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The Potential Water Saved When USA Households Pay a Water Bill

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A continuing problem for both American agriculture and our society is the shortage of usage water. This problem has become more acute as our population grows and as global warming and the demands of agriculture pushes government agencies to look for ways to save water. More efficient devices are now required and households have been asked to voluntarily restrict water usage. Although less wasteful irrigation methods have been introduced, the problem of inadequate water for agriculture has continued to grow.

Interestingly, there is one area where millions of gallons of clean water are potentially wasted each year that has been entirely overlooked. There are hundreds of thousands of apartments, condos, and housing units in America where the household never pays a water bill. In fact, one could view these units as having 'free' water. In these cases, the occupant may use all the water they want with no penalty for wasting this valuable natural resource. This paper has an original model that attempts to estimate potential savings if these households received a water bill for their individual water usage.

The authors use log-log model to estimate residential water demand. Data used in this analysis contains 8 metropolitan areas (Austin, TX; Boston, MA; Hartford, CT; Houston, TX; Las Vegas, NV; Minneapolis/St. Paul, MN; Orlando, FL; San Antonio,

TX) and the data were collected from American Housing Survey 2013 Metropolitan Data.

Results show that increasing the marginal price of water decreases water consumption by 8%. Since the average water consumption of households that pay a bill is 10,135.23 gallons per month, if the marginal price increases by $1, then the water consumption decreases by 779.2 gallons. Overall, a shift to complete volumetric pricing will decrease average household water consumption by 5282.8 gallons per month at existing water prices. Results also show measurable differences between cities. The marginal price is negatively related to the water consumption levels and positively related to the percentage of households with ‘free’ water.

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CHAPTER I: INTRODUCTION

1.1 THE PROBLEM

Not so many years ago, in fact within the lifetimes of many people living in the United States today, clean potable water was viewed as an unlimited natural resource. Most people thought nothing of flushing five gallons or more of potable water down the toilet and few people complained about creating artificial lakes for recreation purposes or pumping water over mountains to irrigate deserts.[1] However, the finiteness of high quality water is becoming a greater problem in many areas, and policymakers and water managers are concerned about ensuring a reliable supply of water for their customers while protecting non-consumptive needs such as habitat and environmental quality.

This paper proposes a method to save one of our most important resources, potable water, and does so using a tried and proven technology. It does this without harming farmers, without asking plumbing companies to change their products, and without requiring a new layer of government. Specifically, we argue that metering water use for residential consumers significantly reduces the quantity of water used. We develop an analytical model that highlights differences in households that pay a volumetric fee for water versus households that pay a flat rate. We use household data to estimate the potential reduction in water consumption form a shift to full metering.

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[1] There are many examples of this wasteful attitude toward water: Growing rice in California, cheap electrical power from Hoover Dam and the Tennessee Valley Authority, water sports in Lake Mead, bringing water to the Los Angeles Basin, and so on. In the early twentieth century, too much water was sometimes viewed as a threat and the US Corp of Engineers job was to control this overabundance of water, for example dredging and straightening the inland waterways. Toilets with restricted flow rates were introduced in 1991, however existing toilet installations that flush five or even ten gallons of water per flush are still legal to use in some parts of the United States.

1.2 CLIMATE CHANGE

The scarcity of adequate, clean, usable water is well documented and has frightening consequences worldwide. Water is essential for all life and used extensively for crop irrigation. Water is becoming a scarce resource in much of the U.S. and global warming is expected to exacerbate that scarcity via shifts in both water demand and supply (Karl, 2009). In the U.S., with surface temperatures rising at an average rate of 0.14^{o}F per decade since 1901, there are ever increasing demands on limited water supplies (EPA, 2014).

Droughts decrease water supply, draw our national consciousness to water conservation, and cause significant economic losses. From 2012 to 2015, California had its most severe drought since the late 1800s and farmers have had to reduce irrigated acreage, shift from inexpensive surface water to costly and finite groundwater, and change crops to respond to water scarcity (Wallander et al., 2015).

1.3 LACK OF VOLUNTARY CONSERVATION

Problematically, voluntary water conservation has not been effective to reduce demand. State government officials in California proposed a 25 percent mandatory statewide reduction in urban water use but they had only achieved a 2.8 percent reduction by February 2015 (Nagourney & Fitzsimmons, 2015). Many newspaper reports say that homeowners with expensive landscaping would rather pay the fines than let thousands of dollars in residential shrubs and ornamental plants die.

Additionally, water shortage has become a litigious issue as individual states try to get a larger share of the limited water supply. Recently, a lawsuit was brought by Kansas against Nebraska over irrigation water use in the Republican River Basin. The final settlement requires Nebraska to pay Kansas $5.5 million for estimated damages (Knapp, 2015). Lawsuits over water use have occurred in several other interstate basins, including the Arkansas River between Colorado and Kansas, the Pecos River between New Mexico and Texas, and the Yellowstone River between Montana and Wyoming (Schlager & Heikkila, 2009). One community going to court to get limited water recourses from another community is at best a 'quick fix' for the winning side. This might be important for one community, but it is not a long-term solution to fundamental and nationwide water problems.

There is virtually universal agreement that water shortages are important worldwide, and in the face of this urgent problem, many US communities are searching for ways to increase available water or to increase the efficient use of this scarce resource. Not only is water essential to life but water availability and usage are closely related to economic growth through what has been called the "energy-water-food nexus," even though water is a local resource (EPA, 2013). Perhaps the first and most critical problem for US communities is facing the potential economic losses related to water shortage. In California alone, the net water shortage in 2014 is 1.5 million acre-feet and the economic cost due to the drought in 2014 was estimated at $2.2 billion and there were a total of 17,100 jobs lost (Howitt et al., 2014).

1.4 POPULATION GROWTH

Fifty-one percent of Americans count on ground water for their water usage (EPA, 2008) but available groundwater has been facing continual depletion. During the period 1900 to 2008, the volume of groundwater stored in US aquifers decreased by about 1000 km^3. The average depletion rate increased from 8.0 km^3/year from 1900 until 2000, and increased to 23.9 km^3/year since then (Konikow, 2015).

As population grows, more water will be demanded. The U.S. Census's prediction is that total U.S. population growth will increase by 98.1 million between 2014 and 2060. The native population is expected to increase by 62 million while the foreign-born population is projected to increase by 36 million (Colby & Ortman, 2015). With the average person using between 80 to 120 gallons of water at home per day, future generations will put additional pressure on the available water resources (USGS, 2016). Most people understand that the US must find ways to use water more efficiently or face serious consequences from inaction.

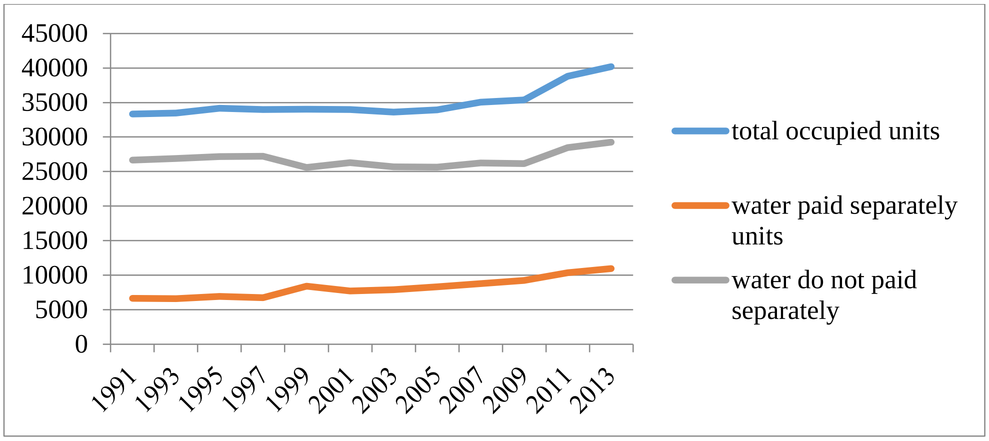
1.5 CHANGING IN HOUSING

There are increasing numbers of households living in rental properties and this is the critical problem whose solution is discussed in this paper. In the national summary table from 2013 American Housing Survey, 40.2 million households live in rental properties and about 73 percent (calculated by author) of them do not pay for their water separately. On the other hand, there are 75.7 million households that own the property they live in and there are still about 30 percent that do not pay for their water separately (AHS, 2013).[2]

For the households that do not pay for water separately, it is incorrect to say that they do not pay for water. Generally, they pay a lump-sum payment that includes water in their monthly housing payment. Therefore, they do not pay the marginal costs of water and the prices do not affect their consumption behavior. Figure 1 is the trend for U.S. renter occupied housing unit from 1991 to 2013. Rental occupied households have increased from 33.3 million in 1991 to 40.2 million in 2013 which was an increase of 6.9 million additional units. There was not a large increase from 1991 to 2007, but there was a huge increase during the period 2008 to 2013 with 5.2 million added units. This was about 75% of the total increase during 1991 to 2013. One explanation for this increase is that millions of homeowners were displaced by foreclosures in the nation after 2008 and that those homeowners were unable to buy a new home because of lower income during the Great Recession (Fernald, 2013).

[2] For example, many converted properties into townhouses and condo owners do not pay a water bill.

Figure 1: U.S. Renter Occupied Housing Unit Trend (in thousand)



Note: Data collected from AHS from 1991 to 2013

Sources: U.S. Department of Housing and Urban Development, 1991 to 2013 American Housing Survey National Summary Table. Plot by author.

1.6 OBJECTIVES

The objective of this thesis is to empirically estimate the potential conservation benefit of volumetric pricing for water for all households. Implementation of this will require meter installation into all apartments and condos, but could potentially have large social benefits and provide incentives for conservation. While the economic intuition is straightforward, actually measuring the benefit of meters on non-metered households is difficult, since consumption measurements do not exist. The analysis in this thesis estimates the effect on those units that provide ‘free’ or unmetered water on the quantity demanded by each household, and relates this to potential changes in aggregate demand. Paying a volumetric fee for water is a cost well known to every homeowner, but is unknown to tenants living in ‘free’ water units. Since some community landlords might need ‘free’ water to remain competitive in their local communities, ordinances need to consider the needs of their communities as new regulations are enacted. When a tenant has ‘free’ water in their rental contract, the tenant is exempt from the obligations known by every homeowner: there is no incentive for tenants to save water or to use water efficiently since water prices do not affect their behavior or their pocketbook.

The situation with a zero marginal cost for water is unusual, and, ‘free’ water is unlike the normal and ordinary expected daily costs of one’s life. If one is in a high risk profession, for example if one is a professional deep sea diver, then one expects to pay higher than normal life insurance premiums. A fast and reckless driver with many tickets and accidents pays a higher rate for car insurance than a driver with no citations. In other areas of life, one expects to pay for what one gets. If a person wants to eat gourmet food, then that person must pay a higher price than a person who lives on macaroni and cheese. If one wears only designer outfits, then one pays higher than average prices for clothing.

The same intuition applies to homeowners and renters who pay a volumetric fee for water consumption. A homeowner with a water meter who also has a swimming pool and has expensive landscaping expects to pay more for water usage and accepts the cost. On the other hand, if one lives in a ‘free’ water apartment, one does not need to care about economics if the toilet runs night and day. One need not care about water if one takes hour long showers. It is a serious waste of resources if there is a leaking faucet, or if a person wastes water in any of dozens of possible ways, but there is never an economic cost. In fact, one might believe one has a right to waste water because one has contracted for a fixed price for a unit with unlimited water. There are no additional costs to the household for uneconomic, poor ecologically wasteful behaviors. This is the problem.

CHAPTER II: LITERATURE REVIEW

This section describes previous research that analyzes the difference between households with separate water meters with water bills and properties that have water included in the monthly payment. There are hundreds of articles about residential water demand analysis, but most focus on the demands and supply of single-family homes. Only a very few studies are concerned with an analysis of 'free' water (Goodman, 1999; Agthe & Billings, 2002; Wentz et al., 2014; Gordon, 1999; Mayer et al., 2004). Research from Goodman and Gordon is now over a decade old and as people have become more aware of water scarcity and the increased pressures caused by global warming. It is time to take a fresh look at new options for water conservation.

2.1 PRICE ELASTICITY OF WATER DEMAND

Many papers have estimated residential water demand, specifically focusing on the price elasticity of demand. Having an accurate measure of the price elasticity of residential water demand is critical for regulators who need to know the impact of price changes on the quantity demanded (Olmstead, Hanemann & Stavins, 2005). The price elasticity of demand measures the percentage changes in quantity consumed for a one percent change in marginal price. For normal economic goods, the price elasticity of demand is negative, which means that water consumption decreases when water price increases. The larger the absolute value of the price elasticity, the greater the potential to use price as a tool to conserve water resources. The literature shows a wide range of estimates of the price elasticity for residential water demand. Espey et al. (1997) conducted a meta-analysis based on a review of 24 journal articles published between

1976 and 1993 and found that increasing block rate areas have significantly more elastic demand than others, implying that the pricing structure plays an important role in influencing how household respond to price change.

Research conducted in Tucson, Arizona, found that in apartment complexes, the price of water was significantly and negatively connected to the water consumption in winter (with coefficient -1923.17 $\text{gallon}^2/\$$) and in summer (with coefficient -2160.93 $\text{gallon}^2/\$$) under linear model[3]. Also, the age of the apartment building (with coefficient 34.34 gallon/year in winter and 42.53 gallon/year in summer) was significantly positive as related to apartment complex water use (Agthe & Billings, 2002).[4]

Not surprisingly, other research has shown that having a water meter increases the demand elasticity. Asci and Borisova (2014) find that the price elasticity for residents using a communal water meter, where the tenants do not pay for water directly, range from 0 (statistically insignificant) in an instrumental variable model to -0.063 and -0.051 in 2SLS and 3SLS models. On the other hand, the price elasticity of households using a separate water meter ranges from -0.24 to -0.31. Other work found that adding meters (i.e., “sub metering”) to properties that provide ‘free’ water significantly reduces water consumption (11% - 26%) from 5.55 to 17.5 kgal per unit per year or 15.2 to 47.94 gallons per unit per day (Mayer et al., 2004). A country wide study (Grafton et al., 2009) that contain 10 OECD countries (Australia, Canada, Czech Republic, France, Italy, Korea, Mexico, Netherlands, Norway and Sweden) found that, on average, households that have no volumetric charge consume more water when compared to those who pay volumetrically and high-income households are less price elastic than middle and lower

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[3] Coefficients are converted from cubic meter to gallon.
[4] Coefficients are converted from cubic meter to gallon.

income households. In other words, the expected happens: When one pays for water separately (via volumetric pricing), then one tends to use less. Table 1 shows a summary of the price elasticity of demand estimated in recent literature.

Table 1: Summary of Price Elasticity of Demand in the Scholarly Literature

Agthe, D. E., & Billings, R. B. (2002)	The price elasticity of demand in the winter is -0.45 and -0.73 in the summer in apartment complex.
Klaiber et al. (2014)	Depending on different level of consumption, the price elasticity of demand ranges from -0.13 to -0.99 in summer and range from -0.94 to -1.93 in winter.
Olmstead, Hanemann & Stavins (2005)	In Discrete/Continuous Choice model, price elasticity of demand is -0.3319 for full sample and -0.609 for only block-price households.
Espey et al. (1997)	In a meta-analysis that based on a review of 24 journal articles published between 1976 and 1993 the price elasticity is range from -0.02 to -3.33 with -0.51 as average and 90% of the estimates are falling between 0 and -0.75.
Grafton et al. (2009)	The overall price elasticity for 10 OECD countries is -0.48 for average price variable.
Mayer et al. (2004)	With different price, price elasticities ranged from -0.12 to -0.65 with an average of -0.29 in the straight line model and -0.275 in the constant elasticity power curve model.
Ito (2013)	The short-run price elasticity with respect to average price is -0.127 in summer and -0.097 in winter while the long-run price elasticity is -0.203 in summer and -0.154 in winter.
Mieno & Braden (2011)	The price elasticity is -0.112 in winter and -0.1982 in summer for an average household with income of 62,205.
Goodman (1999)	The price elasticity is -0.72 at the mean marginal price of 21.56 per 1000 CF (or 2.88 per 1000 gallon).

2.2 OTHER VARIABLES THAT AFFECT WATER DEMAND

Other studies have investigated how variables other than the marginal price affect water demand. Some of these variables are about information, while others are about the rate structure. Borisova and Useche (2013) find that extension workshops that focus on residential water conservation effectively reduce water used in irrigation but the effect is only temporary.

Other research has shown that the entire rate structure (not just the marginal price) affects water consumption. In empirical studies of residential water demand, the marginal price is commonly given as a variable price. In the residential electricity demand analysis with increase block rate, Taylor (1975) suggests that if the average and the marginal price are positively correlated, an upward bias might occur in the estimation of price elasticity if only one is included as an explanatory variable. Nordin (1976) suggests the use of difference variables (also referred to as "rate structure premium") that are defined as "a lump-sum payment that the customer must pay before being allowed to buy as many units as he wants at the marginal price" to correct the upward bias. Because of the similarity between residential water demand and residential electricity demand, the difference variable is used in our analysis. When households face nonlinear water rate structures, they react to the average price instead of the marginal price. Also, when both the marginal and average price are included in the estimation of price elasticity, the marginal price (also for the expected marginal price) has nearly zero effect on water consumption, but the average price has a significant effect on water consumption (Ito, 2013). The difference variable is correlated with the average price, since a larger value implies a lower average price.

Households are also more sensitive to price change in periods of drought and use restrictions and landscaping programs that proved effective in reducing water usage during a drought (Corral, Fisher, Hatch, 1999). Information on price and consumption also affects household water demand. When the bill shows a marginal price, the price elasticity increases from -0.36 (without price information) to -0.51 (Gaudin, 2006).

We can summarize this section as follows: When households receive a water bill, then they behave similarly to single-family homeowners and like households behave when they receive other utility bills such as electricity. When one receives a bill, then one pays extra attention to the costs that created that bill. When one does not receive a bill, one is able to disregard utility usage and the actual costs of that utility. Conservation is normal when one receives a reminder when that reminder takes the form of a utility bill. One would expect nothing less.

CHAPTER III: METHODOLOGY

3.1 THEORETICAL MEDEL

The total households for residential water can be divided into two groups: households that pay water bills (Group 1) and households that do not pay water bills (Group 2). We assumed there are n_1 households in Group 1 and n_2 households in Group 2, thus the total population is $n_1 + n_2$. Also Q_1 and Q_2 are representative household residential water demand for Group 1 and Group 2 while Q is the representative household demand for total population, and Q is simply a weighted average of the two quantities demand. Therefore, the aggregate demand is:

$$(n_1 + n_2) * Q \; = \; n_1 * Q_1 + n_2 * Q_2 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

To normalize population to 1, we divided $n_1 + n_2$ in both sides and get

$$Q \; = \; \frac{n_1}{n_1+n_2} * Q_1 + \frac{n_2}{n_1+n_2} * Q_2 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

where the quantity $\frac{n_1}{n_1+n_2}$ is the percentage of households that pay for water and $\frac{n_2}{n_1+n_2}$ is the percentage of households that do not pay for water. We use α to represent $\frac{n_2}{n_1+n_2}$, thus $\frac{n_1}{n_1+n_2} = 1 - \alpha$.

Therefore, from equation (2) we can get

$$Q \; = (1 - \alpha) * Q_1 + \alpha * Q_2 \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (3)$$

The demand function for a member of group *i* (*i* = 1, 2) is given by

$$Q_i \; = f(I, MP_i, DV, C, Cl) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4)$$

where, *MP* is the marginal price of last block that household consumed (note that MP_2 is zero); *DV* is the difference between what household should pay if all water units were charged at last block marginal price and what the household actually paid; *I* is the household income; *C* is a vector of household characteristics; and *Cl* is a vector of climate variables.

In empirical work, we normally can only observed demand Q_1 for households that pay for water. We can only predict Q_2 from an estimate of how various explanatory variables affect Q_1 when the marginal price is zero. While the parameter α does not have a direct effect on either Q_1 or Q_2, it will affect the aggregate demand Q, which is a weighted average of the two quantities.

3.2 THE EMPIRICAL MODEL

As Olmstead et al. (2005), Mieno & Braden (2011), Ito (2013) do, we use log-log model to estimate lnQ_1 and the regression equation is:

$$\begin{aligned}\ln(Q_1) = {} & \beta_0 + \beta_1 DISH + \beta_2 METRO + \beta_3 TENURE + \beta_4 WASH + \beta_5 BATHS \\ & + \beta_6 HALFB + \beta_7 ln(GRADLEVEL) + \beta_8 ln(HHAGE) + \beta_9 ln(PER) \\ & + \beta_{10} ln(YEAR) + \beta_{11} ln(INCOME) + \beta_{12} MP + \beta_{13} DV \\ & + \beta_{14} ln(MonthlyTEM) + \beta_{15} ln(MonthlyRAIN) + \varepsilon\end{aligned}$$

Table 2 shows the detail description for each variable in the regression equation. The number of full bathrooms (BATHS) and half bathrooms (HALFB) are used in our analysis. We expect the coefficients to be positive for both BATHS and HALFB since in general, whatever valves were installed in the full baths should be the same as those in the half baths. Properties may have been remodel or updated, but this should not affect our methodology. It is possible that the number of bathrooms in the property could change behavior. For example, having more bathrooms in a house or apartment could encourage residents to use more water, such as by taking longer showers.

Age of the building (YEAR) could affect water consumption since older buildings might be more likely to have fewer water saving features and less water efficient devices (faucets, toilets, showers.). Also, the valves in older buildings may not be working properly (e.g., leaking faucets, for example, or toilets that continue to fill after flushing).

We include 4 dummy variables that related to household characteristic. Having a working dishwasher (DISH) and washing machine (WASH) are expected to have a positive effect on water consumption. Even though households need to clean dishes whether they owned dishwasher or not, the dishwasher could potentially use more water because the dishwasher will potentially take a longer time to clean dishes.[5]

On the other hand, the clothes washing machine has a different impact on water consumption. If the household does not have a working washing machine, these people would need to wash their clothes somewhere else. This means the water usage on washing clothes would not be in these household's water bills. Instead they would have to pay to clean their clothes in another location, for example 'do it yourself' laundry or at a professional cleaner. Clearly the in-home water use will be higher when there is a washing machine in the residence. However, we expect that there is a net increase in water consumption relative to home and laundromat use because of the convenience of having a washing machine readily available.

We use METRO dummy variable to indicate whether a household is in downtown area. There is different life style between downtown and suburban of a metropolitan area.

[5] Generally, dishwashers wash dishes twice whereas hand washing would occur one time only. Also, many dishwashers have a 'one hour' cycle. In both cases, mechanical dishwashing uses more water.

Dummy variable (TENURE) is used for whether the household owns the house or rent the house. We want to estimate whether there is different effect on water usage between the house that is rented by the household and that owned by the household.

The age (HHAGE) of the head of the household, that person's education level (HHGRAD), and the number of persons in the household (PER) are used in our analysis.

Climate variables are also commonly used on residential water demand analysis (Kenney et al., 2008; Klaiber et al., 2014; Asci & Borisova, 2014). In our regression analysis, we include average May-September temperature and rainfall the 1984 to 2013. We do not include winter climate variables in our analysis since households usually do not consume water for outdoor purposes during winter. We did not adjust the relevant season for southern climates (e.g., Miami) relative to northern cities (e.g. Boston), though the region could affect the relevant season.

On a problem as complex as this, many other considerations could have been included, for example the socioeconomic conditions of the community and variations in building codes from one community to another. A region that has a strong 'green conscious' population, a community that might be more sensitive to natural resource issues, might behave differently from a community without this commitment.

However, we are limited in the data that we have available for the analysis. We do believe that the balanced distribution of our sample communities keeps our analysis relevant to a large range of cities and conditions. We have Northern, Southern, Midwestern, and Eastern communities, we have communities from the largest population centers down to communities of under one million people, we have communities that have varied sources for their water, and both communities that have current water shortages and communities that have none. The variety of our sample locations is an important strength of the analysis.

Table 2: Variable Descriptions

Variables	Description	Source
Q	Monthly water consumption (measured in gallon)	Calculated using water and sewage rate and annual cost of water and sewage.
DISH	Dummy Variable: takes 1 if unit has working dishwasher and takes 0 otherwise	2013 American Housing Survey
METRO	Dummy Variable: takes 1 if unit is in primary central city and takes 0 otherwise	2013 American Housing Survey
TENURE	Dummy Variable: takes 1 if unit owned or being bought by someone in the household and takes 0 otherwise	2013 American Housing Survey
WASH	Dummy Variable: takes 1 if unit has a working washing machine and takes 0 otherwise	2013 American Housing Survey
BATHS	Number of full bathrooms	2013 American Housing Survey
HALFB	Number of half bathrooms	2013 American Housing Survey
HHAGE	Age of householder	2013 American Housing Survey
GRADLEVEL	Education level of householder	2013 American Housing Survey
PER	Number of persons in household	2013 American Housing Survey
YEAR	Age of the building (in AHS: Year unit was built)	2013 American Housing Survey
INCOME	Household income ($)	2013 American Housing Survey
MP	Water marginal price ($/1,000 gallons)	Water and Sewage Rate
DV	Difference Variable (difference between actual cost and paying marginal cost for all consumption units)	Calculated by the authors
MonthlyRAIN	Monthly average temperature over May to September during 1984 to 2013	National Centers for Environmental Information
MonthlyTEM	Monthly average Rainfall over May to September during 1984 to 2013	National Centers for Environmental Information

3.3 REVISED THEORETICAL MODEL

For consistency with the log-log empirical model we need to revise the analytical model. We have values of $\ln(Q_1)$ from the household survey. We do not have actual values of Q_2 due to a lack of meters. We calculate values for $\widehat{\ln(Q_2)}$ based on the regression coefficients from the $\ln(Q_1)$ demand estimation and characteristics of the households in Group 2. Then,

$$Q = \alpha * EXP\left[\widehat{\ln(Q_2)}\right] + (1 - \alpha) * EXP[\ln(Q_1)] \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(5)}$$

Set $ln(Q_1) = X_1 + \beta_{12} * p$ and $\widehat{lnQ_2} = X_2$

Then we can get

$$EXP(X_1) = \frac{Q_1}{EXP(\beta_{12} * p)}$$

and

$$EXP(X_2) = EXP(\widehat{lnQ_2})$$

where β_{12} is the price coefficient of Group 1 demand; p is the marginal price; X_1 and X_2 are the aggregate terms of all other variables except for the marginal price variable for $ln(Q_1)$ and $\widehat{lnQ_2}$ respectively. Then, we can get

$$Q = \alpha * EXP(X_2) + (1 - \alpha) * EXP(X_1 + \beta_{12} * p)$$

$$= \alpha * EXP(X_2) + (1 - \alpha) * EXP(X_1) * EXP(\beta_{12} * p) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(6)}$$

Thus,

$$\frac{Q - \alpha * EXP(X_2)}{(1 - \alpha) * EXP(X_1)} = EXP(\beta_{12} * p) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(7)}$$

Thus,

$$p = \frac{\ln[\frac{Q - \alpha * EXP(X_2)}{(1 - \alpha) * EXP(X_1)}]}{\beta_{12}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \text{(8)}$$

where $Q \in (\alpha * EXP(X_2), EXP(X_2))$; α is the percentage of households that do not pay their water bill and $\alpha \in (0, 1)$; β_{12} is the price coefficient of Group 1 demand.

CHAPTER IV: DATA ANALYSIS

4.1 DATA OVERVIEW

In this section we discuss the data that we use for the empirical analysis. The majority of variables are from the American Housing Survey (AHS) 2013 Metropolitan Public Use File micro household data (AHS-PUF, 2013). The American Housing Survey is conducted biennially between May and September in odd-numbered years and the purpose of the survey is to provide a current and continuous series of data on selected housing and demographic characteristics. There are approximately 84,400 housing units in the national sample and “Each housing unit in the AHS national sample is weighted and represents about 2,000 housing units in the United States” (AHS, 2014).

Among the metropolitan areas included in the AHS, we selected populations from within the top 50 MSA populations, ones that are generally representative of the contiguous 48 states. We want the sample to reflect a variety of water demands and supply conditions, so we include communities that vary not only in size and location, but in the sources they use to get their water. We included communities that use both surface water and underground aquifers.

For a balanced analysis, we also need our sample to come from the various geographic and climate conditions of the US. We choose to select neither the largest nor the smallest communities in the MSA populations but populations that are representative of the whole country. Table 3 lists the metropolitan areas used in our analysis and the population of each area. We choose these eight MSA from AHS 2013 Metropolitan Statistical Areas.

Table 3: 2013 MSA Population

City	Population
Houston, TX	6,332,710
Boston, MA	4,698,356
Minneapolis/St. Paul, MN	3,460,826
Orlando, FL	2,272,395
San Antonio, TX	2,283,485
Las Vegas, NV	2,028,421
Austin, TX	1,884,439
Hartford, CT	1,214,949

Source: US Census (2016)

Last, it is important to note, the effects of water for agriculture and water resources for irrigation are not included in this analysis. The topic is important since many state governments need agricultural revenue and managing limited irrigation water is the subject of many articles, reports, and books. However, our focus is on residential water use, and understanding the factors that affect residential water demand along with the potential to use water bills to reduce water consumption.

4.2 CREATING A USABLE DATA SET

To get the data set we use in our analysis, we process our data in the following steps. There are a total 33,559 households from these 8 metropolitan areas in the 2013 AHS survey. After we process the data (detail in Appendix A), we have 11,509 usable households that pay for water for the econometric analysis of water demand. The AHS asks about annual expenditures on water and sewage. We use published rate information from each MSA to derive the household water quantity consumed (details on this process are in Appendix B). Table 4 shows the sample size of households that pay for water in each city.

Among these 8 MSA are three forms of rate structure: two communities with uniform rate structure (Hartford, Minneapolis); three communities with increasing block rate structure (Austin (total 5 blocks), Boston (total 6 blocks), Las Vegas (total 4 blocks); and one community with decreasing block rate structure (Houston (total 8 blocks with 3 decreasing blocks and 5 increasing blocks)), Orlando (total 5 blocks), San Antonio (total 4 blocks). We calculate marginal price and different variable for each household and the detail is in Appendix C. The rate structure is in Appendix D.

4.3 DATA ANALYSIS FOR HOUSEHOLDS THAT DO NOT PAY FOR WATER

There are a total of 18,890 households that answer -6 (Not Applicable) for the annual water and sewage cost (AMTW) and we assume these households do not pay separate water bills. We infer the quantity of water consumed by each of these households based on its actual characteristics and the estimated regression coefficients for Group 1. Since the household characteristics provide the link to estimate consumption for unmetered households, it is critical that we have accurate information about those characteristics. Thus, we exclude households that are missing more than one of the explanatory variables included in the demand estimation, or those that report no income or negative income. Our final usable dataset has 9,185 households that do not pay for water (see in Appendix E). The distribution of these households by MSA is in Table 4.

Table 4: Sample Size Distribution

	Pay	Don't Pay
City	Sample Size	Sample Size
San Antonio, TX	2,152	945
Austin, TX	1,628	916
Orlando, FL	1,543	1,135
Houston, TX	1,353	950
Minneapolis/St. Paul, MN	1,310	1,213
Las Vegas, NV	1,047	828
Hartford, CT	1,178	1,777
Boston, MA	1,298	1,421
Total	11,509	9,185

Source: calculated by the authors

4.4 COMPARISON OF THE HOUSEHOLDS GROUPS

A naïve analysis may assume that the average water consumption for households that do not pay for water would be the same as households with a water bill. In other words, if the average household with a meter uses 8000 gallons per month, every new household with a meter will also consume 8000 gallons per month. However, this assumption relies on the fact that households with and without a water meter are comparable to each other. If their characteristics differ, and those characteristics affect expected water consumption, any estimate of water consumption with and without a meter (and the effect of adding a meter) needs to incorporate those differences. Table 5 shows the average values of the explanatory variables for two groups included in the analysis and the test statistic that measures if the means are the same between the groups.

Table 5: Variable Comparisons between Groups

	Pay		Don't Pay		
Variable	Mean (μ_1)	Std. Dev.	Mean (μ_2)	Std. Dev.	T-test ($\mu_1 = \mu_2$)
baths	1.92	0.74	1.50	0.65	Pr(|T| > |t|) = 0.0
gradlevel	11.53	3.13	10.92	3.22	Pr(|T| > |t|) = 0.0
halfb	0.40	0.57	0.24	0.51	Pr(|T| > |t|) = 0.0
hhage	51.85	15.53	48.35	17.90	Pr(|T| > |t|) = 0.0
per	2.71	1.45	2.28	1.38	Pr(|T| > |t|) = 0.0
year	38.58	25.49	42.94	26.24	Pr(|T| > |t|) = 0.0
income	91998.90	95176.16	61874.01	70461.49	Pr(|T| > |t|) = 0.0
monthlyrain	3.80	1.52	3.93	1.47	Pr(|T| > |t|) = 0.0
monthlytem	76.30	6.77	74.10	7.11	Pr(|T| > |t|) = 0.0
q	10135.23	9256.22			
mp	7.78	5.14			
Dummy Variables					
	Pay		Don't Pay		
Variable	Mean (μ_1)	Std. Err.	Mean (μ_2)	Std. Err.	Pr-test (prop(1)=prop(2))
dish	0.84	0.0034	0.69	0.0048	Pr(|Z| > |z|) = 0.0
metro	0.30	0.0043	0.33	0.0049	Pr(|Z| > |z|) = 0.0
tenure	0.83	0.0035	0.38	0.0051	Pr(|Z| > |z|) = 0.0
wash	0.96	0.0019	0.68	0.0049	Pr(|Z| > |z|) = 0.0

Source: calculated by the authors

For simplicity, we named households that pay for water as Group 1 and households that do not pay for water as Group 2. All variable means are significant different between Group 1 and Group 2 as all p-values are zero in the t-test and the pr-test.

First, the mean of dummy variables (dish, metro, tenure, wash) represent as percentage of population that answer 1 in each variable. There are 84% of the population in Group 1 that own a working dishwasher (DISH) while only 69% in Group 2. Also, 96% of the population in Group 1 own a working washing machine (WASH) but only 68% in Group 2. The differences in DISH and WASH between the groups may be partially explained by the large difference in mean income (($91,998 for Group 1 versus $61,874 for Group 2). The TENURE variable indicates that 83% of the population in Group 1 owned the house they live but only 38% of the population in Group 2. Additionally, 30% of the population in Group 1 lived in the primary city center while 33% in Group 2. There is a larger percentage of the population that lived in rental property for Group 2 and normally, there is a larger percentage of the house units are rental property in the primary city center.

The average number of bathrooms and half baths for Group 1 are 1.92 and 0.4 respectively while 1.5 and 0.24 for Group 2. This may also be due to income differences between Group 1 and Group 2. The average education level of the head of household is higher for Group 1 (11.53) than Group 2 (10.92) and the average household age in Group 1 (51.85) is about 4 years older than Group 2 (48.35). Additionally, the average building age in Group 2 (42.94) is older than Group 1 (38.58). Finally, differences in the climate variables is simply due to the fact that the percentage of households with free water varies by city.

CHAPTER V: REGRESSION RESULTS AND DISCUSSION

5.1 REGRESSION RESULT

The regression result in Table 6 is for estimating lnQ_1. The standard error in the parenthesis is the heteroskedastic robust standard error. The heteroskedasticity test shows that the heteroskedasticity is present in our analysis, thus we adjust this problem by using robust standard errors.

Most of the coefficients in the regression result were expected except for DISH and METRO. DISH has negative coefficient and METRO has positive coefficient but both are statistically insignificant. This makes sense, because having a working dishwasher does not mean that the household will use it all the time and the household might wash their dishes even without owning a dishwasher. Also, households living in the primary city center should not use more water compared to the households that live outside the city since households lived in the primary city center are most likely to live in rental units.

The coefficient for TENURE is positive and statistically significant which means that households would consume more water when they owned the property in which they live. Number of bathroom is positive and statistically significant relative to water consumption but number of half bathroom is statistically insignificant.

The coefficients for variables with log transformed (GRADLEVEL, HHAGE, PER, YEAR, INCOME, MONTHLYRAIN, MONTHLYTEM) measure elasticities. Education level is statistically insignificant while the coefficient for LN(HHAGE) is 0.082 and statistically significant. This means that if head of household's age increases 1 percent, then the water consumption will increase 0.082 percent. The coefficient for LN(YEAR) shows that if the building age increases 1 percent, then the water consumption will increase 0.053 percent.

Household size and income are positive and statistically significant related to water consumption. A 1 percent increase in household size or income increases water consumption by 0.226 and 0.018 percent respectively.

In this model, we did not use log transformation on marginal price (MP) and different variable (DV) since we want to use the coefficients from Q_1 to estimate Q_2. As we mentioned, the marginal price for Group 2 is zero which means that if we use log transformation on marginal price, then LN(MP) will be infinite. Also, under the assumption that the demand function is the same for both groups, it would be theoretically inconsistent with the analytical framework if we use LN(MP) as explanatory variable. This is because by using LN(MP) in the regression means that there is a constant elasticity demand, however this is not possible for Group 2 with marginal price equal to zero. The coefficient for MP shows that if marginal price of water increase by 1 dollar, then the water consumption will decrease about 8% when everything else stay the same.[6] Table 7 shows the reduction in water consumption under different consumption levels when the price is increase by 1 dollar.

Monthly rainfall is negatively related to water consumption while monthly temperature is positively related to water consumption. Households are less responsive to

[6] Proof: Assume original marginal price is MP_0 and household consume q_1 water at this marginal price. After the marginal price increase $1, household consume q_2 water. Since everything else stay the same, we set the sum of other variables calculation as X. Then $ln(q_1) = X + (-0.08) * MP_0$ and $ln(q_2) = X + (-0.08) * (MP_0+1)$. We can get $ln(q_2) + 0.08 = ln(q_1)$ then $ln(q_2/q_1) = -0.08$. We then take exponent on both size and get $q_2/q_1 = 0.923$.

monthly rainfall since 1 percent increase in rainfall only reduces water consumption by 0.031 percent. On the other hand, households are more sensitive to monthly temperature since 1 percent increase in temperature will increase water consumption by 1.393 percent.

Table 6: Water Demand Regression Results (dependent variable is *ln(Q_1)*)

Variables	
DISH	-0.022 (0.017)
METRO	-0.021* (0.012)
TENURE	0.083*** (0.016)
WASH	0.024 (0.029)
BATHS	0.077*** (0.009)
LN(GRADLEVEL)	0.014 (0.016)
HALFB	0.011 (0.011)
LN(HHAGE)	0.082*** (0.020)
LN(PER)	0.226*** (0.012)
LN(YEAR)	0.053*** (0.008)
LN(INCOME)	0.018** (0.007)
MP	-0.080*** (0.001)
DV	0.019*** (0.0002)
LN(MONTHLYRAIN)	-0.031*** (0.009)
LN(MONTHLYTEM)	1.393*** (0.093)
CONSTANT	1.964*** (0.4442)
R-squared	0.561
Prob > F	0.000
N	11,509

*, **, *** indicate significance level at 10 percent, 5 percent, and 1 percent respectively. Figures in parenthesis are heteroskedastic robust standard error.

Table 7: Consumption Decrease after a Water Rate Change under Different Initial Consumption Level (in gallons)

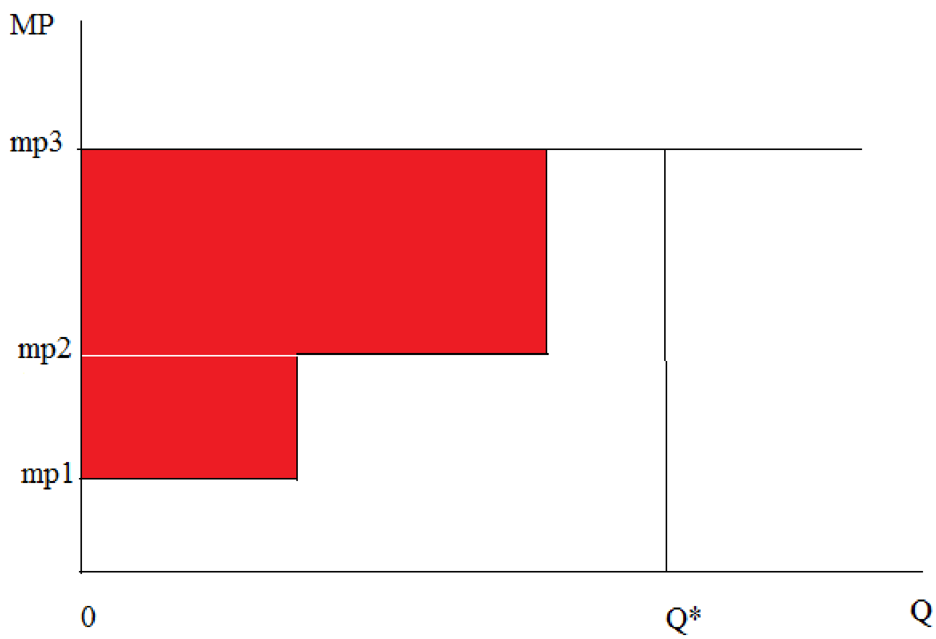
Original Consumption Level	Post Consumption Level when Price Increases $1	Decrease in Consumption
1000	923.1	76.9
2000	1846.2	153.8
3000	2769.3	230.7
4000	3692.5	307.5
5000	4615.6	384.4
6000	5538.7	461.3
7000	6461.8	538.2
8000	7384.9	615.1
9000	8308.0	692.0
10000	9231.2	768.8
11000	10154.3	845.7
12000	11077.4	922.6
13000	12000.5	999.5
14000	12923.6	1076.4
15000	13846.7	1153.3

Source: calculated by the authors

5.2 ESTIMATION OF Q_2

We assume that the demand functions Q_1 and Q_2 are identical and the only difference is that the marginal price for Q_2 is zero and the difference variable depend on marginal price. Thus, the coefficients in Q_2 are the same as Q_1 and we use these coefficients from Q_1 to estimate demand function Q_2, conditional on the actual household characteristics of Group 2. For increasing block rate structures, the different variable (DV) acts as income subsidy since the marginal price increases as households consume more units of water and households had to pay more if all water units are priced at the price of last block they consumed. Figure 2 shows an example where an individual pays mp1 for the first block, mp2 for the second block, and mp3 for any additional water. The DV measure is defined as the red area in for a person that consumes at Q*. Even though the marginal price for Group 2 is zero; the inferred DV is not zero for Group 2.

Figure 2: DV for A Person That Faces Three Increasing Block Water Structures



5.3 ESTIMATION OF THE DIFFERENT VARIABLE FOR GROUP 2

We do not have any information about the different variable (DV) values for Group 2 households. In this section, we explain how we use Group 1 households to estimate the value of DV for Group 2 households. First, we used the coefficients from the Q_1 regression to estimate how much water each Group 1 household would consume with marginal price and the DVs are equal to zero. We also use the coefficients from the Q_1 regression to estimate how much water each Group 2 household would consume with marginal prices and the DV values are equal to zero. For each Group 2 household in the sample, we match the Group 1 household with smallest consumption that is greater than or equal to the estimate of the Group 2 household from that MSA. For each matched pair, we used the marginal price and the DV values from the Group 1 household to replace the marginal price and the DV values for Group 2. This process is done within each city so that matches are as similar as possible.

After all households in Group 2 are matched and replaced with the price variables from the households in Group 1, we have complete data for Group 2 households. Using the coefficients from the Q_1 regression, we estimate that the average monthly water consumption for Group 2 households (conditional on Group 2 households having meters and paying for water) is 6,118.71 gallons (110.02 gallons per day per person). The observed average monthly water consumption for Group 1 households is 10,135.23 gallons (157.64 gallons per day per person). Thus, the average per person daily water consumption for Group 1 households is about 47 gallons more than Group 2 when both groups pay water bills.

5.4 REALITY: GROUP 2 HOUSEHOLDS DO NOT PAY WATER BILLS

In reality, Group 2 households do not pay water bills. This means that the marginal price is zero; however, the DV for Group 2 households is not zero (except for flat rate cities) because as long as households consume more than first block size, then the DV will be positive with increasing block rates. We also know that for households in Group 2, the actual DV will be at least as large as the estimate based on paying the water bill (the estimation method is described in the previous section). We know households in

Group 2 would consume more water when the marginal price is zero which means that the value of the DV will be larger. Thus, when Group 2 households do not pay water bills, the value of the DV should at least be as large as when they do pay water bills. With the marginal price equal to zero and the DV stays the same, the average monthly water consumption for Group 2 households is 11,401.51 gallons (199.3 gallons per day per person). Therefore, on average, each person in Group 2 will save 89.28 gallons of water per day when Group 2 households pay water bills.

5.5 *Q* ESTIMATION

Last, one of our main objectives is to estimate an aggregate Q, or one that is representative of the "average" household. While we assume that the individual household demand does not change, the aggregate demand depends on the proportion of households that pay for water. For water utilities, this is the most important measure since it reflects the expected total consumption and water needs that must be provided. To estimate Q, we need to get the value of α. There are 11,509 households in Group 1 and 9,185 households in Group 2 with total 20,694 households. Thus, α is equal to 44.4% ($\alpha \approx 9185/20694$) and $1 - \alpha$ is 55.6%. We rewrite equation (3) as

$$Q = 0.556 * EXP(ln(Q_1)) + 0.444 * EXP((\widehat{\ln(Q_2)})) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (9)$$

5.6 PRICE FUNCTION ESTIMATION

From the theoretical model, we know the price function is

$$p = \frac{\ln[\frac{Q - \alpha * EXP(X_2)}{(1 - \alpha) * EXP(X_1)}]}{\beta_{12}}$$

where $Q \in (\alpha * EXP(X_2), EXP(X_2))$.

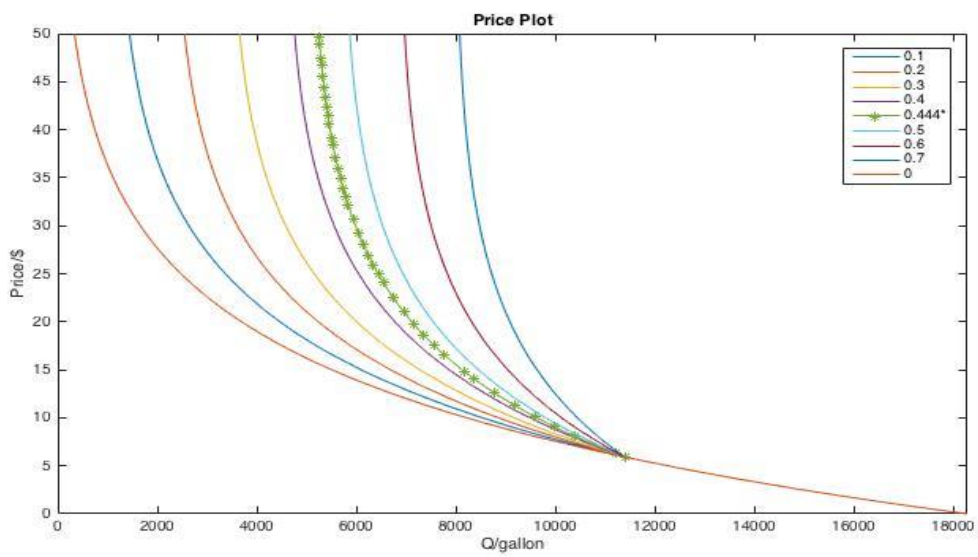
From the empirical demand estimation result, we calculate that EXP(X_1) equals 18284.25 gallons and EXP(X_2) equals 11401.51 gallons. Also, β_{12} is equal to -0.08 gallon^2/$.

Then we get the price function as

$$p = \frac{\ln[\frac{Q - \alpha * EXP(X_2)}{(1 - \alpha) * EXP(X_1)}]}{\beta_{12}} = \frac{\ln[\frac{Q - \alpha * 11401.51}{(1 - \alpha) * 18284.25}]}{-0.08} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (10)$$

Figure 3 shows the aggregate demand curve under different values of α.

Figure 3: Aggregate Demand Curve under Different Values of α



The α is equal to 0.444 from the empirical data. We plug in the value of α and get the price function as

$$p = \frac{\ln[\frac{Q - 5062.27}{10166.04}]}{-0.08} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (11)$$

where $Q \in (5062.27, 11401.51)$.

Then we can get

$$\frac{dp}{dQ} = \frac{1}{404.98-0.08*Q} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (12)$$

As we can see, as Q gets larger, the rate of change gets smaller.

CHAPTER VI: SUMMARY AND CONCLUSIONS

In this thesis, we use the data from 2013 American Housing Survey Metropolitan to estimate the potential water conservation when households pay water bills. There are two types of households in our analysis: households that pay water bills (Group 1) and households that do not pay water bills (Group 2). We use log-log model to estimate Group 1 log-transformation (lnQ_1) demand and then use lnQ_1 coefficient to estimate the water consumption level for Group 1 and Group 2 households after we set the marginal price and DV equal to zero. We use these consumption levels to match Group 2 households with Group 1 households under each MSA. For each matched pair, the marginal price and DV for Group 2 households were replaced by the Group 1 household's marginal price and DV. Then we estimate the consumption level for Group 2 households when they pay water bills and when they do not pay a water bills. The difference in consumption when Group 2 households pay water bills and do not pay water bills is the potential water conservation. The numbers show us what one might have assumed before beginning the analysis: billing for a utility will cause some people to restrict usage. The consumer pays closer attention to usage and monitors waste.

Our work confirms what Grafton et al. (2009) has found using data from 10 OECD countries in Asia, Latin American, and Europe. Researchers found that having metered water makes consumers more conservative with water usage.

People realize that shortages of potable water exist today and that shortages will only increase in the future. Solutions are critical; however, solutions do exist. For example, in September 2015, higher efficiency water heater became mandated by law.

Today, toilets flush with under one and one half gallon per flush whereas older toilets flushed with three and one half gallons per flush.

Multifamily living was common as populations moved into the cities, beginning over a hundred and fifty years ago, when water was not viewed as a scarce natural resource at all. In fact, water was thought of as both a problem and a solution at the same time. Water was not scarce, so rice could be grown in deserts; dams could be built for electric power and irrigation, and water could even be pumped over the California foothills to a desert called the LA basin. No could see the coming problems.

Next, when there is no direct economic fee for a wasteful behavior when water is not billed. Even people who are concerned about the environment can be wasteful when a person does not need to pay.

It is a reasonable hypothesis that 'free' water households are similar to other world populations, the same as the ordinary American homeowners, and will tend not to behave differently about their water use unless there are mandatory restrictions or if they are incentivized to consider conservation because of a change in water rates. As an added benefit, remodeling and building contractors will have new work opportunities. There are additional billing hours for licensed plumbers and the manufacturers of residential water meters will have increased volume. These should be good for a country with eight years of a stagnant residential construction market.

One might assume that objections could come from building owners who fear new remodeling costs. This could be a reasonable objection until one considers the potential benefits to our country. A review of residential water meters advertised on the internet shows prices from about $90 to $160 per unit, depending on the features and the warranty offered. Our model estimates that the average household going from non-metered to metered water would save on average about 5,000 gallons of water per month. With the current average marginal price of water in our Group 1 sample at $7.78 per 1,000 gallons, the water meter would be paid for in 3 to 4 months, less the cost of installation.

Building owners know and accept that changes in plumbing and electrical codes that are required in new construction. Existing units can and should be phased in over a span of time. As we have seen in water restrictions in residential toilets and faucets, existing buildings are phased in and do not cause an undue burden to owners. Only an analysis of construction costs could answer this question and that is beyond the scope of this paper.

Last, and perhaps most important, the measure will be popular with people who are concerned about the diminishing availability of potable water. This should include powerful groups like the National Resources Defense Council and those voters who consider themselves part of the ‘green revolution’. Non metered households may worry that their utility costs could go up, but our analysis shows that this is usually not the case.

This is not an unusual proposal. During the early 1990s, the Federal government passed a simple law requiring toilets to flush with no more than 1.2 gallons per flush. At that time, the average toilet flushed with 3.5 gallons of water with each flush. Both non metered households and single family owned homes were given a discount voucher to make the change to efficient toilets. This law saved hundreds of thousands of gallons of clean, potable water that were being flushed down inefficient toilets. Nothing was lost.

Just last year, Federal regulations changed for water heaters making them more energy efficient. Manufacturers where allowed to sell of their stocks and retailers were given a full year to dispose of the older, less efficient models. This process is still going on and has not disrupted the availability of water heaters and the major manufacturers have been willing partners in the changeover. Residential faucets and showers have gone through similar flow restrictions without problems of supply or engineering. Fortunately, there is no major industry that could be harmed by this proposal, and like the changes in residential flow rates, one could expect this change to mirror water flow rates changes and be welcomed.

This is a democratic proposal. If one wishes to take hour long showers, then nothing in this proposal takes that privilege away. The only change is that each person must pay their fair share of the costs for their behavior; a very American point of view.

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APPENDIX A

PROCESSES TO GET THE USABLE DATA SET

First, we exclude households that answer in the survey that contain -6 (Not applicable) in AMTW. Excluding these in the variables, we have remaining 14,669 households that can be used and are available for our analysis.

Second, we exclude 457 households in the METRO section that answer 2 (households live in the secondary central city) in the METRO question. We have to exclude these households in our analysis because we want to use METRO as dummy variable in our analysis because the dummy variable. Similarly, we exclude 382 households that answer 3 (occupied without payment of rent) in the question about TENURE. We are left with 14,212 households.

Third, we exclude households that report AMTW>INCOME. This leaves us with a total of 13,830 households.

There is one more set of households excluded. When the final Q (water consumption) is negative based on the rates, then the household is excluded in the analysis. This is explained below.

APPENDIX B

PROCESSES OF CALCULATE HOUSEHOLDS WATER QUANTITY CONSUMED

First, figure the monthly water and sewage cost by dividing AMTW by 12. Denote new monthly water and sewage cost as ME0 (monthly water expenditure).

Second, if there are monthly fixed (or service) charges, then subtract these charges from ME0 otherwise go to step 3. Denote new monthly water and sewage cost as ME1. In excel, use ‘IF’ function as if ME1 is positive, then equal to ME1 otherwise 0. Denote new ME1 as ME1’.

Third, use water and sewage rate structure to calculate the total cost needed to consume whole block size in each block. For multiple blocks cities, denote the total cost as BC(i) (i= 1,2,3,4,…,k is the block number and k is the last block) and denote marginal price in each block as MP(i) ($/1000 Gallon).

Fourth, subtract BC(1) from ME1’ and denote new monthly water and sewage cost as ME2. If ME2 is positive, then Q1 is equal to first block size otherwise Q1 is equal to ME1’*1000/MP1. Then, use ‘IF’ function as if ME2 is positive, then equal to ME2 otherwise 0. Denote new ME2 as ME2’.

Fifth, repeat step 4 for all blocks except the last block.

Sixth, since the last block don’t have block size, the quantity consumed is equal to ME(k)’*1000/MP(k) assuming k is the last block. And for flat rate city, the household water quantity consumed is equal to ME1’*1000/P when P is equal to the flat water rate.

Seventh, final water quantity consumed. Add up all Qi together and get the final water consumption quantity Q.

Eighth, if the final Q is negative because ME0 is less than the monthly fixed (or service) charge, then we excluded these households in our analysis.

Ninth, we excluded households that use less than 10 gallons per day per person.

Appendix C

PROCESSES TO CALCULATE MARGINAL PRICE AND DIFFERENT VARIABLE

First, copy value only for all blocks water quantity consumed, then change 0 to M since the water quantity consumed is 0 for blocks that household do not consume.

Second, in Microsoft Excel, use ‘COUNT’ function for all blocks, then the number shows how many blocks that household consumed and denoted as NB (number of blocks). Then, use ‘IF’ function as if NB=i (where i is 1,2,3,4,…,k), then is equal to MP(i), otherwise 0.

Third, for multiple block city, add all MP(i) together to get MP (marginal price) that each household paid in the last block they consumed. For flat rate city, MP is equal to the flat rate (FR).

Fourth, the Different Variable is equal to MP*Q/1000 – MC1’ for households that face fixed charge and FR*Q/1000 – MC1’ for households that face flat rate.

Appendix D

RATE STRUCTURE

Austin, TX

Fixed Charge:	
Customer Account Charge Per Month	$4.83
Equivalent Meter Charge Per Month	$3.68
Fire Protection Component Per Month	$1.49
Single-Family Residential Volume Unit Charge:	Unit Rate Per 1,000 Gallons
0 - 2,000 Gallons	$1.25
2,001 - 6,000 Gallons	$2.80
6,001 - 11,000 Gallons	$5.60
11,001 - 20,000 Gallons	$9.40
20,001 - over Gallons	$12.25
Water Revenue Stability Reserve Fund Surcharge:	Unit Rate Per 1,000 Gallons
All Volumes	$0.12

Source:
https://austintexas.gov/sites/default/files/files/Water/Rates/Approved%20Retail%20Water%20Service%20Rates%202012-13.pdf

Boston, MA

Consumption (Cu. Ft./Day)	Water Rate Per 1,000 Gallons	Sewer Rate Per 1,000 Gallons
First 19	$5.95	$7.70
Next 20	$6.23	$7.94
Next 50	$6.49	$8.10
Next 260	$6.90	$8.55
Next 950	$7.20	$9.02
Over 1299	$7.45	$9.33

Source:
http://www.bwsc.org/SERVICES/Rates/RATES_2013.pdf

Hartford, CT	
Customner Service Charge	$13.48
Water Use Charge	$2.50 per 100 cubic feet
Sewer User Charge	$2.52 per 100 cubic feet

Source: http://themdc.org/

Note: The source in this website is not exist now but we attach the PDF file.

Houston, TX	
Water Rates	
Basic Charge	$4.73
The numbers below this line include both Base and Volume charge	
1,000 gallons	$4.86
2,000 gallons	$11.08
3,000 gallons	$11.45
4,000 gallons	$21.66
5,000 gallons	$25.96
6,000 gallons	$30.26
7,000 to 12,000 gallons	The total charge for 6,0000 gallons + $4.67 per 1,000 gallons
Over 12,000 gallons	The total charge for 12,0000 gallons + $7.69 per 1,000 gallons
Sewer Rates	
Basic Charge	$10.05
The numbers below this line include both Base and Volume charge	
1,000 gallons	$10.21
2,000 gallons	$10.54
3,000 gallons	$10.81
4,000 gallons	$24.80
5,000 gallons	$29.85
6,000 gallons	$37.20
Over 6,000 gallons	The total charge for 6,0000 gallons + $7.35 per 1,000 gallons

Source: https://edocs.publicworks.houstontx.gov/documents/divisions/resource/ucs/2013_water_rates.pdf

Las Vegas, NV

Daily Service Charge	$0.3863 * 30 days = $11.59
SNWA Infrastructure Charge	$9.59
SNWA Commodity Charge	$0.44 per 1,000 gallons
SNWA Reliability Surcharge	0.25% of total bill
Water Rate (Threshold * 1,000 gallons)	Rate per 1,000 gallons
0-6.8	$1.16
6.81-13.5	$2.08
13.51-27	$3.09
27.01-over	$4.58

Source: https://www.lvvwd.com/custserv/billing_rates_thresholds.html

Minneapolis/St. Paul, MN

Water Fixed Charge	$5.25
Sewer Fixed Charge	$6.45
Water Charges Per Unit	$3.29
Sewer Charge Per Unit	$3.14

Source: http://www.minneapolismn.gov/utilitybilling/utility-billing_rates
Note: Water and sewer fixed charges for 2013 were not given in this data. The authors replaced these with 2016 values.

Orlando, FL

Service Charge	$7.50
Fire Protection Rates	$9.70
Volume Charge	per 1,000 gallons
First 3,000 gallons consumed	$0.634
Next 4,000 gallons consumed	$1.077
Next 12,000 gallons consumed	$1.589
Next 11,000 gallons consumed	$2.832
All consumption over 30,000 gallons	$5.300

Source: http://www.ouc.com/residential/service-rates-and-costs/water-rates

San Antonio, TX	
Water Supply Fee Rates	
blocks	rate per 100g
first 1496	$0.1080
next 4489	$0.1080
next 6732	$0.1562
next 4488	$0.2204
over 17205	$0.3857
Residential Class Wastewater Rates	
Monthly Service Availability Charge (includes first 1,496 gallons)	$11.4900
Over 1,496 gallons	$0.3047

Source:
http://www.saws.org/latest_news/water_news/docs/WaterNews201302.pdf

Appendix E

DETERMINING USABLE HOUSEHOLDS THAT DO NOT PAY FOR WATER

There are 18,890 households in Group 2. After we filter out 8,867 households that have one or more missing variables (not include AMTW), we are left with 10,023 households. Also, we filter out 467 households that answer 2 in METRO or 3 in TENURE and this leaves us with 9,556 households. Last, we filter out 371 households that reported negative or 0 income so the final number of households is 9,185.