RESIDENTIAL WATER PRICING AND DEMAND: AN ANALYSIS OF WATER CONSUMPTION IN COLORADO SPRINGS, COLORADO

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Economics

ABSTRACT

Scarcity of water resources necessitates an understanding of residential water pricing and demand, two factors certain to affect water usage in the coming years. This paper pursues a discussion of water pricing theory and previous studies on residential water demand. The culmination of the paper is an analysis of residential water demand in Colorado Springs, Colorado, a city reliant on water from the Colorado River Basin, a seriously stressed water system. A fixed-effect regression with Driscoll-Kraay standard errors is utilized to analyze a panel data set providing average monthly residential water consumption per cubic feet (CF), for forty water consumption zones over the ten-year period January 2000 to December 2009. The study analyzes a number of exogenous variables including average education level to determine the influence of less obvious factors on residential water consumption. Main findings indicate increases in most measures of wealth corresponded positively with residential consumption, but not all. Above average education levels of certain age groups and household value are suggested to have negative relationships with water consumption, so that areas with above average education levels of 18-24 year olds are using less water. For the stressed Colorado River Basin these finding suggest increased investment in education, and full accounting for the price of water resources under block rate schedules will serve effective tools for water demand management.

KEYWORDS: (Water Pricing, Residential Water Demand, Fixed-Effects Regression)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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CHAPTER 1

INTRODUCTION

Water scarcity is increasingly becoming an issue warranting attention. As populations grow continued stressed is placed on the water levels nature provides, which in turn reduces both the quality and quantity of flow in our rivers and streams. A prime example of water scarcity is taking place is in the Colorado River Basin. The Colorado River is stressed. The river serves nearly 40 million people in the American Southwest and is approaching a point where water demand will exceed water supply[1]. The impending crisis necessitates new methods to either increase water supply or decrease water demand. Supply enhancement, or the construction of new infrastructure and the revitalization of old, is able to increase available water resources, but a limit must be recognized. With continued expansion there is only so far supply can be stretched to meet consumer demand. Alternatively, demand management seeks to decrease quantity of water ostensibly required by residential, business, and agricultural water users through conservation and other innovative strategies. Water conservation takes many forms, from water audits, to media awareness campaigns, to xeriscape gardens. Of these many approaches to conservation, some suggest the most cost-effective and influential are price-based (Olmstead & Stavins, 2009). Price teaches value; properly pricing a good or

[1] U.S. Department of the Interior, Bureau of Reclamation. (2012). Colorado River Basin Water Supply and Demand Study. Accessed January 2013, from http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html.

commodity sends a scarcity signal to producers and consumers signifying optimal levels of use. The prices at which urban and residential water providers sell water to their customers, sends signals representative of the water's value. Simply put, if water is underpriced it will be overused, and if water is overpriced it will be underused (Beacher & Shanaghan, 2011). Proper use of price-based conservation approaches identifies the ideal price at which to value water resources.

There is ample theory on how water rates ought to be set and what factors should be included in the determination. The most straightforward of these theories states that water rates need to be efficient, optimal, equitable, and viable (Beacher & Shanaghan, 2011). A rate structure taking these considerations into account will send effective price signals to customers and be sustainable in the long-term. While there are many theoretical approaches to best practices of pricing water resources, in order to fully comprehend effective pricing one must first understand the constituents of water demand.

This paper reviews water pricing theory and previous water demand studies. We then analyze results of our own study to examine the determinants of water demand in Colorado Springs, Colorado, a city reliant on Colorado River Basin water. This analysis is intended to benefit future price-based approaches to water conservation, and demand management strategies in general, by providing a thorough understanding of several factors explaining variation in consumption. This study seeks to expand on current findings by including less obvious indicators of water use such as number of vehicles per household, average age, and average education level. In order to pursue this analysis a panel data set of such factors over a ten year period is analyzed using a fixed-effects regression. Our hypothesis is that upper class residential customers will be the least responsive to changing prices, while lower class customers will be the most responsive to changing prices[2]. These arguments are support by several previous studies (e.g. Mieno & Braden, 2011; Arbués, Barberán, & Villanúa, 2004). This paper will also explore the effects of increase-block pricing, now used by most water providers in the Basin. We hypothesize the presence of increasing block rates, as well other price based measures such as water use restrictions, will decrease residential water demand. Further we hypothesize education and the year homes are built to have negative relationships with water consumption, and temperatures, lack of precipitation, and summer months to have positive relationships.

[2] It is hypothesized all indicators of wealth will have positive relationships with water consumption, e.g. median household income, average household value, and average number of vehicles.

Chapter 2

Historical Background

Water Pricing Theory

Maintaining a sufficient supply of water is not a new problem, but an issue that has been discussed in academic and political circles for centuries. The Rio Earth conference of 1992 acknowledged three fundamental principles of water resources management. The principles were originally composed in Dublin and thus known as the Dublin Principles. The first principle states that water resource management ought to be comprehensive, i.e. not focused on management of just one town or city, but all-inclusive of the entire hydrological basin. The second principle argues for the inclusion of all stakeholders in the decisions of water resource management including governments, municipalities, agriculturalists, and industrialists. The third principle and focus of this paper, recognizes water as a scarce resource and the necessity to create incentives for efficient allocation and use based on economic principles (De Azevedo & Baltar, 2005).

Price-based approaches to water conservation are suggested to be a more efficient mode of conservation than non-price approaches for their achievement of cost recovery and revenue sufficiency for water providers, while simultaneously sending price signals to customers emphasizing efficient use (Olmstead & Stavins, 2009). As opposed to non-price approaches, ranging from water use restrictions to high efficiency device replacement, price-based approaches directly impact customer's pocketbooks. Rogers, Silvia, and Bhatia (2002) outline six fundamental effects of proper pricing: 1) increases in prices reduces demand; 2) increased prices increases supply; 3) price increases facilitates cooperation between water users; 4) increased prices improves marginal efficiency; 5) increased prices leads toward sustainable management of water resources; and, 6) increased prices reduces the per unit cost of water to the poor.

Beecher and Shanaghan (2006) suggest four pillars of proper water pricing: efficiency, optimality, equity, and viability. Efficiently set prices demonstrate proper value, i.e. the most accurate value of water is reflected by its price. Optimizing prices and production requires providing water resources at the least cost means possible. This does not imply prices should be unrealistically low, rather while maintaining efficiency, water providers must pursue the most affordable means to meet water demand. Equitable water prices allow all customers necessary access to water resources in order to satisfy basic human needs, most importantly recognizing non-discretionary uses of water to sustain life. In an equitable system water providers make water available for fundamental uses to all of their customers regardless of income. Lastly, viable water prices allow for long-term sustainability. Water providers must meet the needs of their customers, while also achieving revenue sufficiency allowing for long-term sustainability of water supply and infrastructure. The authors suggest the realization of these four principles will allow for sustainable water pricing and comprehensive water resource management (Beecher & Shanaghan, 2006).

An integral aspect of achieving the four principles of sustainable water rates is full-cost pricing. The primary costs considered in supply of water and which make up the full cost of supplying water to customers are capital, and operational and maintenance costs. However, when the resource in question is both rival and excludable it is not so simple. Rogers, Bhatia, and Huber (1998) suggest full cost water pricing is only achieved when economic and environmental externalities, as well as opportunity cost are accounted for in the price of the resource (Rogers et al., 1998). In the Colorado River Basin there has been little regard for perpetuating in-stream flows and maintaining the health of a diminishing river system. The magnificent river of the American West once ran clear through to the Pacific Ocean, but now only dribbles through agricultural ditches into Mexico and ends thirty miles before the Sea of Cortez[1]. This large scale example of an environmental externality highlights the failure of pricing mechanisms in the Colorado River Basin to account for full cost.

Although monetarily pricing the perpetuation of in-stream flows seems abstract at best, Murphy (2009) suggests a computer-coordinated, automated water market with direct environmental participation to influence water user buy-in to environmental externalities. Such experimental systems could be introduced for specific river basins to works towards full cost pricing.

Others identify marginal pricing as the key to efficient water pricing (Sibly, 2006). Urban water providers experience two primary costs: private and external. Private costs can be broken down into fixed and variable; those independent of the amount of water supplied and those which vary with deliveries, respectively. External costs are comprised of the externalities and opportunity cost of the resource as discussed above. It is suggested to achieve urban price efficiency a two-part tariff system is ideal. In this

[1] Down the River Expedition. (2012) From Source to Sea, *The State of the Rockies Project*. Accessed January 2013 from http://www.coloradocollege.edu/other/stateoftherockies/source-to-sea/.

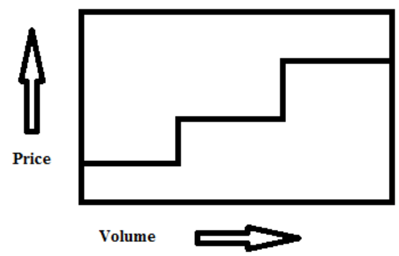
proposed pricing system the first tariff is a fixed rate which covers the fixed costs of supplying the resource (infrastructure and administrative). The second tariff, based on variable costs, is a volumetric charge which accounts for the marginal cost of each additional unit of water necessary to produce in order to satisfy demand. An important consideration of this model is its ability to respond to changing conditions. For instance, in the presence of a drought marginal cost to water providers will increase, therefore, water providers can increase volumetric charges in order to maintain efficient pricing and proper valuation of the resource (Sibly, 2006).

Increasing Block Rates

As opposed to two part-tariff systems recommended by some, here in the Southwest water providers typically utilize increasing block rates. The two systems are similar, but do have their differences. Under increasing block rates residential customers pay a small fixed charge accompanied by a specific volumetric rate based on individual's amount of water usage. These systems are characterized by blocks because as consumers increase usage past a certain amount, all subsequent water use will be charged at a higher volumetric rate. An example of what an increasing block rate schedule may look like is pictured below.

FIGURE 2.1

INCREASING BLOCK RATES



Source: diagram by author

Although increasing block rates differ from two-part tariffs, we can still examine the effects of increased marginal prices within a block rate structure (Nataraj & Haneman, 2008). A California-based study took advantage of a natural experiment when Santa Cruz water providers introduced a third block to an increasing block pricing schedule. The study suggests residential customers do indeed respond to changes in marginal prices even under possibly complex pricing structures. Examining the effects of a 100% increase in water price from one block to another the authors found the increase led to a 12% reduction in residential water demand. A problematic aspect of these findings is the severity of the increase, thus the authors recognize results would potentially differ if the price increase were not so large. The findings do suggest however the importance of marginal price increases and their effectiveness on reducing demand.

From a theoretical standpoint it is possible to encourage water providers to pursue pricing mechanisms which encourage efficient use through well managed marginal price increases. Yet, for Municipal and Industrial water providers it is necessary to recognize the majority of costs are fixed and not subject to change with the amount of water delivered to individual customers. Instead of relying solely on marginal cost, increasing block rate systems attempt to equitably divide the burden of fixed and variable cost among customers through amortization of capital infrastructure and maintenance costs, alongside of volumetric charges for variable costs. Colorado Springs Utilities (CSU), for example, uses a three block pricing structure in which the first block is set as an average for efficient indoor use for a typical family, the second block is set as an average for efficient outdoor use for a typical family (based on peak water usage) and the third block is set for above average water users and large area irrigators in an effort to discourage wasteful use. The tiers from one block to the next are typically characterized by a 50% increase in price from one to the next. Through these three blocks CSU is able to subsidize first block users with revenue from third block users, recognizing the infrastructure necessary to supply higher end users is greater and more expensive than what would be necessary if the utility were only to supply lower end water use customers. Through this system we see customers with higher demand paying increased rates both to cover the relatively low increased marginal cost of each additional unit of water delivered, and the infrastructure necessary to maintain larger deliveries[2].

Water Demand

The question of what factors influence water demand is one frequently discussed and studied in a variety of forms (Billings & Agthe, 1980; Renwick & Archibald, 1998; Nataraj & Haneman, 2008; Ruis, Zimmermann, & van den Berg, 2008; Saleth & Dinar, 1997; Arbués, García-Valiñas, & Martínez-Espiñeira, 2003; Arbués et al., 2004; Mieno & Braden, 2011; Dalhuisen, Florax, de Groot, & Nijkamp, 2003; Olmstead & Stavins, 2009). Depending on the nature of the study different exogenous variables are analyzed,

[2] S. Winter, personal communication (December 5, 2012).

but several prevailing explanatory variables are recognized. These are: price, income, climate, and household characteristics.

Billings and Agthe (1980) present a model to estimate water demand under the presence of increasing block rates. Their model is one of the first to utilize two price variables in agreement with what is known as the Taylor-Nordin specification (Taylor, 1975; Nordin, 1976). This specification comes from a study and subsequent response on electricity demand under block rate tariffs. The two authors argue for the inclusion of a difference variable when marginal price is used to estimate demand under block rate systems to avoid bias from the inclusion of marginal price alone. This variable is the difference between what customers would pay if each unit of a good were purchased at the marginal price, and the price customers actually pay for the good. Billings and Agthe's study (1980) utilizes these two variables in the context of water demand in an effort to study price elasticity in Tucson, Arizona. Their findings conclude water is relatively price inelastic.

Saleth and Dinar's (1997) World Bank study on residential water demand in Hyderabad, India, suggests a need for properly priced, and efficient water markets, similar to the theoretical arguments of Rodgers et al., (1998) presented above. Although greater political involvement and a less reliable source of urban water are characteristics of water resources in Hyderabad at the time of the study, the authors conclude customers would be willing to pay more for water resources if they were reliably supplied, and furthermore suggest tiered rates, much like we see in the American West, to subsidize lower income water users.

A 1998 study conducted by Renwick and Archibald looks at the effects of water efficient technologies in estimating the water demand equation. Their study analyzes marginal price, the difference variable, income, climate, and several indicator variables for the adoption of different water saving techniques. Utilizing a two stage least squares regression the authors conclude demand-side management practices are effective at reducing demand, especially for lower-income households.

For many water demand models calculating price elasticity is fundamental. Arbués, et al., (2003) reviews major contributing studies on residential water demand, and suggests most studies have found water demand to be price inelastic. Arbués et al. (2004) support this argument with empirical evidence through a state of the art study on water demand in Zaragoza, Spain. The 2004 study uses a dynamic panel data approach to estimate the water demand equation for individual households. The study analyzes the demand equation with a random-effects regression, and uses two models to explore the effects of both average and marginal price (along with the difference variable). The authors suggest water is increasingly viewed as a luxury good and therefore increases in prices have little effect on reducing demand. In order for price measures to affect greater conservation it is suggested a less complicated tariff system should be employed. Arbués et al. (2004) recognize the demand equation for water is likely non-linear. The study assumes a semi-logarithmic relationship is present which is preferable because of previous evidence suggesting price elasticity of water demand is not constant.

Mieno and Braden (2011) estimate water demand in the Chicago metropolitan area with a fixed-effect regression on a micro-level panel data set. The study focuses on price, income, weather, seasonality, and community characteristics. In analyzing their data the authors utilize a fixed-effect regression to reduce bias by assuming determinants such as presence of swimming pools and acreage to be estimated by the unobservable error term. The authors recognize previous studies estimating demand from panel data utilize random-effect regressions (e.g. Arbués et al., 2004), however, this does not allow for correlation between exogenous variables and the unobserved constant. The study suggests consumers are more price responsive during summer months, and therefore concludes differing price schedules could be implemented seasonally to increase conservation.

The water demand studies cited above provide the basis for the study pursued by this paper which will be discussed in the following sections.

CHAPTER 3

METHODOLOGY

The essential formula for water demand from which econometric models are analyzed, is:

$$Q_d = f(P,Z)$$

Where quantity demanded, *Qd*, is related to price, *P*, and other relevant factors, *Z*, such as household characteristics and climate. The following study pursues a fixed-effect regression analysis of this equation using panel data for forty water use zones over a ten-year period in Colorado Springs, Colorado.

This study pursues an analysis of a wide variety of exogenous variables, gathered from a variety of sources explained in the following section. Previous studies, as outlined above, have analyzed both marginal and average price in determining this equation (Arbués et al., 2004; Ruis et al., 2008; Mieno & Braden, 2011). For the purposes of this study only marginal price is analyzed.

The most controversial issue in estimating water demand under increasing block rates with marginal price, is how to avoid bias from marginal price. Because marginal price will increase as users increase their water usage, there is a strong correlation between price and usage. Without correction this case of autocorrelation could adversely affect the result and produce a poor estimation. The solution, as highlighted in the previous section, is to introduce a difference variable (Taylor, 1975; Nordin, 1976); Billings & Agthe, 1980, Mieno & Braden, 2011). The specification of this difference variable is the price water users would pay if every unit of water were purchased at the marginal price, minus the price users actually pay. By including this difference variable in the analysis the bias produced by marginal price is removed.

Arbués et al. (2004) suggests the relationship between water demand and explanatory variables is non-linear, and for the purposes of their study, semi-logarithmic. For the purposes of this study a linear model is used for simplicity, however the likelihood of a non-linear relationship is recognized when interpreting results. In order to partially account for non-linearity the natural logarithms of both water usage and median household income are utilized, similar to previous studies (Billings & Agthe, 1980; Mieno & Braden, 2011). While this does not fully solve the problem it allows for a better explanation of results, as a one unit increase in all other exogenous variables will translate to a percent increase in water demand. For water demand and median household income, a percent increase in income translates to a percent increase in water demand. Thus essential trends of exogenous effects on the variability of demand are gathered.

Similar to Mieno and Braden's 2011 study, a fixed-effect model is employed here to estimate demand from the panel data set, as opposed to random-effects. The nature of the data is based on forty water use zones designated by CSU. It is assumed there are distinct differences between each zone not captured by the exogenous variables. Fixed-effect models include an unobservable error term. In this study the unobservable error term signifies these distinct, however unable to measure, differences. Further justification for the use of a fixed-effect regression is provided in Chapter 5.

CHAPTER 4

DATA

Data for this study are acquired from a variety a source. Table 4.1 provides variable names, descriptions, and data sources.

Monthly water consumption data are supplied by CSU for the period of January 2000 to December 2009. The data provided is comprised of average monthly residential water usage per cubic feet (CF) per water consumption zone, and the number of residents per zone. The utility has divided the city into fifty such zones, which are used as the entities by which the panel data is analyzed. In order to determine residential consumption per zone, average water usage is divided by number of residences per zone, providing average household consumption per zone, for each month within the study period.

TABLE 4.1

DESCRIPTION OF DATA

Variables	Description/Unit	Source
MHI	Average median household income for the past 12 months (2009 U.S.$)	US Census
MP	Marginal price for last unit of water consumed (2009 U.S.$)	Colorado Springs Utilities
D	Difference variable (2009 U.S.$) specified by Taylor (1975), Nordin (1976)	
Temp	Mean monthly temperature (degrees Fahrenheit)	Colorado Climate Center
Precip	Average monthly rainfall (inches)	Colorado Climate Center
HS	Average household size (number of residents)	US Census
Rent	Average renter occupancy rate	US Census
Value	Average median household value (2009 U.S.$)	US Census
The below indicator variables all have the value of 1 or 0		
IBR_dummy	Indicator variable for periods within the study experiencing increasing block rate pricing (May – October for the period July 2002 – April 2006, May 2006 – December 2009)	Colorado Springs Utilities
Rec_dummy	Indicator variable for times of economic recession (March – November 2001, December 2007 – June 2009)	National Bureau of Economic Research
WR_dummy	Indicator variable for periods of CSU water use restrictions (June 2002 – September 2005)	Colorado Springs Utilities
Sum_dummy	Indicator variable for summer months (June – September)	
Yb1980_dummy	Indicator variable for zones with the average of households built 1980 or after	US Census
Age25_dummy	Indicator variable for zones with average median age falling below 25% of the distribution	US Census
Age75_dummy	Indicator variable for zones with average median age falling above 75% of the distribution	US Census
ED25_25_dummy	Indicator variable for zones with average education levels for the population 25 years and older falling below 25% of the distribution	US Census
ED25_75_dummy	Indicator variable for zones with average education levels for the population 25 years and older falling above 75% of the distribution	US Census
ED18_25_dummy	Indicator variable for zones with average education levels for the population 18 - 24 years old falling below 25% of the distribution	US Census
ED18_75_dummy	Indicator variable for zones with average education levels for the population 18 - 24 year old falling above 75% of the distribution	US Census
Veh2_dummy	Indicator variable for zones with an average of 2 or more vehicles per household	US Census

Water rate history and presence of water use restrictions are also provided by CSU. The current schedule is comprised of three blocks and a fixed daily service charge. From this data, the marginal price and the difference variable are formulated for each observation. Marginal price is computed by determining the volumetric price residential users pay for the last unit of water consumed for a given month. Marginal price is given as an average marginal price per zone. As mentioned in the previous sections, it is suggested a difference variable is necessary to account for potential bias (Taylor 1975; Nordin 1976; Mieno & Braden 2011). The difference variable specified equals the price residents would pay for usage if all units of water were purchased at the marginal price minus the actual price residents pay. Both marginal price and the difference variable are adjusted monthly for inflation to December 2009 U.S. dollars using the Bureau of Labor Statistics' consumer price index inflation calculator. The two variables are lagged one period to allow for a time lapse between residential use and receipt of the water bill, as suggested by previous studies (Renwick & Archibald, 1998).

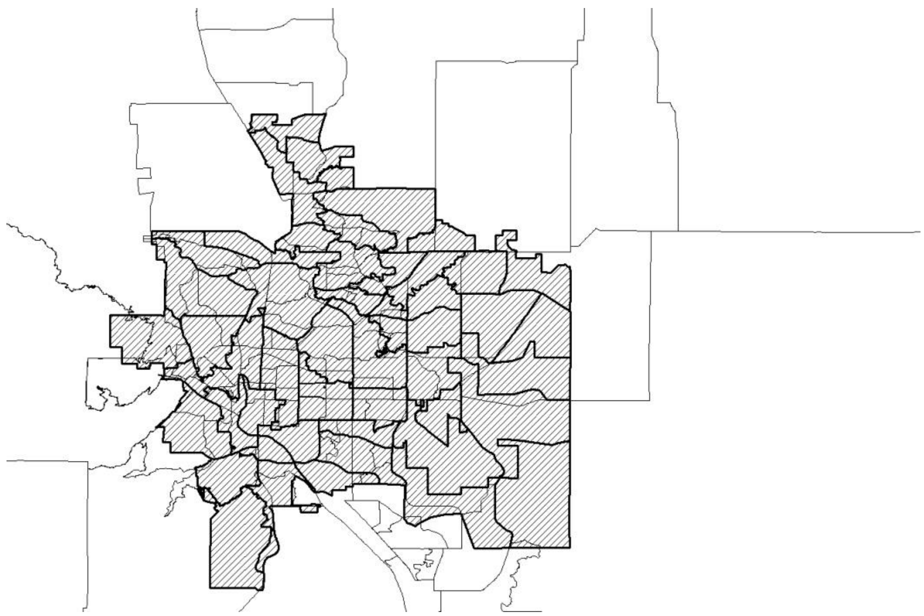
It was during the study period CSU transitioned from flat rate to increasing block rate pricing schedules. The time periods during which residential customers paid a flat rate are January 2000 to June 2002, and the winter months (November to April) for the period July 2002 to April 2006. In order to account for the presence or lack thereof of increasing block rate pricing an indicator variable is included in the model signifying time under increasing block rates.

Climatological data are gathered from the Colorado Climate Center (Colorado State University). Using point-based data for the City of Colorado Springs, average precipitation and mean temperature are given for every month of the study. It is suggested from previous studies residential water users will consume more water during the summer months for such things as irrigation, and therefore an indicator variable signifying summer months (June to September) is utilized in the model (e.g. Mieno & Braden, 2011). In order to provide climatological data for all one hundred twenty months of the study it was necessary to use a single point-based data estimate for the City of Colorado Springs. The flaw of such estimation is the lack of specific data for different zones within the city, however due to lack of availability city-wide estimates are the most feasible.

Demographic data are gathered from the 2000 US Census, for the time period of January 2000 to December 2004, and the American Community Survey five-year estimates, for the period of January 2005 to December 2009. The data are population averages for such things as median household income and average education level, by census tracts; small subdivisions of the county meant to be relatively homogenous and permanent. Because census tract estimates do not align the water consumption zones provided by CSU we use ArcGIS (Geographic Information System) software to produce relevant estimates. US Census tract data are aggregated into CSU water consumption blocks and averaged. This method consisted of overlaying both 2000 and 2009 census tracts with the water consumption zones. Once overlaid, estimates per zone are acquired by computing averages of all census tracts with significant proportions of their area within the boundary of a given zone. Figure 4.1 presents a map of both census tracts and water consumption zones. A potential flaw in using this methodology is the failure to account for the relative weighting of each census tract within a given consumption zone. Although this can potentially lead to false estimates of demographic data, given the lack of shared boundaries between the US census tracts and CSU water consumption zones, the technique used is the most feasible method[1].

FIGURE 4.1

EL PASO COUNTY CENSUS TRACTS AND CSU WATER CONSUMPTION ZONES



Water consumption zones, provided by CSU are outlined in black and shaded gray, US census tracts are in the background and outlined in gray. Source: CSU and US Census, map overlay created by author.

Demographics from the US Census employed are average median household income for the past twelve months (inflation adjusted to 2009 dollars), average household size (i.e. number of people per residence), average household value (inflation adjusted to 2009 dollars), average renter occupancy rate, average numbers of vehicles per household, average range of years homes were built, and average education levels both for the population ages 18-24, and separately, 25 and older.

[1] The other possibility for aggregating demographic data is to compute weighted averages each census tract within a given water use zone, however, this alternative process does not account for population density, and is potentially no more or less reliable than the method chosen.

Due to the assumption of non-linear relationships, indicator variables are used for the following data: average median age, average education level, the average year homes were built, and average number of vehicles. For average median age two indicator variables are created for areas with average ages above the 75^{th} percentile and below the 25^{th} percentile. For the average year homes were built an indicator variable is included for areas with the average year built of homes of 1980 or later. Education levels, both for 18-24 year olds and 25 years and older, were broken into indicator variables each, similar to those created for average age. For each age group there are indicator variables with areas with average education above the 75^{th} percentile and below the 25^{th} percentile[2]. A final indicator variable is included to signify zones with an average of homes owning two or more vehicles.

During the time period of the study there are two significant changes in the environment which are assumed to affect residential water consumption. The first change is the presence of a great drought in the American Southwest which began in 2002. It is debatable as to whether the American Southwest is still experiencing the presence of this drought; because of this we introduce an indicator variable signifying months during which CSU imposed water restrictions as a catch-all for both residents response to drought, and effectively of water restrictions.

The second notable environmental change during this period is the onset of the Great American Recession. We assume the onset of recession causes decreased expenditures, and possibly decreasing water consumption. The precise dates for the start and end of the Recession are acquired from the National Bureau of Economic Research

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[2] The above indicator variables may seem arbitrary, however due lack of previous specifications and similar data sets, quartiles were determined to be the most obvious break points.

(NBER). NBER defines recession as a time of significant economic decline, typically observed for many months through such factors as Gross Domestic Product, employment, production, and real income[3]. An indicator variable is included for the periods specified: March to November 2001, and December 2007 to June 2009. For the periods listed the indicator variable has a value of one and in all other instances zero.

Summary statistics of the endogenous variable and exogenous variables described above are provided in the table below.

[3] The National Bureau of Economic Research. (2013). U.S. Business Cycle Expansions and Contractions. *NBER*. Accessed January 2013, from http://www.nber.org/cycles.html.

TABLE 4.2

VARIABLE SUMMARY STATISTICS

Variable Name	Observations	Mean Value	Standard. Deviation	Minimum Value	Maximum Value
Ln (Average Residential Water Consumption)	4555	7.2190	0.5286	4.3976	9.4051
Ln (Median Household Income)	4555	11.0563	0.3773	10.1776	11.6463
Marginal Price	4515	0.0242	0.0077	0.0005	0.0621
Difference Variable	4515	6.5094	11.0734	0	70.7977
Precipitation	4555	11.6995	13.2884	0.2	60.1
Temperature	4555	49.6067	14.9292	23	75.8
Average Household size	4555	2.5589	0.3591	1.71	3.51
Average Rented Housing Units	4555	32.7002	15.3612	6.75	71.4
Average Value	4555	235164.3000	82798.5300	117438.2	479800
Increasing Block Rate Dummy	4555	0.5644	0.4959	0	1
Recession Dummy	4555	0.2382	0.4260	0	1
Water Restrictions Dummy	4555	0.3267	0.4690	0	1
Summer Dummy	4555	0.3361	0.4724	0	1
Year Built (1980) Dummy	4555	0.4494	0.4975	0	1
Average Age (25th percentile) Dummy	4555	0.2494	0.4327	0	1
Average Age (75th Percentile) Dummy	4555	0.2569	0.4370	0	1
Average Education 25+ (25th Percentile) Dummy	4555	0.2634	0.4406	0	1
Average Education 25+ (75th Percentile) Dummy	4555	0.2373	0.4255	0	1
Average Education 18-24 (25th Percentile) Dummy	4555	0.2465	0.4310	0	1
Average Education 18-24 (75th Percentile) Dummy	4555	0.2481	0.4319	0	1
Average Vehicles 2+ Dummy	4555	0.2909	0.4542	0	1

CHAPTER 5

ANALYSIS AND RESULTS

The study analyzes a panel data set covering the ten year period January 2000 to December 2009, with observations of 40 water use zones over 120 months. The demand equation specific to this model is as follows:

$$ln(Y_{zt}) = \beta_0 + \beta_1 ln(MHI)_{zt} + \beta_2 MP_{zt} + \beta_3 D_{zt} + \beta_4 Temp_{zt} + \beta_5 Precip_{zt} + \beta_6 HS_{zt} + \beta_7 Rent_{zt} + \beta_8 Value_{zt} + \beta_9 IBR\_dummy_{zt} + \beta_{10}\, Recession\_dummy_{zt} + \beta_{11} WR\_dummy_{zt} + \beta_{12} Summer\_dummy_{zt} + \beta_{13} YB1980\_dummy_{zt} + \beta_{14} Age25\_dummy_{zt} + \beta_{15} Age75\_dummy_{zt} + \beta_{16} ED25\_25\_dummy_{zt} + \beta_{17} ED25\_75\_dummy_{zt} + \beta_{18} ED18\_25\_dummy_{zt} + \beta_{19} ED18\_75\_dummy_{zt} + \beta_{20} Veh2\_dummy_{zt} + \mu_z + e_{zt}$$

Where Y is water consumption, β is the coefficient of correlation for independent variables, μ is the unknown intercept for each water use zone, e is the error term, z is the water use zone, and t is time. Independent variables are described in Table 4.1.

The characteristics of the panel data set allow for a fixed-effects regression analysis to determine the variability of water consumption explained by the exogenous variables of each panel. As suggested by Mieno and Braden (2011), this technique is the most relevant for the acquired data because individual zones likely have distinct characteristic affecting water demand that are unable to be measured. A fixed-effect regression provides a measure of the unobserved difference between panels, or zones, expressed by the error term μ. The use of a fixed-effects model also controls for time-invariant variables, many of which are present in the model[1].

Testing Model Assumptions

Prior to regressing the data a correlation matrix is assembled to observe possible instances of multicollinearity and autocorrelation. From this matrix many instances of correlation are found among the exogenous variables, and between the endogenous variable and exogenous variables. Although these correlations are not surprising[2], it is necessary to test for flaws in the model and correct them.

The initial regression performed is a simple fixed-effect regression utilizing all of the above exogenous variables. The results are listed in the table below.

From the initial fixed-effect regression the value of *rho*, or interclass correlation, is 0.904, indicating 90.4% of the variance in water consumption is due to differences across panels. The interpretation of this high *rho* value is that the unexplained differences between panels have a high influence on differences in water demand across zones. Community characteristics, average lot sizes, and prevalence of conservation programs are just a few possible factors influencing differences not measured by the study, thus high interclass correlation is not surprising.

[1] E.g. demographic indicators gathered from the US Census.
[2] E.g. Median household income is highly correlated with water consumption, average household size, average value, year built, certain education indicators, and number of vehicles per residence.

TABLE 5.1

PRELIMINARY FIXED-EFFECTS REGRESSION RESULTS

Exogenous Variable	*Correlation Coefficient*	*Standard Error*
ln (median household income)	0.8504***	(0.0833)
Marginal Price+	-1.5295	(1.1816)
Difference Variable+	0.0040***	(0.0008)
Precipitation	-0.0019***	(0.0004)
Temperature	0.0236***	(0.0005)
Average Household size	0.0262	(0.0919)
Average Rented Housing Units	0.0085***	(0.0018)
Average Value	-0.0000***	(0.0000)
Increasing Block Rate Dummy	-0.0683***	(0.0111)
Recession Dummy	-0.0006	(0.0105)
Water Restrictions Dummy	-0.1190***	(0.0101)
Summer Dummy	0.1293***	(0.0158)
Year Built (1980) Dummy	1.4056***	(0.2730)
Average Age (25th percentile) Dummy	0.0093	(0.0262)
Average Age (75th Percentile) Dummy	-0.0003	(0.0196)
Average Education 25+ (25th Percentile) Dummy	-0.0052	(0.0252)
Average Education 25+ (75th Percentile) Dummy	0.1109**	(0.0560)
Average Education 18-24 (25th Percentile) Dummy	0.0248	(0.0222)
Average Education 18-24 (75th Percentile) Dummy	-0.0242	(0.0173)
Average Vehicles 2+ Dummy	0.0577	(0.0716)
Constant	-3.6926***	(0.8503)
Within R^2	0.6996	
Between R^2	0.0034	
Overall R^2	0.1516	
F-statistic	518.86	
Probability > F	0	
Observations	4515	

*** significant at 99 percent confidence level, ** significant at 95 percent confidence level, * significant at 90 percent confidence level.

+ Marginal Price and the Difference Variable are lagged one period to avoid contemporaneous correlation with the endogenous variable.

Non-normality of the error term is tested for by plotting the residuals of the initial fixed-effects regression, although the distribution appears relatively normal, through testing the inner-quartile range, Table 5.2, we recognize outliers with influence are present. Through running the model with Driscoll-Kraay errors however, non-normality of errors and any potential bias is removed.

TABLE 5.2

TEST FOR NON-NORMALITY OF ERROR TERM

	Fixed-effects w/ Standard errors		**Fixed-effects w/ Driscoll and Kraay Standard Errors**[3]	
	low	*high*	*low*	*high*
Inner Fences	-0.6177	0.6148	4.101	10.25
Mild Outliers (#)	43	67	0	0
Mild Outliers (%)	0.95%	1.48%	0.00%	0.00%
Outer Fences	-1.08	1.077	1.794	12.56
Severe Outliers (#)	9	7	0	0
Severe Outliers (%)	0.20%	0.16%	0.00%	0.00%

The following tests are performed on this initial regression to determine whether estimators are best and unbiased. The results of the following tests are listed in the table below:

- A Hausman test is run first to determine whether a fixed or random-effects regression is best suited to the panel data. The results of the Hausman test give an F-statistic of 49.28 with a probability of 0.000. This rejects the

[3] Inner quartile range and test presented here are performed on the 2nd of the fixed-effects analyses presented in Table 5.4.1

null hypothesis that a random-effects model is superior for this data set, thus a fixed-effect regression is preferable.

- A Wooldridge test for autocorrelation in panel data is performed. The results indicate an F-statistic of 25.861 indicating the presence of autocorrelation in the model.
- A Modified Wald test for groupwise heteroskedasticity is also performed, and indicates a strong presence of heteroskedasticity.
- A Pesaran's test of cross sectional independence is performed, which also shows negative results.

The nature of the data set makes the acquisition of more data, or exogenous variables, to correct for the above problems, difficult. Therefore we analyze the data with Driscoll and Kraay standard errors which correct for heteroskedasticity, autocorrelation, and cross sectional dependence in panel data (Hoechle, 2007).

TABLE 5.3

TESTING MODEL ASSUMPTIONS

Hausman Test for Fixed-effects	F –statistic (39,4455) Probability > F	49.28 0
Wooldridge test for autocorrelation in panel data	F –statistic (1, 39) Probability > F	25.86 0
Modified Wald test for Groupwise Heteroskedasticity	chi2 (40) Probability >chi2	2324.33 0
Pesaran's test of cross sectional independence	Cross-sectional Dependence Probability>CD	113.84 0

Fixed-Effects with Driscoll-Kraay Standard Errors

Proceeding with a fixed-effect regression estimating for Driscoll and Kraay standard errors, allows the best estimation of the data set in question. However, there are still many instances of collinear independent variables. While monotonic transformations of correlated variables can correct for biased estimators, transformations obscure the relationship these variables have on the water consumption. Instead of relying on this technique we test for robustness by running a series of several analyses. This allows for multiple observations of certain exogenous variables' effects on the endogenous variable, as well as variations in the explanatory power of certain exogenous variables based on the inclusion or exclusion of other explanatory variables.

Seven fixed-effects regression analyses are conducted on the data set with Driscoll-Kraay standard errors. The first regression isolates marginal price to determine the explanatory power of price on water consumption.[4] We assume five of the twenty exogenous variables are particularly important to the model, as per previous studies (e.g. Arbués et al., 2003). These five primary variables are median household income, marginal price, the difference variable, precipitation, and temperature.

Marginal price, which is suggested to have a significant effect on water demand, is, as shown below, found to be insignificant. Possible reasons for this insignificance are discussed below.

Average rental rate of zones is strongly negatively correlated with many of the other independent variables such as wealth and education levels, and is therefore

[4] Because marginal price is found to be insignificant in subsequent regressions, this initial analysis is conducted in a step-wise fashion to determine what if any significance marginal price has on this model

removed from the subsequent analyses. The two variables average household value and average household size are analyzed together with the five primary variables.

Each of the indicator variables signifying changes in environment (increasing block rates, recessions, water restrictions, and summer months) are analyzed in isolation with the five primary independent variables to determine their specific influence. The US Census indicator variables are regressed with the five primary independent variables, and again with the exclusion of median household income which is highly collinear with multiple of the demographic indicators.

Results are listed in the tables below. For each regression there are 4,515 total observations. There are forty unbalanced zones, or panels, with a maximum of 119 observations per group, a minimum of 33 observations per group, and average of 112.9 observations per group. The fixed-effect regression technique used is able to deal with unbalanced panels and does not cause biases within the results.

The first regression, examining lagged marginal price in isolation indicates price is significant in explaining variability of consumption but with little explanatory power, demonstrated by the within group R^2 of only 0.0926. Subsequent regressions including other exogenous variables show marginal price as insignificant. These results are surprising as previous studies have had significant results using similar estimation techniques (e.g. Arbués et al, 2004; Mieno & Braden 2011).

Of the five primary exogenous variables selected median household income and temperature are positively significant at the 99th percentile. As expected increases in income explain increases in water usage. The coefficients of correlation suggest a nearly one-to-one relationship between water consumption and median income. [5] As mentioned above, previous studies suggest the demand function for water is likely non-linear (i.e. Arbués et al., 2004).The log-log relationship between water consumption and median income, and the log-linear relationships between consumption and all other exogenous variables are expected to correct for this non-linearity. The results suggest increases in temperature translate to increases in water usage, this is expected as residential households will use more water for irrigation and other similar uses in warmer weather.

Marginal price and the difference variable, as discussed above, are insignificant, as is precipitation. The insignificance of precipitation is likely due to the lack of more specific data. While a single point source for the entire city proves an effective measure of temperature, the data appear too broad of estimates for determining the effect of precipitation.

The correlation coefficient of average household size is insignificant, and moves from positive to negative when median income is excluded. Although household size was hypothesized to lead to increases in usage, the results suggest it explains little of the variability in residential water consumption. Average size of household (number of residents) is shown to have a negative relationship with water consumption with 99% significance. Although the correlation coefficient of value is miniscule the implication is that a $500,000 increase in average household value translates to a roughly 1% decrease in water consumption.[6] As mentioned previously, the relationship is likely non-linear,

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[5] The coefficients of correlation for ln(median household income) range between 0.8504 and 0.9872, the log-log relationship between water consumption and income implies a 1% increase in income translates to anywhere between a 0.85-0.99% increase in residential water consumption.

[6] The coefficient of correlation on average household value is equal to -0.00000223. Therefore a $1 increase in household value relates to a 0. 00000223% decrease in water use, or a $1,000,000 increase in household value will translate to a 2.23% decrease in usage.

however this is an indicator of how the two variables react. As assumed by the hypothesis, more expensive homes are suggested to use less water, likely due to heightened presence of water efficient technologies. Further research could be conducted to see the effect household size in square feet, as well as lot size play on water consumption, as these results would better explained household characteristics and their effects on water consumption.

Of the changes in environment indicator variables, the presence of increasing block rates and water use restrictions are negatively significant at the 95% confidence level, and summer months are positively significant also at the 95% level. The coefficient on the indicator variable for time periods of recessions, although hypothesized to be negative, is positive but insignificant. The three significant changes in environment indicator variables react as hypothesized. Water use restrictions and increasing block rates are both suggested to cause decreases in residential water usage, while during summer months residential water use is suggested to increase use.

The U.S. Census demographic and household characteristics indicator variables, in general, have greater explanatory power without the presence of median household income, as indicated in the 7^{th} analysis. This is not surprising, due to multiple instances of strong correlation between these indicator variables and income. From this analysis the coefficients of correlation for the indicator variables for zones with averages of homes bought after 1980, zones with average ages below the 25^{th} percentile, and zones with average education levels for 18-24 year-olds below the 25^{th} percentile, are all positive and significant at the 99% level. The coefficients for indicator variables for zones with average education of 18-24 year-olds above 75^{th} percentile, and zones with averages of two or more vehicles are negative and significant at the 99% level. Of these results the most surprising is the effect of more recently built homes on water consumption. We assumed modern homes would include more water efficiency, but these results suggest otherwise.

It is hypothesized increases in education lead to decreases in water consumption. This hypothesis is confirmed by significant coefficients for the 18-24 year-old age group, but refuted, albeit insignificantly, for the 25 and older group. Although the coefficients are generally insignificant for the older age group, the relationship is likely due to the positive correlation between higher education and increased income.

Homes with two or more vehicles are suggested to have decreased water demand. These results are contrary to the hypothesis which assumed number of vehicles is almost directly related to wealth, and would translate to increases in water usage. The results suggest the opposite. The following section discusses the results and their implications.

TABLE 5.4.1

FIXED-EFFECTS REGRESSION WITH DRISCOLL-KRAAY STANDARD ERRORS

Exogenous Variable	***1st***		***2nd***		***3rd***	
	Correlation Coefficient	***Driscoll-Kraay Standard Error***	***Correlation Coefficient***	***Driscoll-Kraay Standard Error***	***Correlation Coefficient***	***Driscoll-Kraay Standard Error***
ln (median household income)			0.8504***	(0.1572)	0.9872***	(0.2510)
Marginal Price+	19.2041***	(5.7977)	-1.5295	(3.4600)	0.8927	(3.4317)
Difference Variable+			0.0040**	(0.0018)	0.0013	(0.0021)
Precipitation			-0.0019*	(0.0010)	-0.0010	(0.0012)
Temperature			0.0236***	(0.0018)	0.0257***	(0.0013)
Average Household size			0.0262	(0.0808)		
Average Rented Housing Units			0.0085***	(0.0028)		
Average Value			-0.0000***	(0.0000)		
Increasing Block Rate Dummy			-0.0683*	(0.0359)		
Recession Dummy			-0.0006	(0.0384)		
Water Restrictions Dummy			-0.1190***	(0.0394)		
Summer Dummy			0.1293**	(0.0530)		
Year Built (1980) Dummy			1.4056***	(0.0970)		
Average Age (25th percentile) Dummy			0.0093	(0.0159)		
Average Age (75th Percentile) Dummy			-0.0003	(0.0210)		
Average Education 25+ (25th Percentile) Dummy			-0.0052	(0.0186)		
Average Education 25+ (75th Percentile) Dummy			0.1109***	(0.0345)		
Average Education 18-24 (25th Percentile) Dummy			0.0248	(0.0162)		
Average Education 18-24 (75th Percentile) Dummy			-0.0242**	(0.0091)		
Average Vehicles 2+ Dummy			0.0577	(0.0569)		
Constant	6.7571***	(0.1624)	-3.6926*	(1.8948)	-4.9911*	(2.7957)
Within R^2	0.0926		0.6996		0.6691	
F-statistic	10.97		155.5		129.66	
Probability > F	0.002		0		0	

*** significant at 99 percent confidence level, ** significant at 95 percent confidence level, * significant at 90 percent confidence level.

+ Marginal Price and the Difference Variable are lagged one period to avoid contemporaneous correlation with the endogenous variable.

TABLE 5.4.2

FIXED-EFFECTS REGRESSION WITH DRISCOLL-KRAAY STANDARD ERRORS

Exogenous Variable	***4th***		***5th***	
	Correlation Coefficient	***Driscoll-Kraay Standard Error***	***Correlation Coefficient***	***Driscoll-Kraay Standard Error***
ln (median household income)	0.9218***	(0.2294)	0.8556***	.171935
Marginal Price[+]	0.1587	(3.1827)	-0.8579	3.517803
Difference Variable[+]	0.0030	(0.0018)	0.0028	.0017397
Precipitation	-0.0011	(0.0013)	-0.0017*	.0009942
Temperature	0.0255***	(0.0013)	0.02410***	.0018546
Average Household size	-0.0243	(0.0437)		
Average Rented Housing Units				
Average Value	-0.0000***	(0.0000)		
Increasing Block Rate Dummy			-0.1079**	.0408952
Recession Dummy			0.0017	.0404423
Water Restrictions Dummy			-0.0930**	.0357828
Summer Dummy			0.1317**	.0535961
Year Built (1980) Dummy				
Average Age (25th percentile) Dummy				
Average Age (75th Percentile) Dummy				
Average Education 25+ (25th Percentile) Dummy				
Average Education 25+ (75th Percentile) Dummy				
Average Education 18-24 (25th Percentile) Dummy				
Average Education 18-24 (75th Percentile) Dummy				
Average Vehicles 2+ Dummy				
Constant	-3.6589	(2.5592)	-3.3658*	1.900185
Within R^2	0.6752		0.6899	
F-statistic	102.97		138.83	
Probability > F	0		0	

*** Significant at 99 percent confidence level, ** significant at 95 percent confidence level, * significant at 90 percent confidence level.

[+] Marginal Price and the Difference Variable are lagged one period to avoid contemporaneous correlation with the endogenous variable.

TABLE 5.4.3

FIXED-EFFECTS REGRESSION WITH DRISCOLL-KRAAY STANDARD ERRORS

Exogenous Variable	***6th***		***7th***	
	Correlation Coefficient	***Driscoll-Kraay Standard Error***	***Correlation Coefficient***	***Driscoll-Kraay Standard Error***
ln (median household income)	0.9041***	(0.2343)		
Marginal Price+	0.5160	(3.2566)	-0.1498	(3.5882)
Difference Variable+	0.0023	(0.0019)	0.0015	(0.0022)
Precipitation	-0.0011	(0.0013)	-0.0009	(0.0013)
Temperature	0.0256***	(0.0013)	0.0258***	(0.0013)
Average Household size				
Average Rented Housing Units				
Average Value				
Increasing Block Rate Dummy				
Recession Dummy				
Water Restrictions Dummy				
Summer Dummy				
Year Built (1980) Dummy	1.2653***	(0.1063)	1.3471***	(0.1138)
Average Age (25th percentile) Dummy	0.0940***	(0.0181)	0.1179***	(0.0200)
Average Age (75th Percentile) Dummy	-0.0122	(0.0210)	-0.0758**	(0.0304)
Average Education 25+ (25th Percentile) Dummy	-0.0126	(0.0162)	-0.0230	(0.0154)
Average Education 25+ (75th Percentile) Dummy	0.0514	(0.0376)	0.0700*	(0.0373)
Average Education 18-24 (25th Percentile) Dummy	0.1207***	(0.0341)	0.1259***	(0.0348)
Average Education 18-24 (75th Percentile) Dummy	-0.0117	(0.0083)	-0.0369***	(0.0131)
Average Vehicles 2+ Dummy	-0.1861***	(0.0281)	-0.1948***	(0.0301)
Constant	-4.6293*	(2.6104)	5.3515***	(0.0992)
Within R^2	0.676		0.6639	
F-statistic	136.83		142.72	
Probability > F	0		0	

*** significant at 99 percent confidence level, ** significant at 95 percent confidence level, * significant at 90 percent confidence level.

+ Marginal Price and the Difference Variable are lagged one period to avoid contemporaneous correlation with the endogenous variable.

Chapter 6

Conclusion & Discussion

As water resources are becoming more and more scarce proactive steps must be taken to ensure long-term sustainability of our water. Understanding residential water demand is a fundamental part of this process. Although residential demand typically makes up a small share of water usage, only 22-26% in the Colorado River Basin, it is the fastest growing sector of water demand[1], and one in which many changes can be made. Unlike agricultural production where it is extraordinarily difficult to alter the amount of water used without reducing crop yields, the amount of water used per residence can vary greatly without significant changes. Of the many techniques and technologies available to influence water demand, it is suggested by Olmstead and Stavins (2009), the most effective measures are price-based approaches.

This paper pursues a review of water pricing theory to examine how and why water is priced the way it is, and furthermore how best to price the resource for effective conservation. The paper reviews previous water demand studies to determine both the effectiveness of changes in prices on altering water demand, and the discovery of other factors relevant to the demand equation. Finally, we pursue a water demand study of our

[1] [1] U.S. Department of the Interior, Bureau of Reclamation. (2012). Colorado River Basin Water Supply and Demand Study. Accessed January 2013, from http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html.

own based on monthly water consumption averages for forty water usage zones within Colorado Springs over a ten-year period.

Effective water pricing has many considerations, the two prevailing theories for long-term, conservation-oriented pricing emphasized here are presented by Rodgers et al., (1998), and Beecher and Shanaghan (2006). First, effective pricing ought to take into account the full price of the resource: this includes recognition of opportunity costs for other users of the resource, and economic and environmental externalities caused by use. These costs along with operational, maintenance and capital costs, typically recognized by water providers, if correctly implemented, will encourage effective use of the resource by giving users a proper valuation of their water (Rodgers et al., 1998).

In line with recognizing full costs, four considerations are suggested by Beecher and Shanaghan (2006) to ensure sustainability of water supply. These considerations are: efficiency, viability, equity, and optimality. The authors suggest these four pillars of water pricing will ensure the resource is provided at the least cost means possible, while full price is recognized, necessary access is provided, and both water providers and users recognize amounts so that long-term sustainability of supply is possible.

However relevant these theories are, it is necessary to recognize that a full accounting of such measures is currently idealistic. Strategies to correctly recognize costs of environmental externalities are possible as discussed by Murphy (2003), but there are enormous challenges.

Moving from theoretical to empirical, the many previous studies on water demand have produced important results. The majority of cases suggest water demand is relatively price inelastic (Billings & Agthe, 1980; Arbués et al., 2003), higher income customers tend to be less responsive to changes in price (Mieno & Braden, 2011; Ruis et al., 2008), and customers tend to be more responsive to changes in water prices during the summer months (Mieno & Braden, 2011). Using the findings, and specifications of these, and other, studies this paper studies factors influencing water demand in Colorado Springs, Colorado.

A fixed-effect regression with Driscoll-Kraay standard errors is used to analyze a panel data set for forty usage zones, over a ten year period. It is suggested median household income, temperature, household value, the presence of water use restrictions, the presence of increasing block rates, education level of 18-24 year olds, and the average number of vehicles per household are the most significant exogenous variables for explaining the variation in water demand. There is a high instance of the unobservable error term across panels, suggesting each water use zone has distinct differences affecting water use not measured by the included variables.

From these results a number of conclusions can be drawn. The results presented here, in agreement with many previous studies, suggest wealthy households are less responsive to changes in prices (e.g. Renwick & Archibald, 1998). We see this manifest through positive significant coefficients for median household income and average value. The negative significant coefficient on number of vehicles per household however, indicates that not all measures of wealth translate to increased water use. Further studies analyzing lot sizes and other household characteristics of wealth would be useful to better determine the relationship between wealth and water use in a residential setting. Perhaps steeper increases between blocks would deter wealthier customers from excessive water use. While it is likely lower income customers would not be effected by higher end increases in water use, steeper blocks would still allow for non-discretionary residential use, but send stronger price signals to wealthier customers.

Similar to Mieno and Braden's (2011) study, it is suggested residential customers' demand is increased during summer months. Seasonal increases in pricing blocks can potentially capitalize on these increases in usage and encourage decreases in peak water usage during the summer months.

Regarding education, the results indicate that higher education for the 18-24 year old group leads to decreases in residential water use, while the higher education of the population 25 and older may lead to increases in usage. In order to bring about more effective conservation measures in the Colorado River Basin, this study proposes increases investment in educating the younger generation. The results suggest increases in the education of young adults will result in decreases in water use. The study also supports the use of increasing block rates and water use restrictions for decreasing residential water demand.

Looking back to the Colorado River Basin, as supply threatens to exceed demand, action is required to ensure the sustainability of water supply into the future. Water use restrictions, increased presence of block rate pricing schedules, and increased investment in education are all critically important to improve conservation of water as populations continue to grow in the American West. It is also essential that better accounting measures for the full costs of water are employed. If opportunity costs and externalities are factored into increasing block schedules in a way that the higher block users pay these costs, similar to the way higher block users subsidize lower block users in Colorado Springs, overall residential water usage could decrease.

The high value of the unobservable error term begs questions. There is room for future studies on high income residential customers, further studies on the impact of lot sizes and irrigated area, average square footage of residences, the presence of water conservation programs already in place, and information provided by residential water bills are all important aspects of water demand still to be explored.

Chapter 7

Sources Consulted

Arbués, F., García-Valiñas, M. Á., & Martínez-Espiñeira, R. (2003). Estimation of residential water demand: A state-of-the-art review. *Journal of Socio-Economics, 32*(1), 81-102.

Arbués, F., Barberán, R., & Villanúa, I. (2004). Price impact on urban residential water demand: A dynamic panel data approach. *Water Resources Research, 40*(11), W11402.

Beecher, J. A., & Shanaghan, P. E. (2011). Sustainable water pricing. *Journal of Contemporary Water Research and Education, 114*(1), 4.

Billings, R. B., & Agthe, D. E. (1980). Price elasticities for water: A case of increasing block rates. *Land Economics, 56*(1), 73-84.

Boland, J. J., & Whittington, D. (2000). Increasing block tariffs versus uniform price with rebate. *The Political Economy of Water Pricing Reforms,* , 215.

Dalhuisen, J. M., Florax, R. J. G. M., de Groot, H. L. F., & Nijkamp, P. (2003). Price and income elasticities of residential water demand: A meta-analysis. *Land Economics, 79*(2), 292-308.

De Azevedo, L. G. T., & Baltar, A. M. (2005). Water pricing reforms: Issues and challenges of implementation. *International Journal of Water Resources Development, 21*(1), 19-29.

Down the River Expedition. (2012) From Source to Sea, *The State of the Rockies Project*. Accessed January 2013 from http://www.coloradocollege.edu/other/stateoftherockies/source-to-sea/.

Mieno, T., & Braden, J. B. (2011). Residential demand for water in the chicago metropolitan area. *Journal of the American Water Resources Association, 47*(4), 713-723. doi: 10.1111/j.1752-1688.2011.00536.x

Murphy, J. J., Dinar, A., Howitt, R. E., Rassenti, S. J., Smith, V. L., & Weinberg, M. (2009). The design of water markets when instream flows have value. *Journal of Environmental Management, 90*(2), 1089-1096.

Nataraj, S., & Hanemann, W. M. (2011). Does marginal price matter? A regression discontinuity approach to estimating water demand. *Journal of Environmental Economics and Management, 61*(2), 198-212.

The National Bureau of Economic Research. (2013). U.S. Business Cycle Expansions and Contractions. *NBER*. Accessed January 2013, from http://www.nber.org/cycles.html.

Nordin, J. A. (1976). A proposed modification of taylor's demand analysis: Comment. *The Bell Journal of Economics,* , 719-721.

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

Renwick, M. E., & Archibald, S. O. (1998). Demand side management policies for residential water use: Who bears the conservation burden? *Land Economics,* , 343-359.

Rogers, P., Bhatia, R., & Huber, A. (1998). *Water as a social and economic good: How to put the principle into practice* Global Water Partnership/Swedish International Development Cooperation Agency.

Rogers, P., De Silva, R., & Bhatia, R. (2002). Water is an economic good: How to use prices to promote equity, efficiency, and sustainability. *Water Policy, 4*(1), 1-17.

Ruijs, A., Zimmermann, A., & van, d. B. (2008). Demand and distributional effects of water pricing policies. *Ecological Economics, 66*(2), 506-516. doi: 10.1016/j.ecolecon.2007.10.015

Saleth, R. M., & Dinar, A. (1997). *Satisfying urban thirst: Water supply augmentation and pricing policy in hyderabad city, india* World Bank Publications.

Sibly, H. (2006). Efficient urban water pricing. *Australian Economic Review, 39*(2), 227-237.

Taylor, L. D. (1975). The demand for electricity: A survey. *The Bell Journal of Economics, 6*(1), 74-110.

US Department of the Interior Bureau of Reclamation. (December 2012). Colorado river basin water supply and demand study.