calendar month fixed effects, μ_{my} indicates calendar-month year fixed effects, and δ_d day of the week fixed effects. ε_{hymd} captures all unobservables which affect the dependent variable.

3.5.1 The average effect of Dropcountr

Results for the difference-in-differences with different sets of controls are presented in

Table 3-3. Log of household-level daily water consumption is the dependent variable in

all of the specifications. Standard errors for all the specifications are reported in

parentheses and are clustered at the level of the households to account for within-

household serial correlation in the error term and produce consistent standard errors in

the presence of such correlation (Bertrand, Duflo, & Mullainathan, 2004). In column (1),

we include only *Dropcountr* which is defined by an interaction between post-period and

enrolled households, post-period, and a treated household identifier. As expected, without

controlling for a month and household-specific characteristics, we find a substantial and

negative effect of DC on water consumption. In column (2), we add control for time-

invariant household characteristics by adding household fixed effects. Comparing with

previous specification point estimate for DC effect in column (2) is closer to zero. Not

controlling for household-specific time-invariant characteristics, such as lot size, results

in bias in our point estimates away from zero. One justification for this would be, for

example, lot size is negatively related to enrollment in DC program and positively

associated with our dependent variable (average daily water consumption).

In column (3), in addition to household fixed effects, by adding month by year

fixed effects, we control for consumption factors which are common to all household

within a given calendar month for a specific year, e.g., 2015-16 water restrictions

administered by the California Water Resources Control Board. Comparing results of this

specification to column (2) results indicates that controlling for these types of omitted

variables significantly changes our point estimate of enrollment in DC effect on

consumption. In fact, not controlling for these factors bias our point estimates away from

zero. For instance, 2015-16 water restrictions have a negative impact on consumption, and it is likely that this factor is positively correlated with enrollment in DC program. In our preferred specification, in addition to controlling for a month by year fixed effects, we control for the household by month fixed effects. This type of fixed effects controls for time-constant variables specific to a household and also calendar month specific water-use factors specific to each household. We also use the day of the week fixed effects which control for omitted unobservable variables which are constant over time and specific to each day of the week. Examples of these type of variables would be watering restrictions, weekends, etc. Results of this specification are reported in column (4).

Results in column (4) of this table indicate that, on average, households who enrolled in DC program reduced daily water consumption by 7.8%. This result is both statistically and economically significant, meaning we can reject the hypothesis that there is no effect of DC enrollment on daily water consumption. The change in average gallons per day is an estimated 46.01 fewer gallons for the average enrolled household. To put these reductions in perspective: the average shower uses 16-40 gallons (depending on shower head efficiency), clothes washing machines require 25-40 gallons per wash, while dishwashers use 6-16 gallons per load. Also, the estimates reported here are comparable with those found for *WaterSmart* Software of a 4.9-5.1% average treatment effect for two experimental designs (where no effect was found for a third utility) (Brent et al., 2015).

Notably, although the previous graphs suggest that all households reduced consumption in the post-period, the controls in our regression analysis allow identification of DC's effect on household consumption that takes this general reduction

into account. Thus, we find that DC treated households reduced consumption during the post-period more than households who did not enroll in DC. Taking into account baseline differences and controlling for consumption factors as described in the discussion of the econometric model presented in equation (1).

3.5.2 Investigating Heterogeneity

In this section, we move beyond estimation of average DC effects, and we consider estimating heterogeneity of household's responses to the DC program. Understanding heterogeneity of DC effect will allow targeting households that are more responsive, which will be a cost-effective strategy (Djebbari and Smith 2008, Ferraro and Miranda 2013, Heckman, Smith, and Clements 1997). Also, investigating DC effect by subgroups helps researchers understand generalizability of the result of this study to other populations and places (Ferraro and Miranda 2013, Imai and Ratkovic 2013, Manski 2004).

3.5.2.1 Baseline consumption levels

We explore heterogeneity of DC effect by average summer baseline (pre-) period water consumption. In this study, we defined summer as May-September months (inclusive). For each household, we calculate the mean summer pre-DC water consumption. Next, we create dummy variables for whether that mean summer pre-DC water consumption is in the first, second, third, fourth, or fifth quintile of the whole sample summer pre-DC consumption (i.e., Q.1, Q.2, etc.). Next, we interact these dummies with enrolled household and time dummy indicators. We defined baseline consumption quintiles as 20% and lower, between 20% and 40%, between 40% and 60%, between 60% and 80%, and higher than 80% percentiles. Quintiles thresholds, in average gallons per day, are

401.00 and lower as the first quintile, between 401.00 and 646.32 as the second, between

646.32 and 797.92 as the third, between 797.92 and 1,077.19 as the fourth, and higher

than 1,077.19 as the fifth quintile.

$$\log(q_{hymd}) = \sum_{i=1}^{i=5} \alpha_i Q_i . Dropcountr + \gamma_{hm} + \mu_{my} + \delta_d + \varepsilon_{hymd} \quad (2)$$

In equation (2), Q_i is quintile indicator and other indicators are similar to the

definitions in equation (1). Results for this specification are reported in column (5) of

Table 3-3. The control variables in this regression correspond to columns (4) in the same

table. We find that the DC effect is monotonically increasing in baseline consumption

level-- the largest effect is observed for the group with highest baseline consumption.

These results are consistent with the average effect for all households that are estimated

and presented in column (4) of the same tables.

The analysis suggests that households in the highest quintile of the baseline consumption

reduce consumption by an estimated 18.1% in response to the DC service. However,

there appears to be an increase in usage in daily consumption for those households in the

lower quintiles of the baseline consumption. This response is referred to as a *"boomerang*

effect", where customers who learn that they are using less than their neighbors or other

like-households increase their demand (Clee and Wicklund 1980). It should be noted that

the analyses on both *Opower* and *WaterSmart* do not find evidence of a boomerang effect

in any of the studied markets. The techniques employed here take a rather coarse

approach to segmenting the population. Regarding gallons per day, households in quintile

one increased their consumption by 24 gallons per day, households in quintile two, three,

four, and five decreased consumption by 0.68, 33, 70, and 172 gallons per day.

Note that, the coefficient -0.078 in column (4) of summarizes average percent reduction across all households. This is different from the aggregate reduction in consumption resulting from DC because it does not take into account the fact that households with high levels of baseline use experienced larger percentage reductions than households with lower baseline use. Therefore, the average percentage reduction capture by the coefficients in columns (4) is less than the weighted aggregate effect of DC. To measure weighted aggregate DC effect, we use average use in each quintile in the baseline period, a number of households in each quintile, and the estimated effect of DC in each quintile. Aggregate DC effect for the population of households participating in DC is calculated using equation (3):

$$Aggregate\ Effect = \frac{\sum_{i=1}^{5} \bar{q}_i * \beta_i * (NHH)_i}{\sum_{i=1}^{5} \bar{q}_i * (NHH)_i} \qquad (3)$$

where: *Aggregate Effect* is aggregate DC effect for the population of households participating in DC, $\bar{q}_i$ indicates average usage in 2013 for households who eventually enrolled in DC, β_i indicates estimated coefficient for the quintile i from Table 3-3, $(NHH)_i$ indicates the number of enrolled households in quintile *i*.

Results indicate that aggregate DC effect is 9.21% for the population of households participating in the DC program. Assuming all the households in the City of Folsom water utility service area participate in DC and have a similar response, then aggregate DC effect would be 9.24%. Aggregate DC effect from the second case, assuming everybody in the utility service area participates in DC, is slightly higher than aggregate DC effect from the first case. This larger effect is because the composition of households, in terms of baseline use, is shifted towards lower end users for the overall population (e.g., more households will be in the lower quintiles)

3.5.2.2 What are the specific mechanisms of DC effect?

The discrete specification above provides no sense of the dynamics of DC adoption and water consumption: how quickly water consumption decreases after a household enrolled in DC program and whether this effect grows, decrease, or stabilizes. Following Autor (2003), we explore these dynamics using equation (4):

$$log(q_{hym}) = \sum_{i=-m}^{i=m} \alpha_i . Dropcountr_i + \gamma_{hm} + \mu_{my} + \delta_d + \varepsilon_{hym} \quad (4)$$

In equation (4), m is an indicator for a month. In the first specification, we include indicators for one, two, and three months before enrollment in DC, 0-3 months after enrollment, and from month four forward. Of these eight indicator variables, note that the first seven are equal to one only in the relevant month, while the final variable is equal to one in each month, starting with the fourth month of enrollment.

Table 3-4 presents results for this specification. Results indicate that DC effect is not significant months before DC program starts. In the first month of the program, households who participated in the program reduce average daily water consumption by 2.8%, on average. This effect is between 4.6%-6.9% in the subsequent months. In the long run (4-months or more after enrollment in DC), households who participated in DC program reduce their average daily water consumption by 7.8% in response to DC.

Next, we divided the sample into two groups and then add an indicator variable for months 1-5 before enrollment in DC, and months 0-12 after enrollment in DC. The first group includes all never enrolled households plus DC participant households who enrolled between 1-1-2015 and 1-7-2015. The second group includes all the never enrolled households plus DC participants who enrolled between 1-1-2016 and 1-7-2016.

Using results from these specifications, we can identify how quickly does water consumption decreases after a household enrolls in the DC program, do conservation-minded people adopt first, and do early adopters respond differently.

Figure 3-5 presents the result of this specification. The coefficients on the enrollment leads are not statistically different from zero, showing evidence of common trends assumption, which supports the use of difference-in-differences estimator. For the first group, in the month of enrollment, DC program reduces average daily water consumption by 5.44%, after which this reduction fluctuates at between 3.52% and 11.22% over the subsequent 12 months. On average, we observe that households who enrolled in the program reduce average daily water consumption by 6.52% which is consistent with our findings in column (4) of Table 3-3. For the second group, in the month of enrollment, DC program reduces average daily water consumption by 0.78%, after which this reduction fluctuates at between 3.44% and 6.99% over the subsequent 12 months. On average, we observe that households who enrolled in the program reduce average daily water consumption by 5.86%.

Results from this figure indicate that DC have stabilized over time. Also, we did not find any evidence that early enrolled households are different from households who adopted later and the response of these two groups to DC is not substantially different. Finally, we these results indicate that DC effect is persistent.

3.5.2.3 Does Dropcountr indicator measure an omitted variable such as being conservation minded?

One concern with these analyses might be that DC indicator is measuring an omitted variable such as being conservation minded. The issue is that we cannot directly test for

this, but we conduct the following indirect test.

Assume there is two states of the world, one with DC and another without DC. Suppose that in a world with DC a conservation-minded person sees an advertisement for water conservation, then looks for ways to conserve and finds DC and as a result conserves water. Now, suppose that in a world without DC, the same conservation-minded person sees the same advertisement and looks for ways to conserve and, since there is no DC, finds conservation tips from the water utility website and conserves. Figure 3-6 shows these two states of the word with and without DC.

Another feature of the daily data use in this study is that it indicates which type and time of messages sent to the customers. DC sends messages like monthly report email, leak alert, and new users tip. Note that messages like monthly report emails and leak alerts are only available through DC. However, households can have access to messages like new user tips without DC (e.g., through utility website, monthly bills, etc.). Table 3-5 indicates all messages sent by DC to the customers enrolled in DC by May-2017. To identify the effect of each message type on water consumption, we treat each message type as a separate treatment. Specifically, we used the following specification to capture the effect of each message type on daily water consumption:

$$log(q_{hymd}) = \sum_{i=1}^{i=3} \sum_{d=1}^{d=14} \alpha_{id} . Message_{id} + \gamma_{hm} + \mu_{my} + \delta_d + \varepsilon_{hymd} \quad (6)$$

In equation (6), the variable of interest is Message. Message indicator only takes value one if household i received message i at day d or d-1, d-2, …, d-13. For example, $Message_{12}$ Takes one for households who received message type 1 and on one day after receiving the message. Figure 3-7 indicates the results of this specification. Starting with

leak alert, we observe that leak alerts increase consumption by 60% on the first day. This effect decreases quickly on days following the leak alert message. This result indicates that households are paying attention to the leak alerts and trying to stop the leak immediately following the alert. For example, one day after receiving a leak alert message, consumption decreases by 30%. Six days after a leak alert, consumption decreases by 50%. Monthly report emails effect on daily water consumption is negative and significant but reduces over time. Households have the biggest reduction in consumption on the day that they receive the report (approximately 10%). In the next 13 days, this effect fluctuates between 2%-6%.

On the other hand, new user tips type of message is not statistically significant in any of the days after households receive these tips. This is at some level is evidence that DC indicator is not measuring an omitted variable like being conservation minded. Even if conservation minded type households are enrolling in DC, these results suggest that without DC there would not be water conservation.

3.5.3 Does Dropcountr act through efficiency channel?

Following Allcott and Kessler (2015), nudges (in our application, DC reports) can affect demand through two main channels. The first view is that nudging is informative. Based on this view, the water market is characterized by imperfect consumer information (households have imperfect information about their consumption history, others consumption, methods to increase efficiency, etc.). Based on this view, we assume that there is no moral utility and a nudge only provides information or eliminates bias. In Figure 3-8, D_0 represents the water demand curve before the introduction of social comparison program (in our application, DC), while D_1 represents the demand curve after

the introduction of such a program. In fact, nudges improved efficiency and shifts

demand curve from D_0 to D_1 and changed consumption by $E = Q^*_{DC} - Q^*$.

Nudging effect on consumption through the efficiency channel has important

implications for calculations of ratepayer welfare losses due to disruptions in the water

supply. We assumed the water supply disruption of $R = Q^* - Q^R$, where R> E. Without

programs like DC, welfare loss due to disruption R will be an area of *ABCD*. However, if

programs like DC are in place, and it is acting through the efficiency channel, then

welfare loss due to a similar supply disruption of R will be *A'B'CD'*. Note that *ABCD-

A'B'CD'= ABD'D>0* and represents an upward bias in welfare loss estimations without

considering the effect of low-cost information programs (nudging, like DC) on demand.

The larger effect of DC on water consumption means larger shifts in the water demand

curve and larger upward bias in estimations of welfare losses due to supply disruption of

R.

The second view is that nudging effects through Moral Suasion. In this view, the

nudge itself may directly impose negative utility. For example, seeing cigarette warning

labels with graphic images of smoking-related diseases can be unpleasant, and body

weight report cards could make children feel guilty or shameful. In our application,

seeing neighbors and affect households consuming less water could make a household

feel guilty. Building on Caplin (2003) and Loewenstein and O'Donoghue (2006), Glaeser

(2005) argues that many nudges are essentially emotional taxes that reduce utility but do

not raise revenues.

Now we assume full efficiency in water consumption (perfect information) and

the nudge only raises the moral price of water (in this scenario, nudge effects

consumption through the Moral Suasion channel.) In this case, D_0 in Figure 3-9 reflects the demand curve with and without the nudge. However, P^* moves to P^*_{DC} which reflects water price plus moral tax. Similar to a regular tax, moral tax reduces consumer surplus by AP*P*DCA' area. Note that moral tax does not generate revenues and only reduces consumer surplus (reduced utility). Figure 3-9 illustrates this scenario. Same as the first scenario, before DC, welfare loss due to a supply disruption of R would have an area of ABCD. Welfare loss due to supply disruption of R after a moral tax, because of programs like DC, reduces the area from ABCD to A'B'CD. However, in this scenario, we need to account for the reduction in the consumer surplus due to the moral tax.

Taken together, welfare loss due to a supply disruption of R after a moral tax will result in a net welfare loss of WL(R)= A'B'CD + AP*P*DCA'. WL(R) could be greater, equal to, or smaller than ABCD, depending on the difference between ABB'E and A'EP*P*DC. However, it is more likely to be the case that ABB'E < A'EP*P*DC, which suggests that without considering programs like DC, we are underestimating welfare losses due to water supply disruptions.

In this paper, we conduct an empirical test to evaluate the channel in which DC is acting. If DC changes the weekly consumption composition, then one possibility is that households are reoptimizing their consumption after receiving the information through DC. To identify if households who enrolled in the program have different consumption patterns than those who did not enroll we interact day of the week indicator with Dropcountr indicator.

$$log\big(q_{hymd}\big) = \sum_{i=1}^{i=7} \alpha_i . D_i . Dropcountr + \gamma_{hm} + \mu_{my} + \delta_d + \varepsilon_{hymd} \ (7)$$

In equation (7), the variable of interest is Dropcountr, which denotes whether a household

observation is in the enrolled group during the post period in which DC was active, multiplied by day indicator D_i.

Figure 3-10 indicates the results of this specification. Results indicate that DC has the largest effect on Mondays and lowest effect on Saturdays and Sundays. Consumption is at its highest level on Saturdays and Sundays and is at its lowest level on Mondays. Next, we interact quintile indicators with a day of the week and Dropcountr indicators. Coefficients on these variables indicate the effect of DC by day of the week and quintile of water consumption. Results are presented graphically in Figure 3-10. We observe that, first, DC effect is monotonically increased regardless of the day of the week. Second, we observe the same pattern that we observed for the average effects: DC has the largest effect on Mondays in all the quintiles. Interestingly, we observe boomerang effect for the second quintile only on Saturdays and Sundays. DC has the lowest effect during the weekend in a way that this effect is positive for first two quintiles, not significant in the third quintile, and negative in the fourth and the fifth quintile.

Using this test, we observe that households change their consumption composition within a week and it is suggestive that DC works through information channel rather than moral suasion. It seems that households are reoptimizing their consumption composition in a week after receiving the information from DC. Note that this is only one test in one location and further research requires for answering this question explicitly.

3.5.4   Information and effectiveness of non-linear pricing
The City of Folsom water utility uses an Increasing Block Pricing (IBP) for the water rate. IBP thresholds are shown in Figure 3-11. To test whether enrollment in the DC

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program improves response to the marginal price we conduct the following test. Using daily consumption data, we could identify households jump date from one tier to another within a month. However, to do so, we need to observe everyday water use within a month (e.g., households i in month m jumps from tier one to tier two in day 15 and from tier two to tier three in day 25). For this purpose, we create a subset of data that were complete within a month for each household.

Following Chetty et al. (2011); Saez (2010); and Ito (2014), we used bunching around the non-linear pricing kink points to examine whether enrollment in DC makes consumers respond to the marginal price. We used bunching of the consumers at the kink points of nonlinear price schedules for DC enrolled households and not enrolled households. Such bunching must be observed if consumers respond to marginal price.

As shown in Ito (2014) consumers respond to the average price rather than marginal price without information interventions such as DC. Therefore, distribution of consumption for not enrolled households can provide a baseline for this empirical test. We employed consumption data from all 12 months of 2016. Next, daily water consumption is aggregated for each household within a month. The top panel in Figure 3-12 shows the consumption distribution for the control households, households who never enrolled in DC, and results indicate that consumption is smoothly distributed. The bottom panel in Figure 3-12 shows the histogram of consumption for the DC enrolled, households. The distribution is as smooth as the distribution in never enrolled households, and there is no bunching around the kink points. We also find no bunching for any year of the data. The absence of bunching implies one possibility. Consumers have no response to the marginal price and information provided by DC did not improve

this response. Further studies required to investigate this question in greater detail.

3.6 Conclusion and Policy Implications

This study provides insight into how social-norm-based conservation programs affect water usage. Specifically, the effect of DC on water usage was examined by using household-level panel data and adopting a difference-in-differences approach. Results suggest that the introduction of the DC services for the population of households participating in DC causes ATOT of 7.8% reduction in daily water usage.

These are also evidence that not all of the households react alike to DC. The results hold, as a general rule, that those in the higher quintiles of baseline water usage had the largest responses. The analysis suggests that in response to the DC service households in the highest quintile of baseline consumption reduce water usage by an estimated 18% --at the margin, these are a large effect. This result is comparable with the existing literature (Allcott 2011, Brent, Cook, and Olsen 2015, Ferraro and Miranda 2013). Such a result indicates the effectiveness of sub-group targeting in social-norm-based conservation programs towards baseline users with higher consumption.

Future analyses suggest that there is heterogeneity in response to the DC program. We have evidence that DC program acts through the information channel. The simple test indicates that DC program did not improve households' response to marginal price in the City of Folsom water utility service area.

3.7 Figures and Tables

Figure 3-1 Dropcountr Home Water Use Report Sample
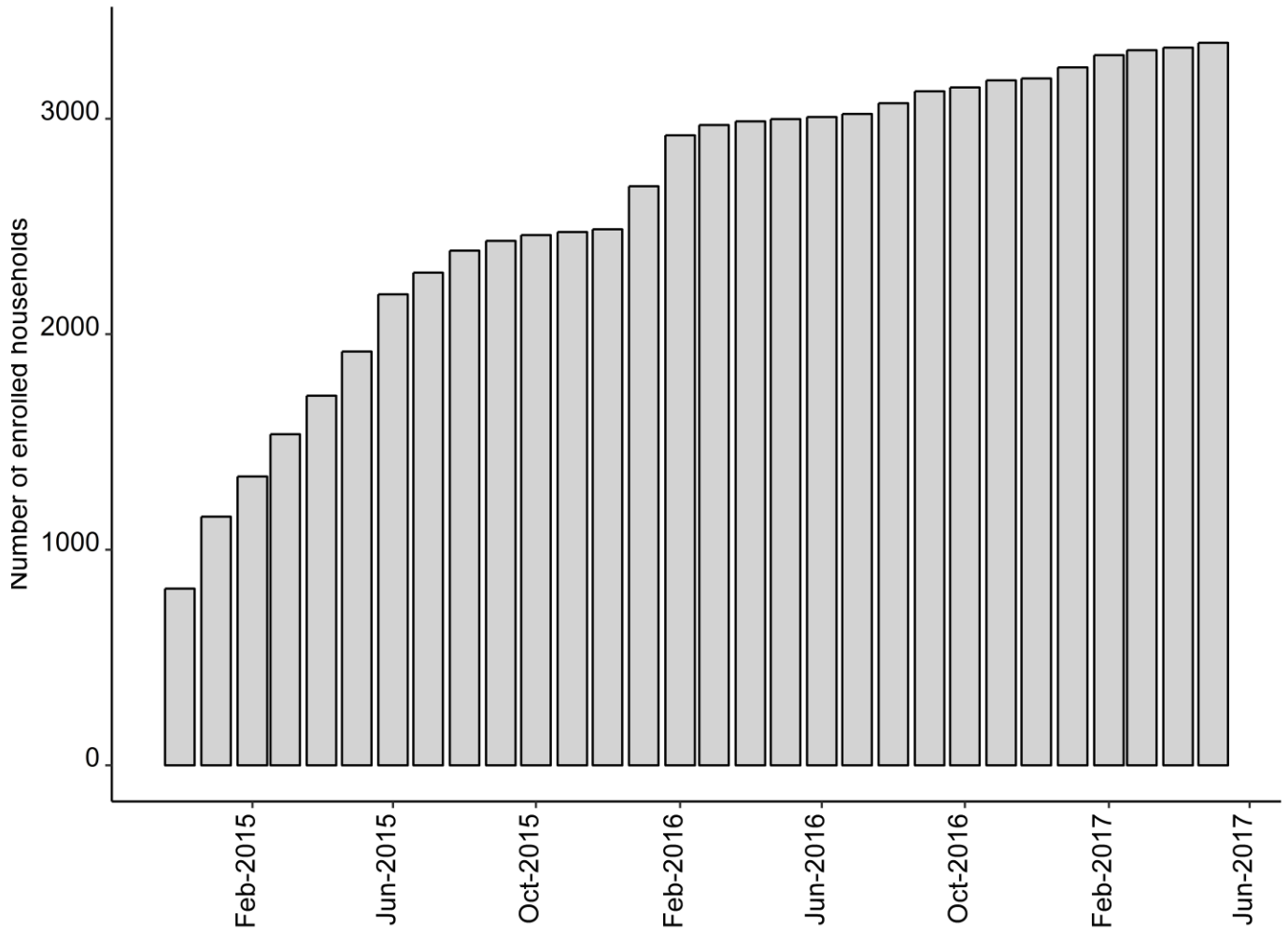
Figure 3-2 Enrollment Evolution in Dropcountr Program Over Time. A Total Number of 3,353 Households Enrolled by the End of April 2017 Was 3,353
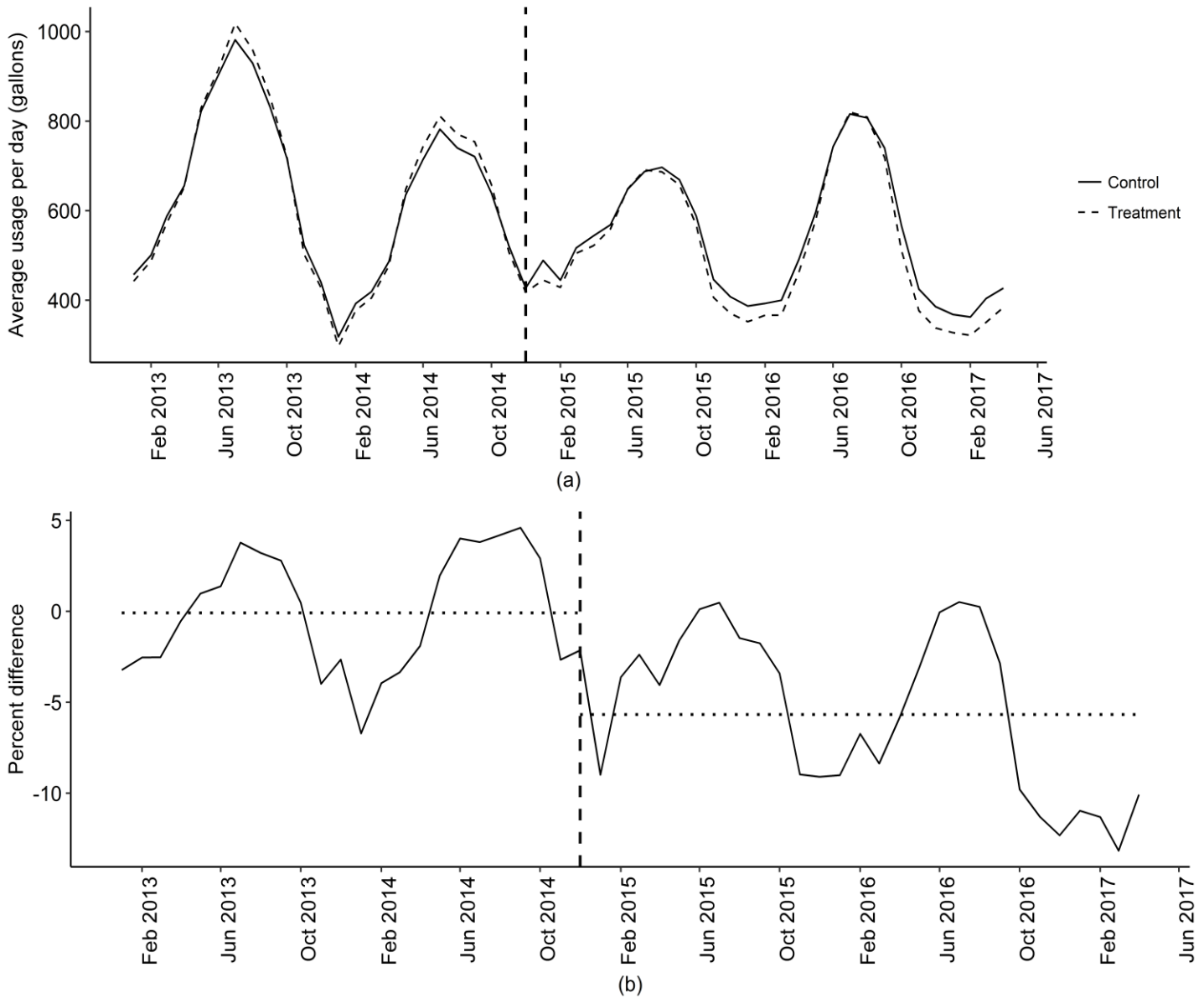
Figure 3-3 (A) Average Water Consumption (Gallons Per Day) by Enrollment Status During the Study Period. (B) The Difference in Average Water Consumption, As a Percent, Across Time by Enrollment Status

Notes: Vertical dashed lines Indicate start of the Dropcountr program (December 2014). Horizontal dot lines represent the average percent difference in household consumption for the pre- and post-Periods. Average percent difference in household consumption for the pre-periods is approximately 0% and for post-periods is approximate -6%.
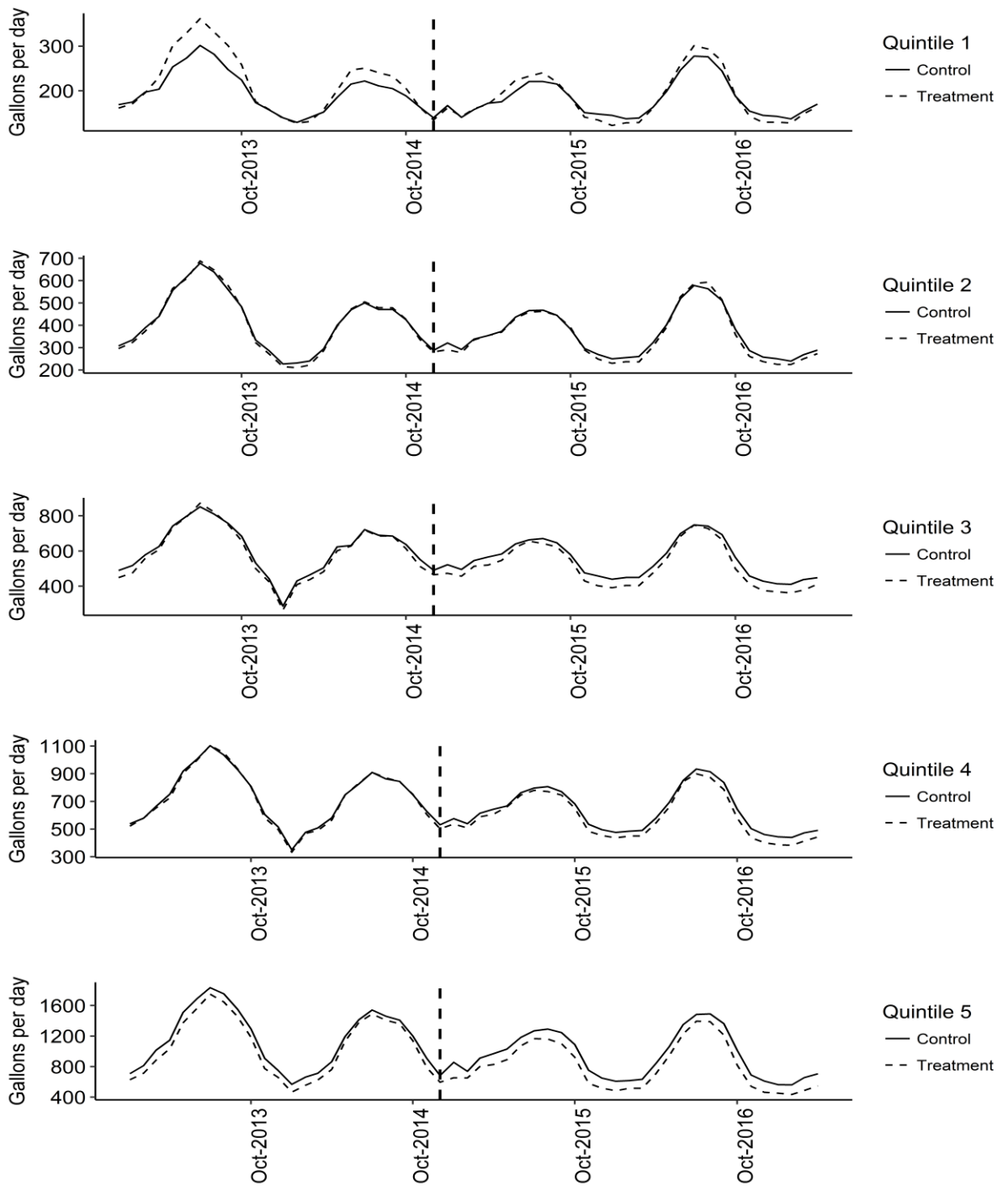
Figure 3-4 Average Consumption (Gallons Per Day) for Enrolled and Never Enrolled Groups by Quintile

Notes: The Vertical Dashed Line Indicates the Start of the Program (December- 2014)

Notes: Quintiles of consumption are defined based on the average baseline summer usage. Quintiles thresholds in gallons per day are 401.00 and lower as first quintile, between 401.00 and 646.32 as second, between 646.32 and 797.92 as third, between

797.92 and 1,077.19 as fourth, and higher than 1,077.19 as the fifth quintile.

Figure 3-5 The Estimated Impact of Dropcountr on Water Consumption for Months Before, During, and after Enrollment in Dropcountr Services (Includes 95% Confidence Intervals)

Notes: Estimated effects presented in percentage forms. Horizontal bold dash lines indicate average effect for before and after the program start date. The top portion of this figure uses a subsample of households and includes all never enrolled households plus DC participant households who enrolled between 1-1-2015 and 1-7-2015. The bottom portion of this figure includes all the never enrolled households plus DC participants who enrolled between 1-1-2016 and 1-7-2016.
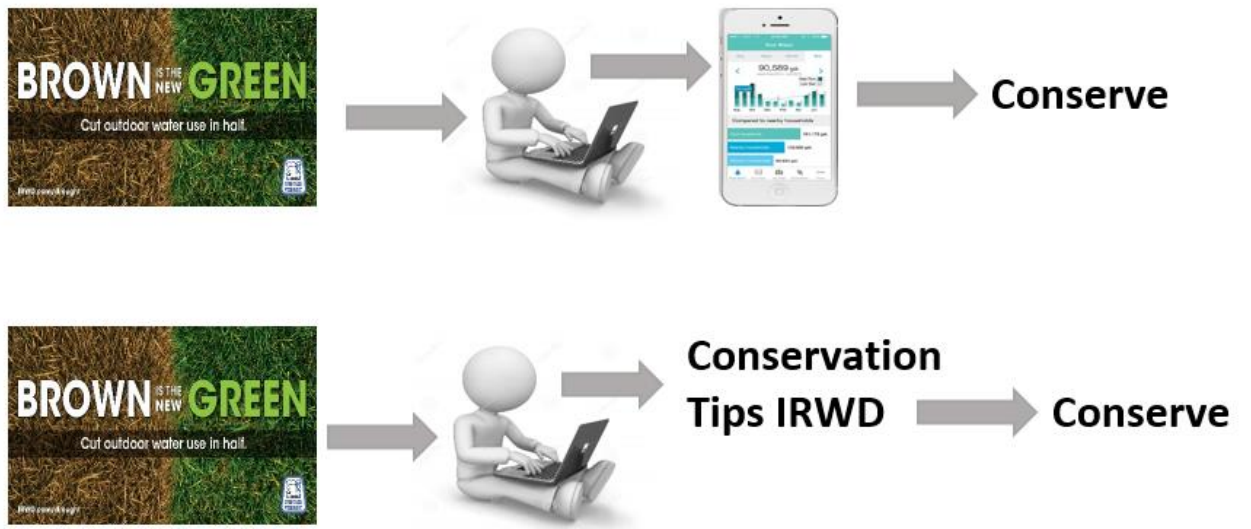
Figure 3-6 Two States of World, Top Portion with Dropcountr and Bottom Portion without Dropcountr
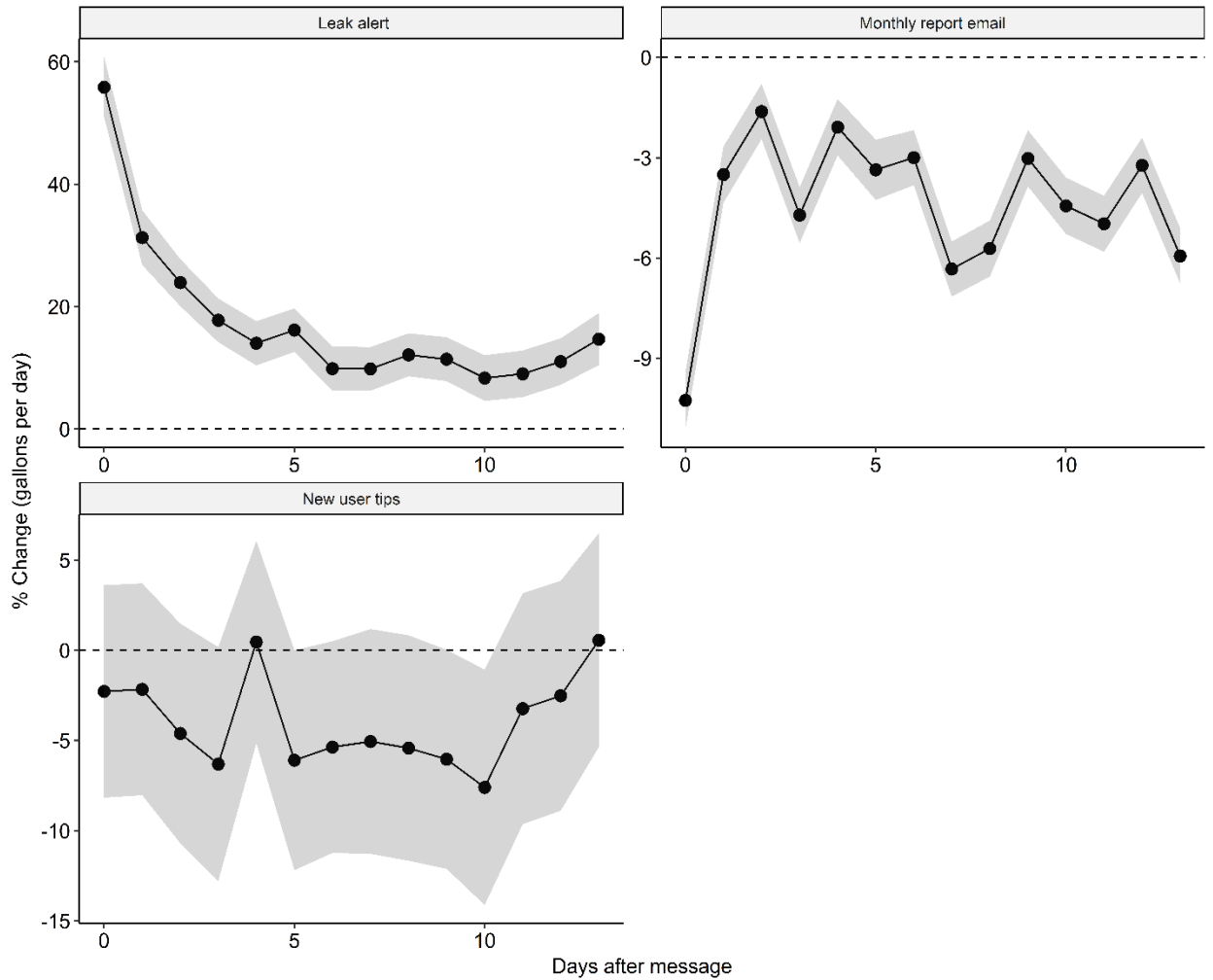
Figure 3-7 The Estimated Impact of Dropcountr on Water Consumption by Message Types (Includes 95% Confidence Intervals)

Notes: Month by year fixed effects, household by month fixed effects, and day of the week fixed effects used in estimation.
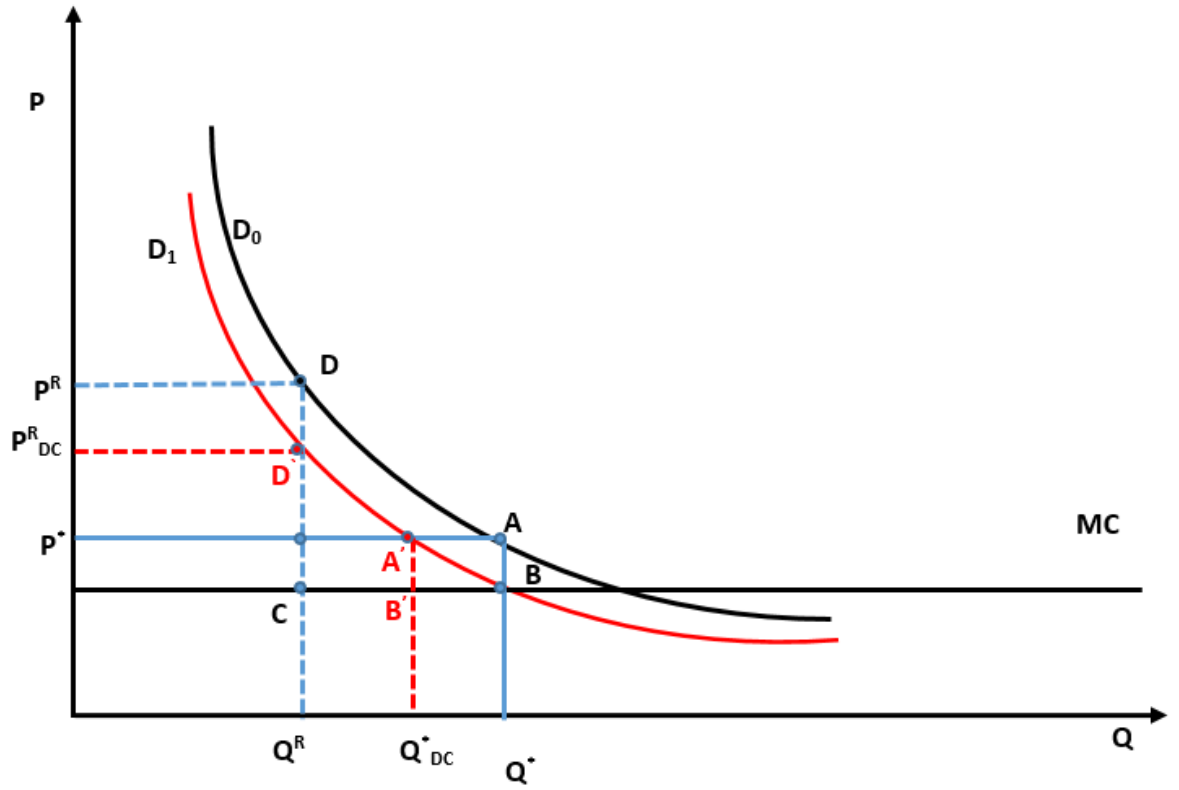
Figure 3-8 The Effect of a Nudge That Acts Through Efficiency Channel on Welfare Losses Calculations due to Water Supply Disruptions

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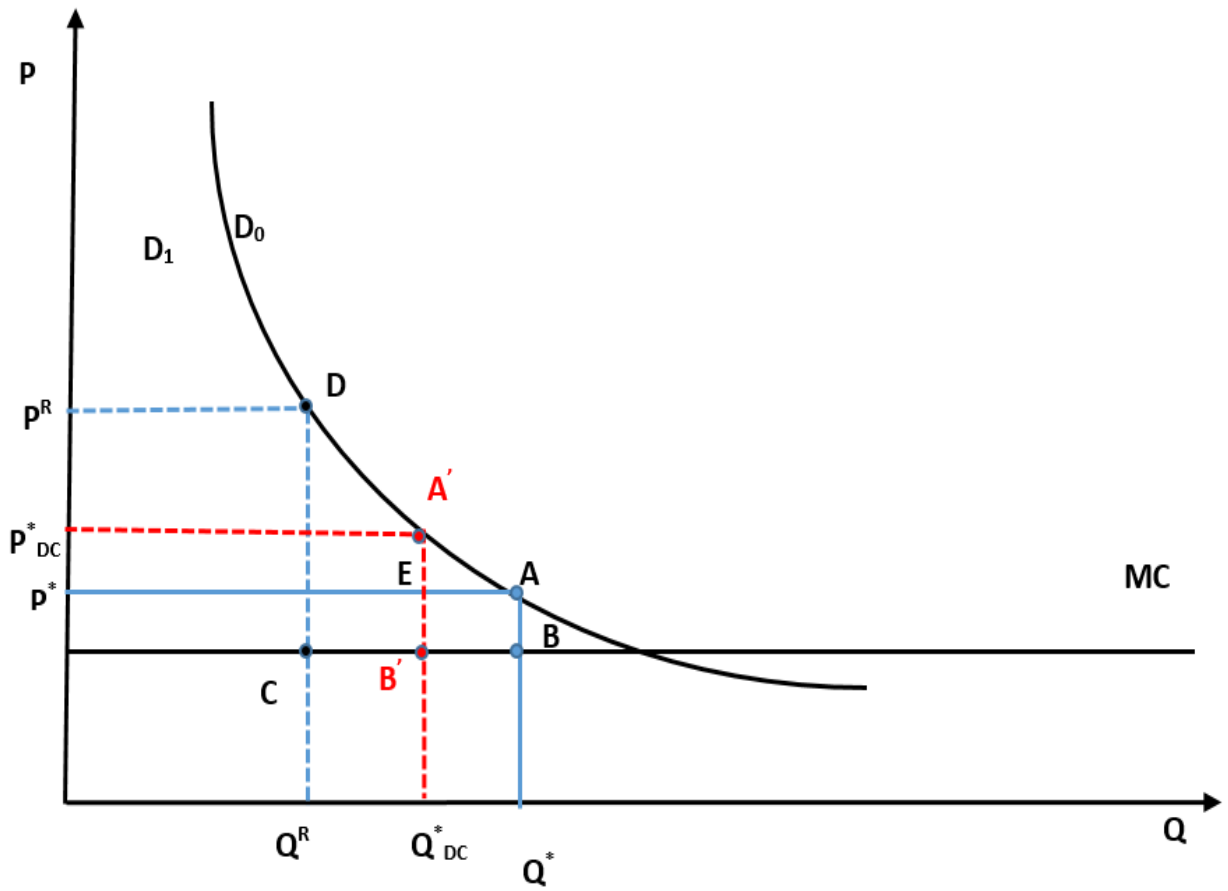
Figure 3-9 The Effect of a Nudge that Acts Through Moral Tax Channel on Welfare Losses Calculations due to Water Supply Disruptions
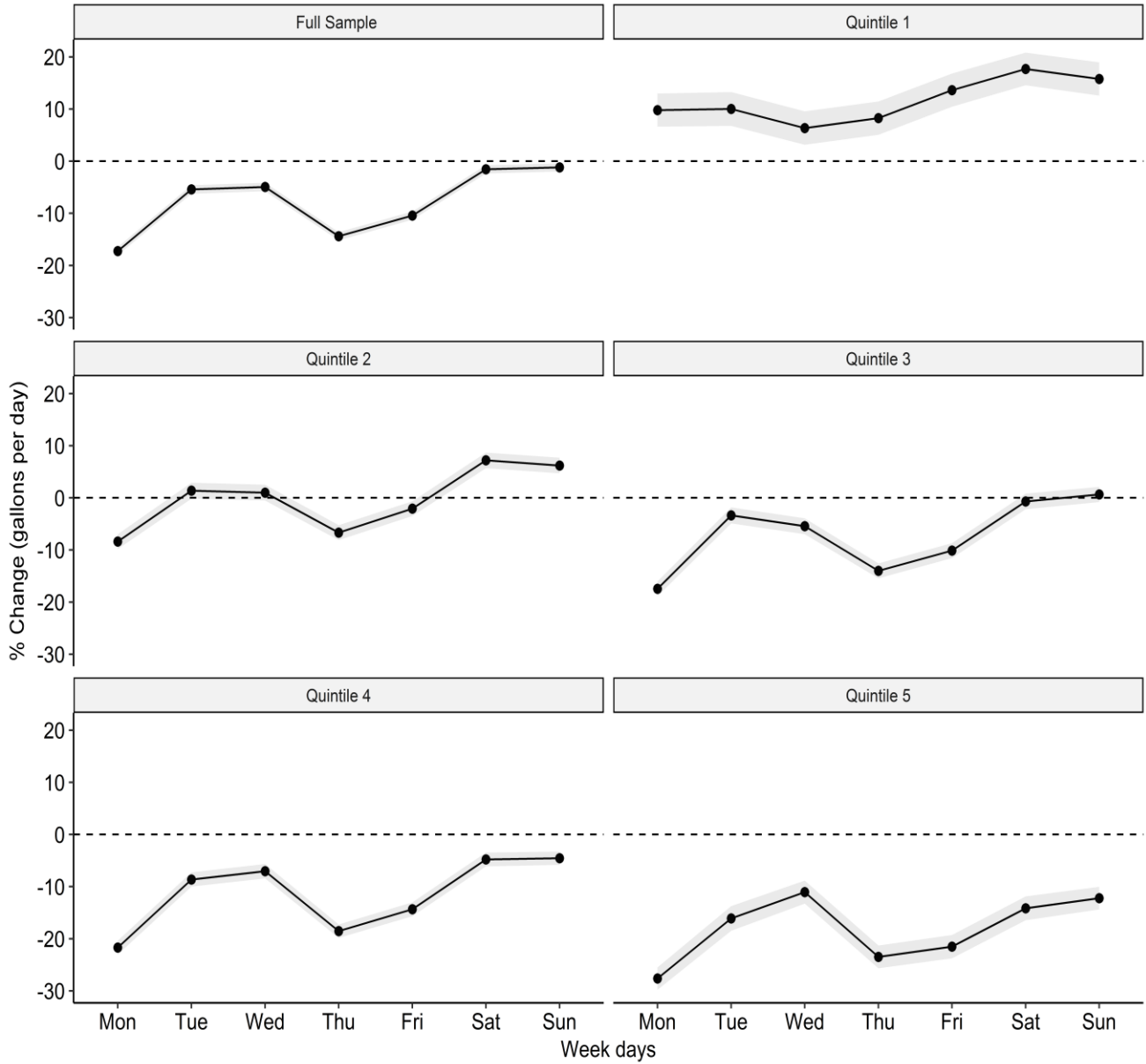
Figure 3-10 The Estimated Impact of Dropcountr on Water Consumption for each Day of the Week (Includes 95% Confidence Intervals)

Notes: Month by year fixed effects, household by month fixed effects, and day of the week fixed effects used in the estimation
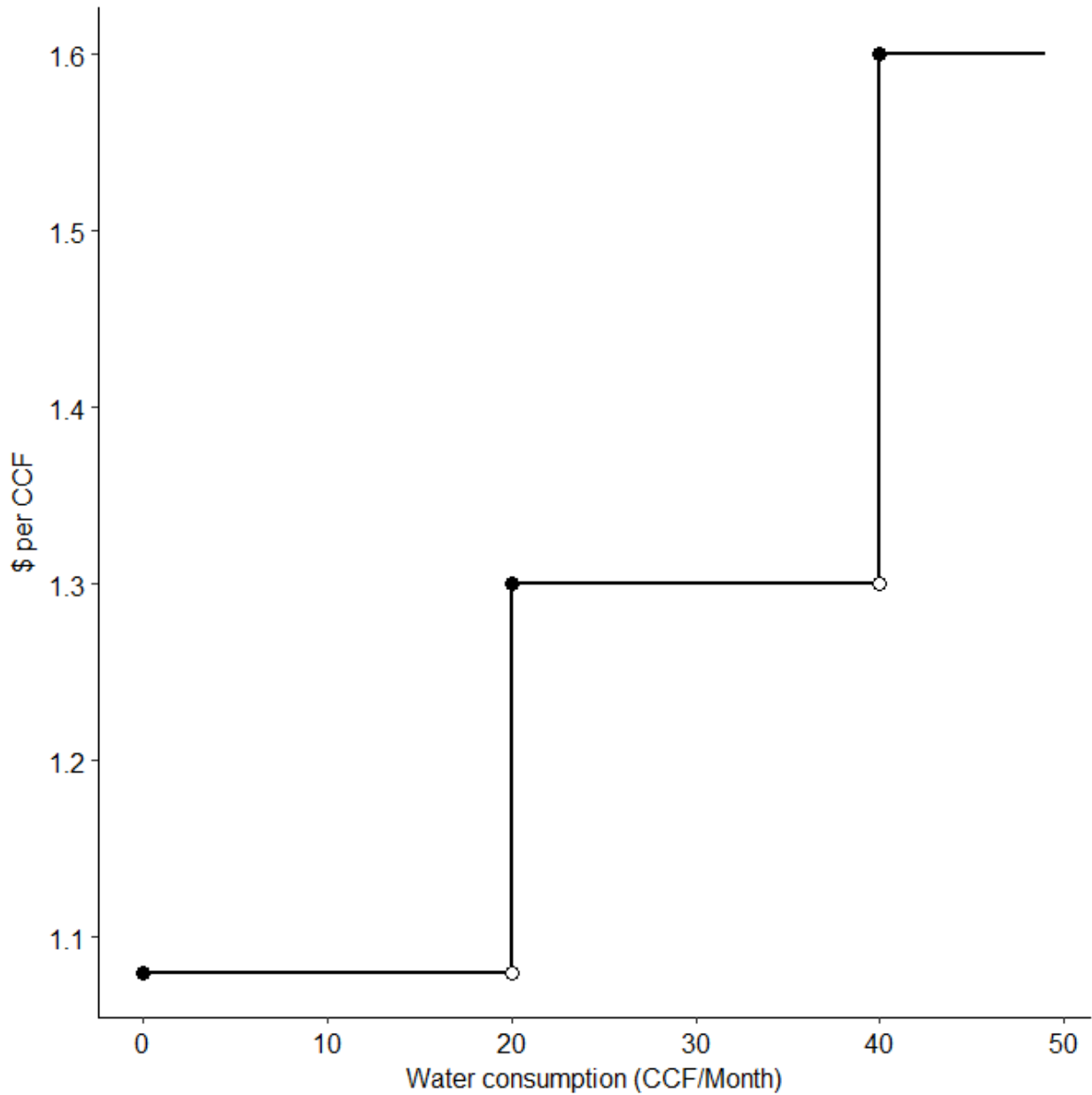
Figure 3-11 Increasing Block Pricing Structure in the City of Folsom Water Utility Service Area, Effective Since January-2013. Before January-2013 the City of Folsom Water Utility Used a Flat Pricing Structure
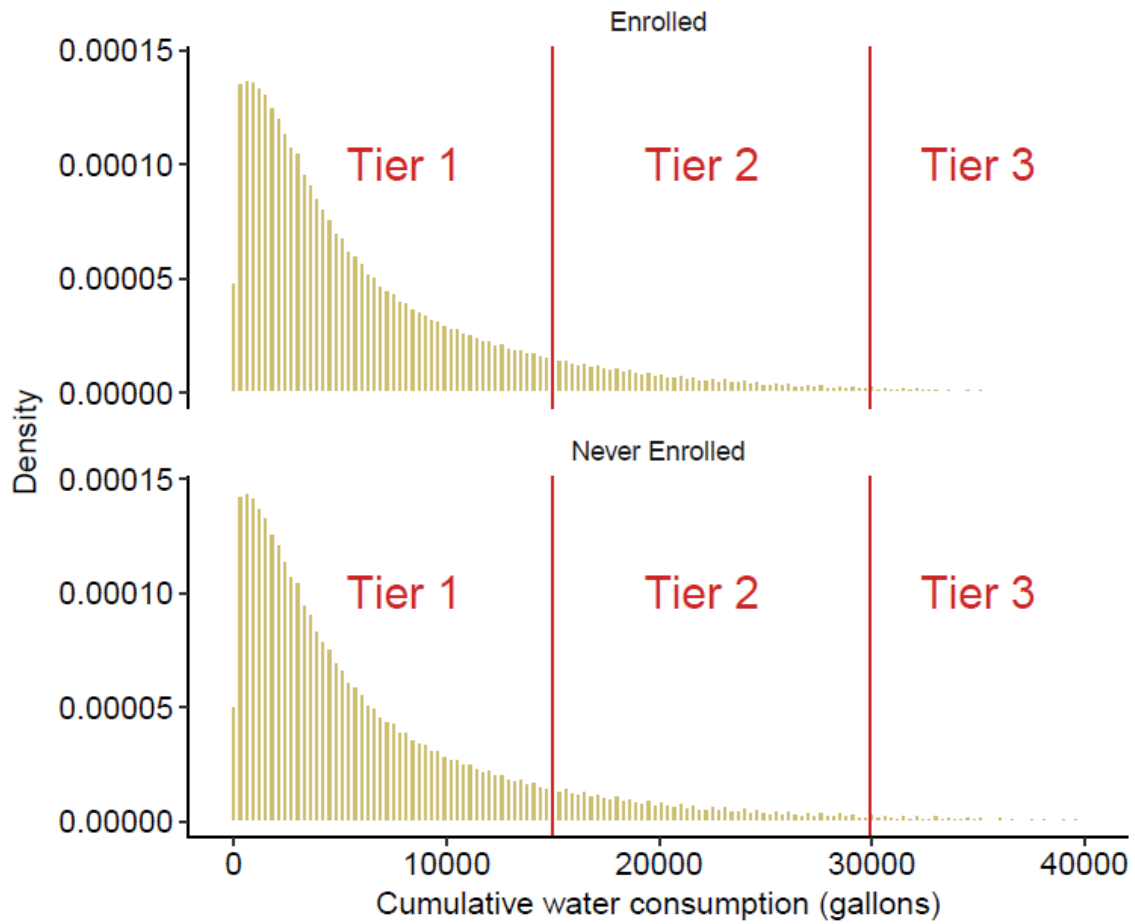
Figure 3-12 The Figure Shows the Histogram of Household-Level Monthly Cumulative Water Consumption in the City of Folsom, CA Water Utility Service Area.

Notes: The Vertical Solid Lines Show the Kink Points of the Nonlinear Price Schedule.

Table 3-1 Summary Statistics of Data Available for Analysis. Average Daily Consumption Values in Gallons for the Baseline Period

	All accounts	Never enrolled group	Enrolled group
Number of accounts	19,524	16,171	3,353
Pre-DC observations	10,769,093	8,893,550	1,875,543
Post-DC observations	10,874,899	8,825,345	2,049,554
Baseline:			
Average	589.54	589.23	591.02
25th percentile	157.09	155.60	164.57
Baseline median	403.95	396.47	433.87
75th percentile	748.05	748.05	748.05

Notes: Baseline period is January 2013 through December 2014. Dropcountr is still active.

Table 3-2 Average Daily Water Consumption in the Enrolled and Never Enrolled Groups (Gallons Per Day)

	Never enrolled households	Enrolled households	Difference (level)	Difference (%)
Pre-period	589.23	591.02	1.79	0.3
Post-period	476.86	446.61	-30.25	-6.34
Double difference	-112.37	-144.41	-32.04	-6.65

Notes: Households that never enrolled in Dropcountr consumed on average 589.23 gallons of water pre-period; this number reduced to 476.86 gallons in post-period. However, households that eventually enrolled in Dropcountr consumed 591.02 gallons of water pre-period and 446.61 gallons in post-period. Comparing two groups indicates that Dropcountr reduced water consumption in the enrolled group by 32 gallons per day. In percentage terms, Dropcountr reduced water consumption in the enrolled group by 6.65%.

Table 3-3 Dropcountr Effect on Daily Water Consumption (Gallons/Day) in the City of Folsom, CA Water Utility Service Area

	(1)	(2)	(3)	(4)	(5)
Dropcountr	-0.11***	-0.101***	-0.081***	-0.078***	
	(0.001)	(0.008)	(0.008)	(0.008)	
Post	-0.312***	-0.263***			
	(0.001)	(0.003)			
Dropcountr Enrolled Household	0.055***				
	(0.001)				
Dropcountr Effect in Quintile 1					0.118***
					(0.031)
Dropcountr Effect in Quintile 2					-0.002
					(0.013)
Dropcountr Effect in Quintile 3					-0.071***
					(0.013)
Dropcountr Effect in Quintile 4					-0.111***
					(0.013)
Dropcountr Effect in Quintile 5					-0.181***
					(0.022)
Household Fixed Effects	No	Yes	Yes	No	No
Household X Month Fixed Effects	No	No	No	Yes	Yes
Month X Year Fixed Effects	No	No	Yes	Yes	Yes
Day of the Week Fixed Effects	No	No	No	Yes	Yes
Observations	21,643,992	21,643,992	21,643,992	21,643,992	21,643,992
R-square	0.019	0.398	0.495	0.534	0.534

Notes: * $p<0.1$; ** $p<0.05$; *** $p<0.01$.

Log of household-level daily water consumption is the dependent variable in all of the specifications. Standard errors for all the specifications are reported in parentheses and are clustered at the level of the households.

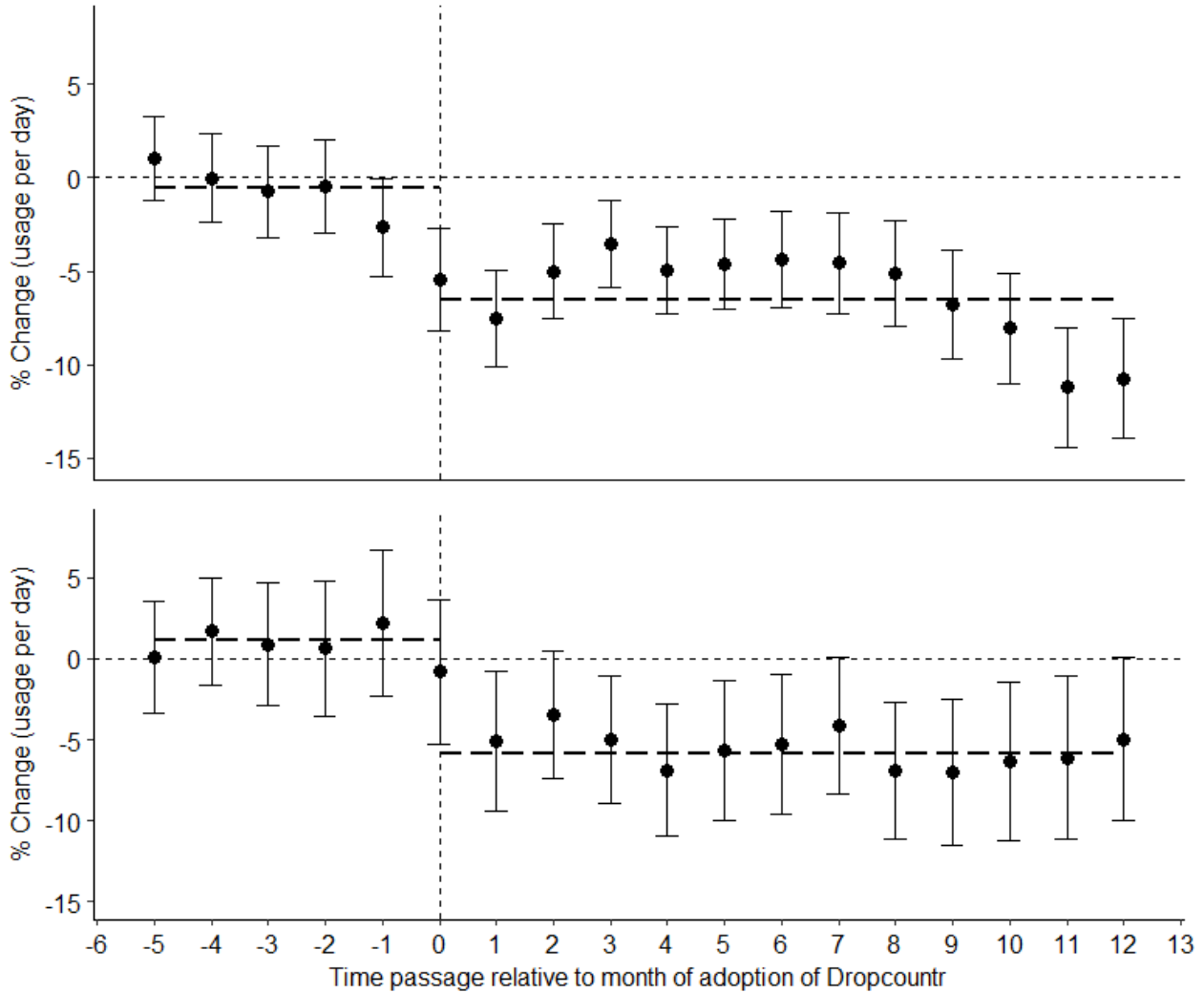**Table 3-4** The Estimated Impact of Dropcountr on Water Consumption for Months Before, During, and after Enrollment in Dropcountr Services in the City of Folsom, CA Water Utility Service Area

	(1)	(2)
Dropcountr Average Effect	-0.078***	
	(0.008	
Three Months before Enrollment		0.008
		(0.009)
Two Months before Enrollment		0.017
		(0.010)
One Month before Enrollment		0.0002
		(0.011)
Enrollment Month		-0.028**
		(0.011)
One Month after Enrollment		-0.069***
		(0.011)
Two Months after Enrollment		-0.051***
		(0.010)
Three Months after Enrollment		-0.046***
		(0.010)
Four Months or more after Enrollment		-0.078***
		(0.009)
Household X Month Fixed Effects	Yes	Yes
Month X Year Fixed Effects	Yes	Yes
Day of the Week Fixed Effects	Yes	No
Observations	21,643,992	911,613
R-square	0.534	0.702

Notes: * p<0.1; ** p<0.05; *** p<0.01.
Standard errors for all the specifications are reported in parentheses and are clustered at the level of the households.

Table 3-5 Summary of Messages Sent by Dropcountr to the Enrolled Customers in the City of Folsom, CA Water Utility Service Area from December-2014 to May-2017

Message Type	Sending Frequency
Monthly report email	38,348
Leak alert	3,157
New user tips	628

Chapter 4.   ISO-14001 STANDARD AND FIRMS' ENVIRONMENTAL
  PERFORMANCE: EVIDENCE FROM THE U.S. TRANSPORTATION
  EQUIPMENT MANUFACTURERS

Abstract

Manufacturers have been increasingly relying on environmental management systems (such as ISO 14001 based ones) to comply with government regulations and reduce waste. In this paper, we investigated the impact of ISO 14001 certification on manufacturers' toxic release by release level. We applied the censored quantile instrumental variable estimator (CQIV) to data on the U.S. transportation equipment manufacturing subsector facilities. Results show that ISO 14001 had a negative and statistically significant effect on the top 10% manufacturing sites regarding the on-site toxic release, but it did not reduce off-site toxic release. Therefore, one should not expect ISO 14001 to have a uniform impact on manufacturing sites' environmental performance. For large firms, encouraging voluntary adoption of ISO 14001 might be an effective government strategy to reduce on-site pollution. However, for small firms and to reduce off-site pollution, other economic incentives or regulations are warranted.

Keywords: Censored quantile regression, Environmental performance, ISO 14001, Manufacturing.

4.1 Introduction

Many manufacturers have an environmental management system (EMS) to comply with government regulations and reduce waste. Most EMSs are based on International Organization for Standardization (ISO) 14001, a private standard that helps manufacturing facilities to develop organized environmental policies, goals, and plans for achieving their environmental objectives, and to monitor and evaluate their success. To obtain certification to ISO 14001, a facility needs to choose a certifier (known as certification body) that will conduct an audit and determine if the facility can be certified. Adoption of ISO 14001 is fast-expanding in the world. For the United States, the number of facilities with ISO 14001 certification increased from 639 in 1999 to 6,071 in 2013 (ISO, 2013). Figure 4-1 shows the top 10 countries with ISO 14001 certificates in 2013. China ranked the highest with over 100,000 certificates, and the United States ranked the ninth.

Adoption of ISO 14001 is growing for many different reasons. First, many governments encourage self-regulation and voluntary actions among industries to reach overall environmental goals. Governments want to do this because voluntary actions in comparison with government environmental policies and economic incentives (e.g., pollution tax, pollution quotas, and emission trading) are less costly and may be administratively more acceptable to the industry (Anton, Deltas, and Khanna 2004, Arimura, Darnall, and Katayama 2011). The U.S. government has also begun to promote greater adoption of EMSs that can be implemented through the ISO 14001 certification process (Anton, Deltas, and Khanna 2004, Rondinelli 2001). For example, if facilities had an active EMS in place (e.g., ISO 14001 certified) at the time of a violation of environmental regulations, the Environmental Protection Agency (EPA) would reduce

the penalty associated with this violation (Curkovic, Sroufe, and Melnyk 2005, Lally 1997).

Secondly, ISO 14001 adoption may result in other benefits for manufacturing facilities. These benefits include, based on the assumption that the environmental performance of facilities may improve after adopting ISO 14001, improvement in stakeholder satisfaction, fewer inspections by the EPA or other environmental regulatory agencies, better company image, lower public pressure, and lower insurance costs (Begley 1996a, b).

Promotional efforts toward the adoption of ISO 14001 are primarily based on the assumption that ISO 14001 has a positive effect on facilities' environmental performance. However, this assumption may not hold true from either theoretical or empirical standpoint (as shown in later sections). For this reason, many researchers have begun to empirically examine the effect of ISO 14001 adoption on facilities' environmental performance. Research findings of this effect are largely inconclusive. On the one hand, some researchers found adopting ISO 14001 had a strong positive impact on environmental performance (e.g. (Comoglio and Botta 2012, Franchetti 2011, Nguyen and Hens 2013, Testa et al. 2014)). On the other hand, some studies only found weakly statistically significant evidence of the effect of ISO 14001 on environmental performance (e.g. (Barla 2007, Dahlström et al. 2003, Ziegler and Rennings 2004)), and some others found no relationship between ISO 14001 adoption and environmental performance at all (e.g. (Darnall and Sides 2008, Gomez and Rodriguez 2011, King, Lenox, and Terlaak 2005, Zobel 2015)).

A commonality between all of the previous studies is that they did not

differentiate between the levels of pollution across facilities. In reality, the effect of ISO 14001 adoption may be dependent on the actual levels of pollution a facility is currently at, which becomes the focus of this study. For example, there is a possibility that facilities with a high pollution level get certified because they want to lower public pressure and get fewer inspections from the EPA. For these types of facilities, the effect of ISO 14001 on pollution level can be weak or even positive due to selection issue. Similarly, the effect for facilities with low pollution level can also be weak because they may have reached the minimum level of pollution and having ISO 14001 does not induce them to further reduce pollution. Therefore, we hypothesize that the effect of ISO 14001 adoption is different for facilities with various levels of pollution and this study provides the first attempt to provide empirical evidence on this issue.

4.2 Background Literature

4.2.1 ISO-14001 standard overview

The first version of the ISO 14000 series, ISO 14001, was released in 1996 and then revised in 2004. ISO 14001 provides a framework for facilities to follow so they can set up an effective EMS. The ISO 14001 standard can assure company management, employees, and external shareholders that environmental impact is being monitored and improved (ISO, 2002).

To be certified by ISO 14001, facilities are required to have third-party verification (the use of a third-party certification body) to ensure that they follow the standard. In the first step, the facilities agree to reduce environmental impacts over time. After the facilities agree to reduce their environmental impacts, they should prove that their EMS meets the five key component of ISO 14001 requirements (Arimura, Darnall, and Katayama 2011, Arimura, Hibiki, and Katayama 2008). The five essential

components are: (1) environmental policy—a facility needs to draft an environmental

policy statement, determine objectives of the facility in terms of environmental impact,

and make this policy publically available, (2) planning—an agenda outlining the facility's

plan to meet the goals, (3) implementation and operation—a facility will establish

necessary components to implement the program such as structure and operation,

training, and documentation, (4) checking and corrective action—a facility needs to

perform periodic monitoring to assure that the facility's EMS meets its targets and

objectives and, if not, what corrective actions should take place, and (5) management

review—management staff should do periodical review, mostly once a year, to assure the

EMS continues to be effective and sustainable. ISO 14001 certified facilities should

follow Plan-Do-Check-Act cycle over time to maintain its registration with the ISO

(Arimura, Hibiki, and Katayama 2008, Welford 1998, Whitelaw 2004).

4.2.2   ISO 14001 and environmental performance

Considering the rapid, worldwide growth of ISO 14001 adoption, research about

the effect of this certification on the environmental performance of facilities is also

growing. As mentioned above, ISO 14001 is a non-governmental voluntary standard

through which facilities can successfully implement their EMS. The certification process

itself does not force facilities to improve their environmental performance as long as the

facilities have satisfied the requirements for certification (Corbett and Kirsch 1999).

Overall, various studies found that ISO 14001 can improve or have no impact on

environmental performance, depending on the facility's location, the sector/industry, and

the measure of environmental performance. When we discuss "improvement of

environmental performance" or "a positive effect of certification" in this study, we mean

a reduction of waste release/generation/emission as a result of certification. Table 4-1

provides a summary of the studies in this area, grouped by the impact of ISO 14001.

Many studies report that ISO 14001 improved environmental performance.

Montabon et al. (2000) found evidence that ISO 14001 improved both overall

environmental performance and economic efficiency of facilities. Russo and Harrison

(2001) considered the electronics sector in the U.S. and had concluded that the

certification could have a positive (and statistically significant) effect on toxic release

reduction. Another study for the same sector by Russo (2009) indicates that ISO 14001

has a positive impact on facilities emission. Also, this study showed that the earlier they

adopt it, the higher the positive impacts are. These results were also supported by the

Babakri et al. (2004) whose results indicated that recycling performance in the U.S. is

significantly positively affected by ISO 14001 certification. Also, they found that smaller

facilities and early adopters of the certification had greater improvement in recycling

performance than bigger facilities as well as late adopters. Melnyk, Sroufe, and

Calantone (2003) used North American data and found that facilities with ISO 14001

standard reduced their waste disposal. Potoski and Prakash (2005) provided evidence that

ISO 14001 certified facilities in the U.S. reduced their toxic emissions faster than non-

certified facilities. More recently, Franchetti (2011) used the U.S. manufacturing firm-

level data and found that ISO 14001 certification reduced solid waste.

Some studies also provide evidence on the positive relationship between

environmental performance and ISO 14001 standard in countries other than the United

States. Ziegler and Rennings (2004) found that ISO 14001 has a weak (statistically

significant at the 10% significance level) positive effect on environmental performance at

German manufacturing facilities. Using Japanese facility-level data, Arimura, Hibiki, and Katayama (2008) found that ISO 14001 helped to reduce environmental impact. Nguyen and Hens (2013) used Vietnam cement industry data and found a positive relationship between ISO 14001 certification and environmental performance in this industry. Testa et al. (2014) examined the effect of ISO 14001 certification effect on carbonic anhydride emissions in energy-intensive facilities of Italy. Their result indicated a positive relationship between ISO 14001 certification and environmental performance.

On the other hand, several studies found that ISO 14001 certification had no statistically significant effect on the environmental performance, such as Andrews et al. (2003); Dahlström et al. (2003), and King, Lenox, and Terlaak (2005). Barla (2007) studied the ISO-14001 certification effect on the environmental performance of the paper and pulp industry in Canada. This study indicated that facilities with ISO 14001 certification did not improve their environmental performance compared with non-certified facilities. Darnall and Sides (2008), using meta-analysis method, did not find any significant relationship between ISO-14001 certification and environmental performance improvement in the U.S. facilities. Gomez and Rodriguez (2011) tested the effect of ISO 14001 on the toxic release of industrial facilities in northern Spain and found that ISO 14001 certification did not have an impact on pollution. A similar finding was reported by Zobel (2015) using Swedish manufacturing firm-level data.

Overall, the literature largely shows an inconclusive relationship between ISO 14001 standard and environmental performance. Nawrocka and Parker (2009) used 23 different studies in a meta-analysis framework to display the relationship between environmental performance and the ISO 14001 standard. They conclude that this

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relationship is mixed and case specific.

Our study differs from the studies above in that we examine the effect of ISO 14001 on the environmental performance of facilities at different levels of pollution. This has not been previously addressed in the literature. In the theoretical model section, we show theoretically why the relationship between ISO 14001 certification and environmental performance might depend on the levels of pollution. We subsequently provide an empirical test of the hypothesis using detailed facility-level data in the U.S. transportation equipment manufacturing subsector. In this paper, we will consider toxic release as a representative case of environmental performance.

4.3 Theoretical Model

4.3.1 From a cost-minimization perspective

In this section, we first illustrate the impact of ISO 14001 from a simple cost reduction standpoint (which is more applicable to perfect competition market structure) and then analyze the impact from a full profit-maximization perspective (which is more applicable to imperfect competition). Based on Mishan (1974) and Dasgupta, Hettige, and Wheeler (2000), optimal emission level by facilities can be determined by the following argument. For each facility, cost-minimizing emission intensity ($i =$ pollution/output) is determined by the intersection of expected marginal penalty (EMP) and the facilities' marginal abatement cost (MAC). EMP is the price of the pollution and increases with the pollution intensity level. On the other hand, MAC is downward sloping and indicates that marginal abatement cost is higher for lower levels of emission (see Figure 4-2). MAC can be a function of different variables. For specific levels of pollution intensity, larger facilities will generally have lower MAC than smaller firms(Dasgupta, Hettige, and Wheeler 2000).

Denote *tc* as the total cost of pollution to the facility that is the sum of (*c*)

pollution abatement cost, and (*f*), the penalty for different pollution levels. We assume

that pollution abatement cost is a function of pollution intensity. Also, there is a penalty

associated with each level of pollution intensity. Hence, *f* is a function of pollution

intensity as well. Equation 1 shows the cost function that facilities are minimizing:

(1) $tc(i) = c(i) + f(i)$.

Taking first order conditions with respect to *i* yields equation (2), by which we can

determine the optimal level of the pollution intensity:

(2) $\frac{\partial c}{\partial i} + \frac{\partial f}{\partial i} = 0$ or $\frac{\partial f}{\partial i} = -\frac{\partial c}{\partial i}$.

Note that in equation (2), $-\frac{\partial c}{\partial i} = MAC$ and $\frac{\partial f}{\partial i} = EMP$. MAC can be defined as the

cost to reduce an extra unit of pollution intensity. EMP can be defined as the penalty for

an extra unit of pollution intensity, which is the price of pollution. Figure 4-2 shows this

basic framework. From the interaction of MAC_1 and EMP_1 the optimal level of the

facility pollution intensity can be determined, which in this case is i^*.

Having different MAC and EMP functions, each facility has it is own unique

pollution intensity level. A downward shift in MAC can occur when facilities change

their production process or EMS to reduce pollution intensity (e.g. adopting ISO 14001).

In fact, pollution-intensive facilities will face higher marginal cost because regulatory

scrutiny intensifies at a higher level of pollution intensity (e.g. marginal production cost

increases as a result of more frequent inspections by the regulator) and these facilities

also face higher pressure from consumers, shareholders, and the local community. As

shown in figure 4-2, as a result of ISO 14001 adoption, we expect that MAC_1 shifts

downward to MAC_2 and holding EMP constant at EMP_1, optimal pollution level

decreases from i^* to i^1. On the other hand, certification may act as a signaling tool and reduce the pressure from consumers, shareholders, and community on the facility. As a result of this, we can expect a downward shift in EMP (from EMP_1 to EMP_2). Holding MAC constant at MAC_1, this shift leads to an increase in the pollution level by the facility from i^* to i^2. Optimal pollution intensity could, therefore, increase, decrease or remain unchanged following ISO 14001 certification. Therefore, the impact of ISO 14001 depends on the cost effect (MAC), the benefits effect (reduced EMP), and likely the original optimal pollution intensity. If the cost effect dominates, then we would expect pollution intensity to decrease due to certification. If the benefit effect dominates, pollution intensity should increase due to certification.

4.3.2 From a profit-maximization perspective

In this paper, we propose a new framework to analyze the impact of certification on pollution intensity, in which facilities maximize profit instead of minimizing cost. The main advantage of this framework is it provides insight into why certification's effect on pollution intensity might depend on the production technology that generates pollution (we show this using a monopoly market structure) and firm size (we illustrate this point in an asymmetric Cournot model).

Consider a profit-maximizing monopolist whose profit depends on price (p), the quantity of production (q), and production cost (c).[21] We specify the production cost as $c[q, l(q), t]$, where l is the total pollution level ($l = i*q$) and t denotes certification (we assume a continuous degree of certification to facilitate comparative statics analysis). The inclusion of pollution level in the cost function reflects the abatement cost of pollution,

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[21] We did not specify the aforementioned penalty for different pollution levels (f) to make results more generalizable. In addition, such cost is more closely tied to the pollution intensity rather than the production level, and will drop out of the first-order condition.

which should increase with production level. The profit function for a monopolistic firm is

$$(3)\ \pi = p(q,t)q - c[q,l(q),t)]\,,$$

Where we assume certification may enhance demand for the firm's products if buyers (especially institutional ones) care about this attribute. The first order condition with respect to q is:

$$(4)\ \frac{\partial \pi}{\partial q} = p + qp_q - c_q - c_l l_q,$$

where p_q denotes the partial derivative of p with respect to q, and so on. Totally differentiating equation (4) leads to the following:

$$(5)\ p_q dq + p_t dt + p_q dq + q(p_{qq} dq + p_{qt} dt) - (c_{qq} dq + c_{ql} dl + c_{qt} dt) -$$

$$(c_{ql} dq + c_{ll} dl + c_{lt} dt)\, l_q - l_{qq} c_l dq = 0.$$

To focus on the impact of certification, we assume the following second-order derivatives are zero without losing much generalizability: p_{qt} (certification does not change the slope of the demand curve), c_{qq}, c_{ql}, and c_{ll} (constant marginal cost with respect to production and pollution). After simplifying and some rearrangement, equation (5) becomes

$$(6)\ \frac{dq}{dt} = \frac{p_t - c_{qt} - c_{lt} l_q}{-2p_q - qp_{qq} + l_{qq} c_l}$$

Note that by definition, the pollution intensity is expressed as $i = \frac{l}{q}$. To see how certification may affect pollution intensity, we can totally differentiating i with respect to t and obtain:

$$(7)\ \frac{di}{dt} = \frac{(l_q - i)}{q}\frac{dq}{dt} = \frac{(l_q - i)(p_t - c_{qt} - c_{lt} l_q)}{q(-2p_q - qp_{qq} + l_{qq} c_l)}.$$

Equation (7) warrants some additional analysis. Note that $-qp_{qq}/p_q$ is the elasticity of the slope of the inverse demand curve (a measure of the convexity of the demand curve),

which is generally assumed to be less than two in the literature (Dixit 1986, Zheng, Bar, and Kaiser 2010). Therefore, given the assumption of a downward sloping demand curve p_q, the $-2p_q - qp_{qq}$ term in (7) is positive (this is most clear when demand is linear and $p_{qq} = 0$). In addition, we expect that pollution increases with production ($l_q > 0$) and pollution increases cost ($c_l > 0$); certification enhances demand ($p_t \geq 0$), reduces marginal cost of producthe tion ($c_{qt} \leq 0$), and/or reduces marginal cost of pollutionthe ($c_{lt} \leq 0$). The last three effects capture the intended impacts of certification. Therefore, the ($p_t - c_{qt} - c_{lt}l_q$) term in (7) is positive. Assume $l(q) = \alpha_1 q + \alpha_2 q^2$, so that $\frac{(l_q - i)}{q}$ becomes α_2. Therefore, we will have three scenarios for the impact of certification on pollution intensity, depending on the production technology that determines the sign of l_{qq}.

Scenario 1: $l_{qq} = 0$, pollution increases with production linearly. Under this scenario, certification increases production but does not affect pollution intensity.

Scenario 2: $l_{qq} > 0$, that is, pollution increases with production at an increasing rate. Under this scenario, the sign of (7) is positive. That is, certification will increase both production and pollution intensity.

Scenario 3: $l_{qq} < 0$, that is, pollution increases with production at a decreasing rate. Under this scenario, the sign of (7) is indeterminate. If l_{qq} is sufficiently negative, then certification will decrease production but increase pollution intensity; otherwise, certification will increase production but decrease pollution intensity.

Overall, the above analysis shows that the impact of certification on production and pollution intensity depends crucially on the production technology that generates pollution. For some facilities, especially smaller ones without much investment in new

technology, certification may increase pollution intensity. Large facilities may generate

pollution at a decreasing rate along with production. For them, certification should reduce

pollution intensity. It is this theoretical ambiguity that necessitates an empirical

investigation of the impact of certification on environmental performance.

We now show how the size of a facility might affect the impact of certification on

production building on the work by Zheng, Bar, and Kaiser (2010). The impact of

certification on facility j's production in an asymmetric Cournot market assuming

constant marginal cost and $l_{qq} = 0$ can be expressed as (Zheng, Bar, and Kaiser (2010),

equation 5)

$$(8)\ \frac{dq_j}{dt} = \frac{p_t(s_j NE - E + 1)}{-p_Q(1 + N - E)}$$

where Q is market demand, N is the number of facilities supplying products in the

market, s_j is the market share of the output of the j-th facility, and $E = -Q p_{QQ}/p_Q$ is a

measure of demand curve convexity. Zheng, Bar, and Kaiser (2010) show that the

denominator of (8) is positive. Therefore, the impact of certification on production

depends on the facility's market share and demand convexity. For example, for convex

demand curve that features $E > 1$, then only sufficiently large facilities' production will

increase with certification. For concave demand ($E < 0$), only sufficiently small facilities'

production will increase with certification, highlighting how facility size may affect the

impact of certification.

4.4 Data

This study uses facility-level cross-sectional data for the year of 2013 because

certification data over the years are not available. We focus on the facilities in the U.S.

transportation equipment manufacturing subsector, which is under code 336 based on the

North American Industry Classification System (NAICS). By definition, industries in this subsector produce equipment for the transportation of people and goods (U.S. Census Bureau, 2015). We chose to use this subsector because it is one of the largest industrial sectors in the United States and ISO 14001 adoption is popular in this subsector. In 2014, this subsector had 1.6 million employees (Bureau of Labor Statistics, 2015). Also, a random sample of all facilities in the U.S. industrial sector shows that this subsector is the most popular for adopting ISO 14001 with 20 percent adoption rate in 2013. Regarding pollution level, this subsector had the second highest amount of toxic release in 2013, after the metal manufacturing subsector (NAICS 331). This high degree of pollution is another reason we chose this subsector for further investigation (Toxics Release Inventory, 2013 and author calculations).

We use data from three different sources. The first part includes environmental variables such as toxic release that is obtained from The EPA Toxics Release Inventory (TRI) database. TRI contains annual facility-level data on toxic release. Based on Emergency Planning and Community-Right-To-Know Act (EPCRA) law, all manufacturing facilities in the U.S. are required to report to the EPA the amount of toxic they release into the air, land, and water for more 320 toxic chemicals. Using the TRI database, there were 1,261 facilities in the U.S. transportation equipment manufacturing subsector that reported their amount of toxic release. The second part of the data is the information about facility characteristics such as sales volume and the number of employees. We obtained this data from the ReferenceUSA Company, which provides data on U.S. businesses. Because ReferenceUSA did not have information on all facilities on our list, our usable sample size reduced to 678. Finally, information about the number

and type of certification for these facilities was obtained from the Independent

Association of Accredited Registrars Directory (IAAR).

4.5 Empirical Model

4.5.1   A measure of environmental performance
          Given that total pollution/emission is assumed linearly related to

pollution/emission intensity, the dependent variable in this paper is environmental

performance measured by the total toxic release by sample facilities in 2013. For

robustness purpose, we use both on-site toxic releases and off-site transfers as dependent

variables. Using disaggregated emission data, we could identify the effect of ISO 14001

adoption on a particular type of disposal method.

EPA has regulations on off-site toxic chemicals transfer under the Resource

Conservation and Recovery Act (RCRA). Based on the RCRA, only facilities that meet

technology-based standards for construction and operation can have an off-site toxic

release. There can also be extra costs, such as the cost of shipping, related to off-site toxic

treatment. Also, there are technical standards for waste treatment at the end-of-the-pipe

(Andrews 2006, Anton, Deltas, and Khanna 2004). As a result, compared to off-site

releases, on-site releases may be cheaper and more convenient for facilities to pursue thus

can create more social pressure from the neighboring communities and shareholders

(Anton, Deltas, and Khanna 2004).

4.5.2   Control variables
          We provide detailed information on all variables used in this study in Table 4-2.

The first and most important group of variables are the types of certifications that

facilities held in 2013. In this group of variables, we have environmental certification

such as ISO 14001 and other types of certification such as ISO 9001 (general quality

management system). In our models, ISO 14001 is a binary variable that takes the value of one if the facility has ISO-14001 certification in 2013 and takes the value of zero otherwise. Number and type of certification for these facilities was obtained from the IAAR. Variable ISO 9001 is defined and obtained similarly.

Facility characteristics such as sales volume, production growth ratio, facility credit score, facility type, community population of the facility location, and facility size represent the first group of independent variables. These variables are measured at 2013 and were provided by RefrenceUSA dataset except the production growth ratio. Most of these variables are self-explanatory except a few: the production growth ratio, provided by the TRI dataset, indicates the rate of production growth by each facility over the previous year. A facility credit score is a number from 0 to 100; a higher number indicates a better credit score. Four different groups of facilities are created based on facilities type. Facilities can be headquarters, branch, subsidiary, and single location. Finally, we have the industry type fixed effects. The NAICS divided the U.S. Transportation Equipment Manufacturing Subsector into seven smaller subsector groups. These subsectors are: Motor Vehicle Manufacturing (NAICS 3361), Motor Vehicle Body and Trailer Manufacturing (NAICS 3362), Motor Vehicle Parts Manufacturing (NAICS 3363), Aerospace Product and Parts Manufacturing (NAICS 3364), Railroad Rolling Stock Manufacturing (NAICS 3365), Ship and Boat Building (NAICS 3366), and other Transportation Equipment Manufacturing (NAICS 3369). To differentiate between different subsector groups, we have dummy variables for each industry.

The third group of independent variables in this paper is pollution related. We use a binary variable to indicate if a facility is releasing chemicals under the Clean Air Act

(CAA) regulation. The idea is that if the chemicals released are under the CAA

regulation; then there may be more pressure from the public on the facility which may

subsequently lead to a lower level of pollution level. In addition to chemicals, we use a

dummy variable to indicate whether a facility is releasing metals that are regulated by the

EPA.

4.5.3 Summary statistics

Table 4-3 shows summary statistics for the sample facilities used in this paper.

The first panel shows toxic release by the facility. On average facilities in 2013 release

around 6,000 pounds, with two-thirds of release coming from on-site release. The second

panel shows facility characteristics. Sales for these facilities in 2013 vary from 83 dollars

to 22 million dollars, providing ample degree of variation for our estimation.

Table 4-4 shows the summary statistics for different types of certification held by

facilities. About 15 percent of the facilities in our sample have at least one type of

certification, and about 6 percent of the facilities have ISO 14001 certification. The most

popular certification is ISO 9001 (held by 10 percent of facilities).

4.5.4 Statistical method and econometric specification
Our basic estimating equation is:

(9) $\quad \ln(TTR_i) = \beta_0 + \beta_1 ISO14001_i + \beta_i X_i + \mu_i + \varepsilon_i$

where TTR_i is the environmental performance in facility i which in this paper is defined

as totaa l toxic release in facility i, $ISO14001_i$ is a dummy variable previously defined,

and X_i is a vector of control variables such as log of sales volume,a log of population, aa

nd etc. which is explained in the Table 4-2, μ_i is an industry fixed effects, and ε_i captures

all unobservable factors affecting the dependent variable.

We chose the econometric models to fit our objectives and nature of data. Our goal is to test the effect of ISO 14001 on environmental performance and check if this effect is different for high pollution-generating facilities compared with low pollution-generating facilities. Quantile regression is the appropriate model in this case.

A potential problem with our dataset is sample selection bias. Based on TRI dataset, facilities that manufacture or process more than 25,000 pounds of TRI-listed chemicals or use more than 10,000 pounds of a listed chemical in a given year must report to TRI (USEPA 2013). In other words, the probability of not reporting to TRI is related to the level of toxic release, and this can cause sample selection bias. Facilities that do not report their toxic release level cannot affect our estimation (Russo 2009). To address this issue, we use the censored quantile regression (CQR) (Powell 1986).

Endogeneity is also another potential problem in our study. Specifically, in our study, this can be a potential problem because of measurement error (Frisch 1934) and sample selection (Heckman 1979). It is possible that facilities choose to have ISO 14001 because they have high pollution level, and certification helps them lower the pressure from consumers as well as inspection regulators. The estimation will be biased if these endogeneity issues are not addressed. Anton, Deltas, and Khanna (2004) used an instrumental variable to deal with this issue. A quantile regression estimator that considers both our potential problems was introduced by Chernozhukov, Fernández-Val, and Kowalski (2015), known as the censored quantile instrumental variable (CQIV) estimator. Combining quantile regression with censoring and endogeneity, we use the CQIV estimator. Our preferred estimating equation becomes:

(10) $\ln(TTR_i) = \beta_0 + \beta_1 \widehat{ISO14001}_i + \beta_i X_i + \mu_i + \xi_i$

where $\widehat{ISO14001}_i$ is $ISO14001_i$ instrumented with ISO9001 in the first-stage regression equation:

(11) $ISO14001 = \gamma_0 + \gamma_1 ISO9001_i + \gamma_i X_i + \delta_i + \upsilon_i$

4.6 Results

      Tables 4-5 and 4-6 present the empirical results. We report the coefficient for ISO 14001 here and report the estimated coefficients for the other controls in Appendix Table A1. OLS and quantile regression results are reported in table 4-5 and both suggest that ISO14001 certification does not have a statistically significant effect on total toxic release.

      We then applied the quantile regression with consideration of endogeneity and censoring in our models and results are presented in Table 4-6. In the case of endogeneity, variables that are correlated with ISO 14001 adoption but not with the pollution level (i.e., the error term) are needed. To address this issue, we used ISO 9001 as instrumental variables (IV) for ISO 14001. ISO 9001 is a quality management system standard. To become certified, an organization needs to demonstrate its ability to consistently provide product that meets customer and applicable statutory and regulatory requirements, and aims to enhance customer satisfaction through the effective application of the system, including processes for continual improvement and the assurance of conformity to customer and applicable statutory and regulatory requirements (ISO, 2015).

      ISO 9001 certification is a good candidate for an instrument for several reasons. First, certification decisions to ISO 9001 and ISO 14001 are correlated. Christmann and Taylor (2001) investigated the relationship between ISO 14001 and ISO 9001, and their result indicates a positive relationship between these two certifications. The positive

relationship is mostly because ISO 9001 certified facilities could have lower learning cost in the adoption of ISO 14001. These two certifications share the management system-based approach including document and record control, internal audits, corrective actions, preventive actions, continual improvement, and management reviews (Christmann and Taylor 2001, Potoski and Prakash 2004). Second, facilities with ISO 9001 certification would be familiar with the general structure of an ISO management standard, the necessary paperwork involved in certification. These facilities may already have established relationships with local ISO auditors. Therefore, it is reasonable to expect that a facility may start with ISO 9001 certification. As they become more familiar with ISO standards, they may proceed to adopt ISO 14001 environmental standard. We also tested for the weak instrument hypothesis in the first-stage regression. The t-value for the ISO 9001 coefficient (which is positive) is 3.2, implying this is not a weak instrument.

Despite these similarities, there is a major difference between ISO 9001 and ISO 14001. While ISO 9001 focuses on facilities' product and management quality aspects, ISO 14001 focuses on facilities' environmental aspects and impacts. With ISO 9001 certification, facilities need to fulfill requirements and ensure customer satisfaction, while continuously improving the effectiveness of its operations. ISO 9001 is to control product quality and does not require companies to account for the impact of their activities on their surroundings. However, ISO 14001 is for environmental management and facilities need to minimize its effect on the environment. One requirement of both of these standards is that facilities document their processes (assuming that facilities control the quality of their products under the ISO 9001 certification and the environmental impact

of their activities under the ISO 14001 certification) if they have those processes are written down (Bénézech et al. 2001, Larsen and Häversjö 2001). Overall, ISO 9001 adoption should not affect pollution much due to the standard's scopes and emphases.

Panel A in Table 4-6 shows CQIV estimation results. The effect of ISO 14001 now is not statistically significant for the first, second, or third quartile of data. However, such effect is negative and statistically significant (at the 5% significance level) for the 90th percentile (that is, the top 10% of facilities regarding total toxic release). The 95% confidence intervals of estimated parameters were obtained via non-parametric bootstrap. We used Wald test statistics to test for differences in the coefficients across quantiles. Wald test results show that the null hypothesis (that they are identical) can be rejected at the 1% significance level.

For robustness check, we differentiated pollution levels as on-site and off-site and conducted a similar analysis, respectively. These can be seen in Panel B and C in Table 4-6. The results indicate that the effect of ISO 14001 on on-site pollution level is similar to the effect of ISO 14001 on total toxic release level. However, we found that ISO 14001 had no statistically significant effect on off-site pollution level.

4.7 Summary and Conclusion

Manufacturers have been increasingly relying on EMSs to comply with government regulations and reduce waste. In this paper, we investigated the impact of EMSs on facilities' toxic release. More specifically, we tested the hypotheses that the effect of ISO 14001 certification is related to facilities' pollution levels. We used three different sources to collect data on facility characteristics, toxic release by facilities, and finally, certification types that facilities hold.

We applied the censored quantile instrumental variable estimator (CQIV) to data

on the U.S. transportation equipment manufacturing subsector facilities. CQIV estimator results indicate that ISO 14001 had a negative and statistically significant effect on the top 10% facilities in terms of on-site toxic release and total toxic release (on-site and off-site combined). We did not find any impact of ISO 14001 on off-site toxic release. In other words, ISO 14001 is effective for decreasing on-site pollution by facilities and is not effective in decreasing off-site pollution.

These findings may have important policy implications. We should not expect ISO 14001 to have a uniform impact on manufacturing sites' environmental performance, as indicated by our theoretical section and empirical evidence. We found that the impact of ISO 14001 depends on whether the toxic release is on site or off site, and on whether the toxic release is large enough. Therefore, for large facilities, encouraging voluntary adoption ISO 14001 might be an effective government strategy to reduce on-site pollution. However, for small facilities and to reduce off-site pollution, other economic incentives or regulations are warranted.

4.8 Figures and Tables

Figure 4-1 Top 10 Countries for ISO 14001 Certificates in 2013
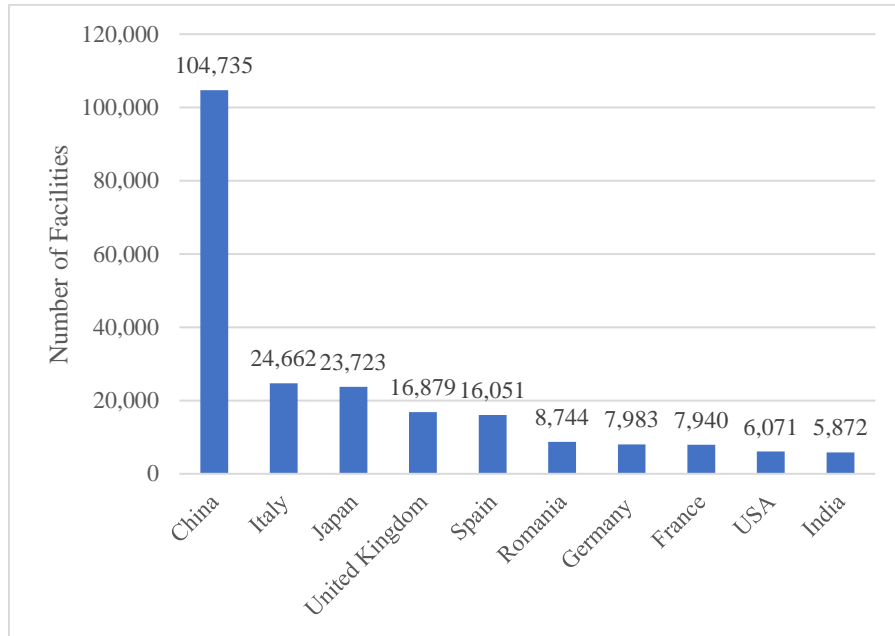
Source: The ISO Survey of Certifications 2013.

Notes: In the United States firms with ISO 14001 increased from 639 in 1999 to 6,071 in 2013.

Figure 4-2 Optimal Pollution Intensity Determination

Pollution Intensity
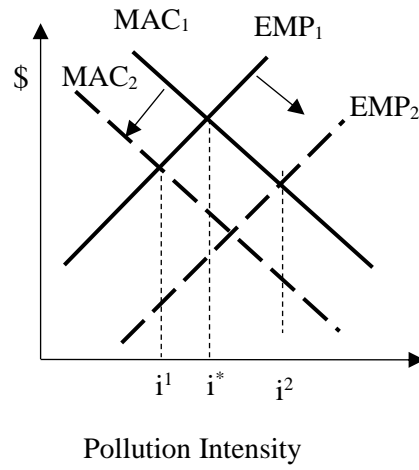
Notes: Pollution intensity level could increase or decrease after certification adoption depending on the movements of MAC and EMP.

Figure 4-3 Log of Total Toxic Release in Different Quantiles
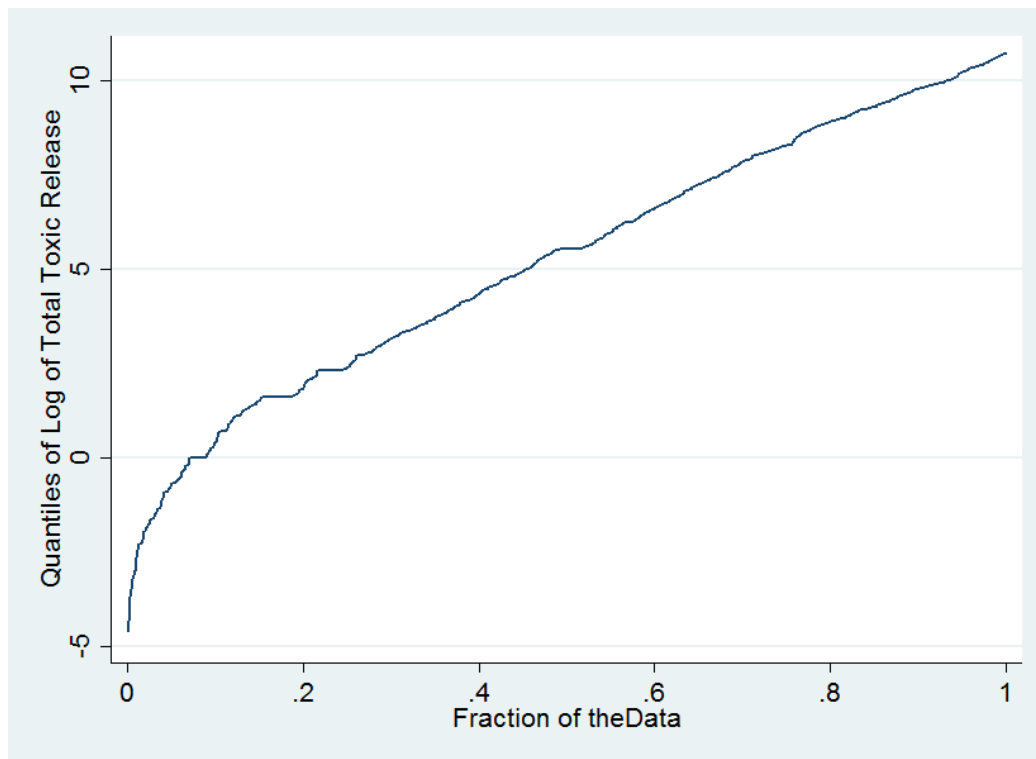
Table 4-1 Summary of the Literature on How ISO 14001 Affects Environmental
Performance

Authors (year)	Country	Sector/Industry	A measure of Environmental Performance	Impact of ISO 14001 on Environmental Performance
Montabon et al. (2000)	U.S.	Manufacturing (SIC 20-39)	not specified	Improves
Russo and Harrison (2001)	U.S.	Electronic sector	toxic release	improves
Russo (2009)	U.S.	Electronic sector	toxic release	improves
Babakri et al. (2004)	U.S.	Not specified	recycling	improves
Melnyk et al. (2003)	U.S.	manufacturing (SIC 20-39)	waste disposal	improves
Potoski and Prakash (2005)	U.S.	Manufacturing (SIC 20-39)	Toxic release	improves
Franchetti (2011)	U.S.	Manufacturing (SIC 20-39)	Solid waste generation	improves
Arimura et al. (2008)	Japan	manufacturing	Use of natural resources, Solid waste generation, and Wastewater effluent	improves
Comoglio and Botta (2012)	Italy	Automotive sector	Use of resources, waste management, release to water, etc	improves
Nguyen and Hens (2013)	Vietnam	cement industry	dust, SO_2, and NO_2	improves
Testa and et al. (2014)	Italy	energy intensive facilities	carbonic anhydride emissions	improves
Ziegler and Rennings (2004)	German	manufacturing (NACE-Codes 15-37)	not specified	weakly positive
Dahlström et al. (2003)	U.K.	Not specified	compliance with environmental regulations	did not improve
Barla (2007)	Canada	paper and pulp industry	discharges of BOD or TSS	did not improve
King et al. (2005)	U.S.	Manufacturing (NACE-Codes 15-37)	The deviation between observed and predicted waste generation	no relationship
Darnall and Sides (2008)	U.S.	Not specified	not specified	no relationship
Gomez and Rodriguez (2011)	Spain	manufacturing	toxic release	no relationship
Zobel (2015)	Sweden	manufacturing	waste generation	no relationship

Table 4-2 Description of Variables

Variable	Definition	Variable used	Data source
Total Toxic Release	A "release" of a chemical means that it is emitted to the air or water, or placed in some type of land disposal (See the EPA website for more information).	Log of total toxic release	TRI
ISO 14001	Environmental management certification published by ISO	Dummy (1 if facility holds ISO 14001 certification, 0 otherwise)	IAAR
ISO 9001	Quality management system standard certification published by ISO	Dummy (1 if facility holds ISO 9001 certification, 0 otherwise)	IAAR
Sales Value ($)	Sales value of the facility	Log of sale for each facility	RefrenceUSA
Production Growth Ratio	An indicator of facility production volume changes with respect to the previous year. Production ratio is calculated by dividing production volume in year t to production volume in year t-1.	Continuous variable	TRI dataset
Facility Credit Score	Credit rating code of the facility (0-100). A higher number indicates better credit score.	Continoues variable	RefrenceUSA
Facility Type	Indicates facility type including headquarter, branch, subsidiary, and single location.	Dummy variable	RefrenceUSA
Community Population	The resident population of the city in which the facility is located. Some assignments can be unclear, such as when cities cross county lines. To maintain this granularity, the actual assignment is done at a zip level.	Continoues variable (log of population size)	RefrenceUSA
Size of the Facility	Indicates the square footage of the location that a facility operates at.	Continoues variable (log of facility size)	RefrenceUSA
CAA Chemical	If a facility is releasing chemical under the Clean Air Act (CAA) regulation.	Dummy variable	TRI dataset
Metal Category	If a facility is releasing metal defined by the EPA. (See the EPA website for categories and takes)	Dummy variable	TRI dataset

Table 4-3 Summary Statistics, 2013

Variable	Number of Observations	Mean	Min	Max	S.D
Panel A: Toxic release by facilities (unit: pound)					
Total Release	678	6,355	0	139,733	16,984
On-Site Release	678	4,679	0	139,733	15,222
Off-Site Release	678	1,674	0	93,867	7,968
Panel B: Firm characteristics					
Sales ($)	678	290,288	83	22,372,184	1,187,161
Production Ratio	678	0.98	0	7.69	0.56
Facility Credit Score	678	96	70	100	5
Community Population	678	88,225	12,500	1,000,000	198,928
Size of the Facility	678	34,980	1,250	40,000	10,058
CAA Chemical	678	0.77	0	1	0.421

Table 4-4 Summary of the Certification Types Held by Facilities in 2013

Certification Type	Number of Facilities	Percentage of Total Sample (Percent)
At Least One Type of Certification	102	15.05
ISO 14001- 2004	37	5.46
ISO 9001-2008	64	9.44
AS9100C-2009	19	2.80
ISO/TS 16949	30	4.42

Table 4-5 OLS Regression Result and Quantile Regression Result at Different Quantiles

Panel A: Dependent variable: log of total toxic release (pounds)					
		Quantile Regression			
	OLS Regression	25%	50%	75%	90%
ISO 14001	-0.92	-1.52	-1.43	-1.02	-0.904
	(0.56)	(1.02)	(0.98)	(0.64)	(1.05)
Panel B: Dependent variable: log of total on-site toxic release (pounds)					
ISO 14001	-1.05*	-1.35	-2.02	-0.88	0.39
	(0.58)	(0.91)	(1.58)	(0.68)	(0.69)
Panel C: Dependent variable: log of total off-site toxic release (pounds)					
ISO 14001	-1.25	-0.83	-1.76	-1.09	-0.18
	(0.80)	(0.94)	(1.23)	(1.01)	(1.14)

Table 4-6 OLS Regression Result and Instrumental Variable Censored Quantile Regression Result at Different Quantiles

Panel A: Dependent variable: log of total toxic release (pounds)					
	OLS Regression	CQIV Regression			
		25%	50%	75%	90%
ISO 14001	-0.92	-3.31 (-9.06) [1.52]	-1.14 (-11.36) [2.08]	-1.10 (-6.63) [1.16]	-0.31** (-5.02) [-0.25]
	(0.56)				
Panel B: Dependent variable: log of total on-site toxic release (pounds)					
ISO 14001	-1.05*	-1.78 (-11.02) [1.64]	-1.25 (-9.50) [1.52]	-0.56 (-8.35) [1.23]	-0.36** (-4.52) [-0.15]
	(0.58)				
Panel C: Dependent variable: log of total off-site toxic release (pounds)					
ISO 14001	-1.25	-5.18 (-11.87) [9.74]	-1.41 (-3.85) [10.41]	-1.75 (-2.11) [8.06]	-1.47 (-1.06) [11.25]
	(0.80)				

N=678

Notes: Lower bounds of bias-corrected 95% confidence intervals from bootstrap replications are in parentheses and upper bounds are in brackets. ** indicates the 95% confidence interval does not include zero. Industry dummies are not displayed but can be seen in the appendix.

t-value from first stage=6.24

4.9 Appendix A

Table 4-7 Instrumental Variable Censored Quantile Regression Result at Different Quantiles

| | Quantiles | | | |
	25	**50**	**75**	**90**
Log of Sales	-0.192	0116	0.111	0.084
	(-0.218)	(-0.161)	(-0.214)	(-0.220)
	[0.558]	[0.455]	[0.358]	[0.378]
Production Growth Ratio	0.674	0.433	0.224	0.129
	(-0.310)	(-0.176)	(-0.030)	(-0.321)
	[1.254]	[0.671]	[0.420]	[1.476]
Facility Credit Score	0.137	0.033	0.033	0.050
	(-0.035)	(-0.011)	(-0.007)	(-0.028)
	[0.230]	[0.187]	[0.159]	[0.118]
Facility Type (Branch)	3.090	-1.717	-0.494	-0.172
	(-3.864)	(-1.761)	(-1.668)	(-2.173)
	[4.215]	[4.908]	[6.941]	[1.330]
Facility Type (Single Location)	3.964	-1.035	-0.352	0.187
	(-3.267)	(-1.711)	(-1.151)	(-2.361)
	[5.346]	[6.475]	[7.044]	[1.791]
Log of Population	-0.232	-0.183	-0.008	-0.078
	(-0.348)	(-0.556)	(-0.454)	(-0.370)
	[0.250]	[-0.014]	[0.215]	[0.186]
Log of Facility Size	-0.638	-0.642	-0.579	-0.480
	(-2.234)	(-2.016)	(-1.992)	(-1.650)
	[-0.453]	[-0.211]	[-0.321]	[-0.365]
CAAC Chemical	0.190	0.633	0.126	-1.518
	(-0.418)	(-0.701)	(-0.736)	(-1.011)
	[1.756]	[1.173]	[1.618]	[1.264]
Metal Category 1	-2.470	-1.890	-0.656	1.146
	(-3.992)	(-3.147)	(-2.439)	(-2.005)
	[0.116]	[2.387]	[6.317]	[3.746]
Metal Category 2	-6.486	-6.242	-4.327	-1.268
	(-8.377)	(-6.209)	(-5.692)	(-4.941)
	[-3.911]	[-1.453]	[3.010]	[1.238]
Constant	2.490	7.484	11.966	10.690
	(-3.993)	(-4.399)	0.265	2.192
	[14.475]	[15.668]	[21.854]	[28.285]

Notes: Dependent variable: log of total toxic release (pounds). Lower bounds of bias-corrected 95% confidence intervals from bootstrap replications are in parentheses and upper bounds are in brackets

Chapter 5. CONCLUSION

5.1 Summary

This dissertation sought to investigate non-price based environmental policies with a primary focus on water conservation policies and pollution control policy. In the first essay, we evaluate a command- and- control type policy; the second essay considers voluntary adoption of a water conservation technology, and the third essay evaluates the effectiveness of voluntary adoption of a pollution control certification. Results of each essay are discussed below, along with broader implications, and their connection to each other.

California's 2015 urban water mandate is an example of a regulatory, environmental policy that adopted most recently. To mitigate the adverse impacts of drought, in April 2015 Governor Jerry Brown issued an executive order mandating a statewide reduction in water use by 25% in urban areas, which generally targeted residential water-use. The aggregate cost of the governor's mandate regarding lost consumer welfare is an estimated $875 million. The cost to implement the water conservation mandate is $106 million in the San Francisco Bay area and $769 million in Southern California. In other words, Northern California households have a WTP of $24 per month to avoid the conservation mandate. Households in Southern California have a WTP of $26 per month to avoid this mandate.

Results of this essay indicate that California's water mandate, as an example of regulatory, environmental policy, is associated with welfare losses which may not be so tangible to some policymakers. Also, estimating these losses would be beneficial for evaluating alternative policy options such as market-based policies. Another important result of the first essay is the evidence that welfare losses are substantially different

across different utilities, depending on several factors such as elasticity of water demand. The results also indicate that on average, consumers in Northern California over-complied with the conservation mandate, while those in Southern California slightly under-complied.

Results of the first essay provide evidence on the two main concerns with command-and-control type policies including welfare losses and compliance. However, voluntary approaches, as another type of non-price method, compared with regulatory approaches might be more cost-effective. The central issue with voluntary approaches is that it is difficult to empirically evaluate the effectiveness of these policies. In the second and the third essay, we focus on evaluating the effectiveness of two popular voluntary programs: a water conservation technology and a pollution control certification. We use these two programs as examples of voluntary approaches as an environmental policy.

These two programs provide insights from different angles in two important ways. First, the first program is in the water sector and applied by city water managers but the second program is in the industrial manufactures level and applied by firms. Second, the first program is at the consumer level and the second one is at the producer level.

For the second essay, we estimate how web-based Home Water Use Reports (HWURs) affect household-level water consumption in Folsom City, California. The HWURs under study, offered by the company Dropcountr (DC), share social comparisons, consumption analytics, and conservation information to residential accounts, primarily through digital communications. In mid-December of 2014, all account holders in the City of Folsom water utility service area were offered the option of participating in the DC pilot program on a "first come, first served" basis. The data

utilized in this essay is a daily panel tracking single-family residential households from January-2013 to May-2017. We found that there is a 7.8% reduction in average daily household water consumption for a typical household under treatment of the DC program. Results suggest that the effect of DC varies by the baseline consumption quintile, the number of months in the program, the day of the week, quartile of the year, message type, and enrollment wave. We also conduct empirical tests to evaluate the channels through which DC may act to reduce consumption.

The main results of this essay indicate that with technology advances, information provision is a low-cost way to reduce residential water consumption which could be used in other sectors as an environmental policy as well. Using price to achieve similar conservation would require a 34% increase in price which is politically difficult to impose such an increase in prices. Finally, we have evidence that enrollment effects are heterogeneous; largest impacts likely on households with outdoor water use.

In the last essay, we examine another type of voluntary environmental policy that is adopted by the producers rather than consumers. Manufacturers have been increasingly relying on environmental management systems (such as ISO 14001 based ones) to comply with government regulations and reduce waste. In this essay, we investigated the impact of ISO 14001 certification on manufacturers' toxic release by release level. Results show that ISO 14001 had a negative and statistically significant effect on the top 10% manufacturing sites regarding the on-site toxic release, but it did not reduce off-site toxic release. Therefore, one should not expect ISO 14001 to have a uniform impact on manufacturing sites' environmental performance. For large firms, encouraging voluntary adoption of ISO 14001 might be an effective government strategy to reduce on-site

pollution. However, for small firms and to reduce off-site pollution, other economic incentives or regulations are warranted.

Comparing results across three essays indicate that welfare consequences of regulatory policies or effectiveness of voluntary policies are heterogeneous across different subgroups. Considering this heterogeneity is important for future policy designs as well as targeting groups with the lowest cost or highest effectiveness. Also, voluntary policies are effective at least for some of the subgroups. In terms of consumers, results from the second essay indicate that water users with highest baseline usage are the most responsive to the technology adoption. In terms of producers, results of the third essay indicate that only firms with the highest level of pollution are those that reduce pollution after the adoption of ISO 14001 certification.

5.2 Implications and Recommendations

Timely water management policies are essential for allocating scare water resources among different users and especially providing enhanced water access for the urban users. Water management is far more challenging with climate change disturbing water cycles, which changes where and how much participation falls. Most of the western states are facing longer and frequent droughts. This pattern is not limited only to the western states in the U.S., but many other countries are facing water shortage crisis. For example, South Africa's drought-stricken Cape Town has estimated 2019 for "Day Zero," when taps in the city run dry and people start queuing for water. In this dissertation, we shed light on non-market-based approaches as environmental policy tools, including distributional effects of water mandates and effectiveness of voluntarily approaches. Results of these essays expand our knowledge of water policies and the ways we can use

different strategies to achieve conservation goals.

Results of this dissertation indicate three main policy implications. First, the command-and-control approach is associated with welfare losses that are not tangible to some policymakers. Estimated welfare losses in this dissertation could be used in the benefit-cost analysis of projects that provide enhanced water access for the urban users. Also, it is essential to consider these estimates in evaluating the cost of environmental policies, such as requirements for water flow in a stream. Besides, we learned that utilities have different compliance levels with the mandate. As a future work, it would be beneficial for policymakers to understand why some water agencies over/under comply with the mandate requirements.

Second, through this dissertation, we learned that providing frequent and more information for the water customers is a low-cost way to achieve conservation goals. Interestingly, we observe that high-end water users are conserving the most. High water users are usually those with bigger lot sizes and larger yards, which typically have higher incomes. These are the type of households that are not very responsive to pricing policies. Providing information also has the potential to increase the effectiveness of pricing policies.

Finally, we observed heterogeneity in welfare losses, compliance levels with the mandate requirements, and effectiveness of information on reducing water consumption. One lesson for policymakers and water agencies is that they should account for these sources of heterogeneity in their policy/program designs. Targeting specific households could be a cost-effective way to achieve conservation goals.

As a final note, altogether these essays provide some evidence on the effectiveness of

non-market-based approaches as an environmental policy. However, we suggest that cost-effectively achieving water conservation goals cannot be met only through one specific policy, but rather a mix between price and non-price approaches. The partnership between researchers and agencies could be beneficial to find an optimal combination of the policies at the local level. For the agencies, it would be valuable to understand their customers' preferences and effectiveness of different programs for the different type of users. Using this knowledge, agencies could target specific users, achieve higher customer satisfaction rates and meet their conservation goals. Partnership with academic researchers could provide this knowledge for the agencies. However, without insight, direction, and input from agencies, the research community may miss its mark.

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VITA

Mehdi Nemati

Education

- Ph.D. Candidate Agricultural Economics, University of Kentucky, *2018. Major Professors:* Steven Buck and Wuyang Hu
- M.S. Economics, University of Kentucky, *2014*
- M.S. Agricultural Economics, University of Tehran, Tehran, Iran, *2013*
- B.S. Agricultural Economics, University of Kurdistan, Sanandaj, Iran, *2010*

Publications

- **Nemati, M.**, S. Buck, and D. Sunding. 2018. "Cost of California's 2015 Drought Water Conservation Mandate." *ARE Update.* 21(4):9-11. University of California Giannini Foundation of Agricultural Economics.
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Grants & Honors

- Grant, "Conservation through Behavioral Change" (with J. Penn). Student Sustainability Council at the University of Kentucky. $2500. *Fall 2017*
- Travel Grant, "Water Resources & Policy: Exploring the Risks, Benefits, and Opportunities for Conservation Workshop. "Agricultural & Applied Economics Association Trust. $400. *Spring 2017*
- Grant, "Purify the Air Around You Naturally with Indoor Plants" (with S. Zare). Student Sustainability Council at the University of Kentucky. $1695. *Spring 2017*
- Travel Grant, "Agricultural & Applied Economics Association Annual Meeting." Agricultural & Applied Economics Association Trust. $500. *Summer 2016*
- Travel Grant, "International Energy Program Evaluation Conference." $1,600. *Summer 2015*
- Travel Grant, University of Kentucky Graduate School and Department of Agricultural Economics. $5,000 (Cumulative). *2014-20177*
- *1ˢᵗ* Place at National Agricultural Economics Entrance Exam (National Champion), Tehran, Iran. *Spring 2010*