THESIS

HETEROGENEITY IN THE PRICE ELASTICITY OF DEMAND FOR COMMERCIAL WATER

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2018

Master's Committee:

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ABSTRACT

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The gap between projected future water demand and supply are increasing the importance of conservation policies. Commercial users are a major source of utility withdrawals, heightening the need for increased understanding of commercial responsiveness to utility policies. Despite an abundance of empirical studies on residential water demand, there are limited commercial sector studies exploring demand elasticity heterogeneity. In this paper, we estimate commercial water demand elasticity for firms served by a local utility, employing a novel instrumental variables approach. We then present evidence that firms respond to one period lagged average price rather than marginal price. Finally, we find notable differences in elasticity among different categories of businesses and among businesses of different consumption variance levels. The findings in this paper are particularly important as utility providers across the country consider how to cope with growing demand and limited water supply.

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CHAPTER 1: INTRODUCTION

The Colorado Water Conservation Board's 2010 Colorado Statewide Water Supply Initiative warns that by 2050 Colorado will face a significant gap between municipal/industrial water demand and supply. This gap will be between 190,000 and 630,000 acre-feet depending on the success of projects anticipated to increase supply (Colorado Water Conservation Board (2010)). This gap, in both Colorado and other states, has generated substantial interest in water conservation among utilities and policy makers. In fact, the 2010 Statewide Water Supply Initiative identifies conservation as one of the key strategies for meeting the gap.

Despite the growing need for, and increasing use of water conservation programs, and the abundance of literature focused on residential water demand, relatively little is known about how commercial users respond to utility policies. Yet, the commercial sector demands 30-40 percent of total public water supply on average across American cities (Renzetti 2015). We add to the commercial water demand literature in four important ways. First, we estimate a commercial water demand elasticity using a new instrumental variable approach. Second, we are the first to our knowledge to find that firms respond to lagged average price using a test developed by Shin (1985). Third, we explore heterogeneity in commercial responsiveness to water prices across business categories. Finally, we show that commercial sector demand elasticities vary based on within-firm water consumption variance.

Our paper has four main findings. First, we find that commercial customers of the local utility at the focus of this paper respond to changes in lagged average prices (mean elasticity of -0.80). Second, we present suggestive evidence that firms are responsive to lagged average price but not marginal price. Third, we estimate separate demand elasticities for thirteen commercial categories, and find variation in the elasticity estimates across the categories. In particular, we find some business types do not have a statistically significant price response (e.g., eating and drinking establishments, living spaces, and medical facilities) while others are exceptionally price responsive with elasticities as high as -1.18 (e.g., car washes and animal services). Finally, we find that businesses with low-consumption-variability do not respond to price signals (elasticity not statistically different from zero) while elasticity estimates for businesses with mid and high-consumption-variability are -0.82 and -0.95 respectively.[1]

Our research has important policy implications. As utility companies plan for continued growth in the number of premises drawing on a limited water supply, they would benefit from knowledge on how their commercial customers respond to conservation policies like price increases and how those responses differ among different classes of firms. Furthermore, if utilities are anticipating growth in certain types of businesses that are less (or not) price responsive, utilities can begin planning and testing non-price conservation strategies.

While much of the water demand literature explores the residential sector (see Sebri (2014) for a review of this literature), surprisingly little research has focused on the commercial sector. What empirical studies exist have some variation in the choice of elasticity estimation technique.[2] Lynne, Luppold and Kiker (1978), Renzetti (1992), Angulo et al. (2014), and Reynaud (2003) derive a demand curve through a partial differentiation of the cost function. Lynne, Luppold and Kiker (1978), one of the first studies to isolate commercial elasticities, find elasticities ranging from -0.174 (motels/hotels) to -1.074 (department stores) in Miami, FL,

[1] Consumption variability is defined as within-firm variance in billed consumption over the first 5 years of the study period (2001-2005).

[2] See the Appendix for a list of commercial water elasticity estimation studies and the corresponding elasticity estimates

though their OLS specification likely suffers from biased estimates. Renzetti (1992) derives demand from a trans-log cost function and finds price elasticities ranging from -0.153 (plastics and rubber sector) to -0.589 (pulp and paper sector) in the Canadian manufacturing sector using water intake data from 1981. Notably, this study is one of the earlier papers to model industrial water use as sum of four internal components: external water, treatment of intake, recirculation, and treatment/discharge of waste water. This approach allows Renzetti to estimate substitution elasticities among these various inputs. Angulo et al. (2014) also derives demand from a trans-log cost function to find insignificant elasticities in restaurants and bars-cafes and an elasticity of -0.375 in hotels in Zaragoza, Spain. Reynaud (2003) derives demand from the trans-log cost function to estimate elasticities ranging from -0.095 in the alcohol industry to -0.734 in the extractive industry in the Gironde district of France. Wang and Lalla (2002), on the other hand, derive the marginal productivity of water in the Chinese industrial sector from a Cobb-Douglas and two trans-log production functions.

Other studies, often constrained by limited data, strive for econometric consistency in their demand and elasticity estimation rather than deriving demand from a generalized cost minimization problem. Moeltner and Stoddard (2004) model demand using a random effects specification and estimate elasticities ranging from -0.045 in the eating and drinking sector to -0.141 in the amusement and recreation sector. This was also one of the first studies in the literature to use panel data over a long time horizon rather than aggregating consumption and price data annually like most previous studies. Kumar (2006) utilizes a trans-log input distance function to characterize demand in Indian manufacturing plants, finding elasticities ranging from -0.030 for the drug and pharmaceutical sector to -0.490 for the leather sector. Malla and Gopalakrishnan (1999) estimate elasticities ranging from -0.317 to -0.393 in the food processing sector of the city and county of Honolulu, HI. However, they model consumption as a function of only the real price of water and the number of employees, a more simplistic representation than most modern approaches. Deya-Tortella et al. (2016) use an instrumental variable quantile regression to estimate elasticities in hotels on the island of Mallorca, though their price terms are insignificant which they argue is due to water costs representing only a small share of total operational costs. The existing commercial water demand studies create a range of elasticity estimates of -0.12 (the petrochemicals sector in Renzetti (1988)) to -1.07 (department stores in Lynne, Luppold and Kiker (1978)).

Economic theory suggests that rational consumers respond to the marginal price of water. However, as Nieswiadomy and Molina (1991) point out, it is difficult for a consumer to know their marginal price in an increasing block rate pricing schedule, the type employed by the local utility and many other utilities across the country. This is because calculating marginal price requires routinely checking the water meter which is both potentially difficult to read and time consuming. Furthermore, as Kenney et al. (2008) point out, the unclear nature of a water bill makes it difficult to identify the marginal price of water. When the marginal benefit of ascertaining the marginal price is less than the expected marginal cost, argue Nieswiadomy and Molina (1991), a rational consumer will react to a proxy for marginal price, such as ex post calculated average price.

Of course, since we lack the data to know which price consumers truly respond to, there is room for debate on the appropriate price term. This debate has received considerable attention in the residential water demand literature (see Taylor (2008) for an early exploration of this issue in the residential electricity sector and Worthington and Hoffman (2008) for a review of this issue in the residential water literature). In the commercial sector, however, this debate has received much less focus. Some commercial studies opt for contemporaneous average price—Angulo et al. (2014), Reynaud (2003)—while others opt for marginal price—Kumar (2006), Moeltner and Stoddard (2004), Renzetti (1992), Renzetti (1993), Deya-Tortella et al. (2016). A few earlier commercial papers considered both marginal and average price. Williams and Suh (1986), for example, estimate demand with both prices, with elasticities ranging from -0.44 to -0.97. Similarly, Ziegler and Bell (1984) argue that average cost provides a better statistical fit and predictive power than marginal cost. However, notably absent from these commercial studies is substantial discussion or an explicit test to determine which price term is appropriate.

For this, we must turn to the residential water literature. It was in this literature that a test developed by Shin (1985) to test whether users respond to marginal or average price was first applied to water demand. Nieswiadomy and Molina (1991) used this test to find that residential water users respond to marginal price when facing an increasing block rate pricing structure but respond to the one-period lagged average price when facing a decreasing block rate structure. Applications of this test to the commercial sector are extremely limited, though Arbués, García-Valiñas and Villanúa (2010) found that customers do not respond to marginal or two-period lagged average price but rather a price somewhere below the marginal price.

We add to this limited commercial water demand literature by employing this test in our sample of commercial firms. To our knowledge, this is the first commercial water demand study in which the Shin (1985) test indicates firms respond to one-period lagged average price. We also employ a previously unused instrumental price variable in the commercial literature—one period lagged average price—and a previously unused instrument—the one period lag of the days of service (billed days). Finally, we explore heterogeneity in commercial demand elasticities across commercial sectors and by demand variance. To our knowledge, this is the first commercial water demand study to consider how variance level impacts elasticity.

The remainder of the paper is organized as follows: section 2 discusses data sources and cleaning, section 3 develops the econometric model, section 4 summarizes key findings, and section 5 offers concluding remarks.

CHAPTER 2: DATA AND STUDY SETTING

Our initial dataset includes 451,857 monthly firm-level water consumption observations across 2,996 commercial premises served by the local utility. Observations span from January 1, 2001 – December 31, 2016. The dataset includes consumption over the billing period, rate type, billing period dates, premise code, and customer code.

Duplicate observations, observations included only to reflect adjustments to previous billing information, observations with days of service (billing period) outside of the standard 20-40 day meter read schedule, observations with negative consumption values, observations with a lagged average price equal to 0, and observations with a consumption value between 0 and 10 gallons were removed for analysis.[3] Further, our primary specification uses lagged average prices, which means we cannot use consumption data from January 2001. Finally, our estimation strategy employs a rich set of fixed effects, which ultimately drops a handful of singleton observations, resulting in a final dataset of 364,979 observations across 2,956 premises.

In addition to estimating demand across all firms, we complete a business category-level analysis. To identify the business type of each customer, we were able to match Assessor parcel-level data to 1,633 of 2,956 commercial premises, or 251,721 observations.[45] The Assessor data includes information on square footage, square footage with sprinklers, age of the structure, and other related variables describing the physical characteristics of the parcel and associated

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[3] According to the local utility, the meters only record gallons consumed in increments of 10 gallons. Therefore, a consumption value between 0 and 10 reflects inaccurate data entry.

[4] The matching procedure was implemented in Stata. First, the Assessor data was matched to a file linking the Assessor parcel ID to the premise ID assigned to each water user by the local utility. Then, this file was matched to the water data, thereby assigning parcel characteristics to each premise.

[5] Note that this smaller file of 251,721 observations is used to estimate demand by business type, but the larger file of 364,979 observations is used to estimate demand for all firms together and by variance group.

building. Most importantly, the Assessor file included a variable for business type, which we use to create our commercial categories. We assume that business type stays constant throughout our study period. We employ a fixed effects regression specification, outlined below, which ultimately subsumes the physical parcel characteristics. However, parcel summary statistics are displayed in Table 1.

Table 1: Summary Statistics on Select Assessor's Variables[6]

Variable	Mean	Std. Dev.	Min	Max
Sq. Ft.	13,713	24,570	1	337,566
Sprinkler Sq. Ft.	9,069	22,696	0	337,566
Age	17	12	0	75
Stories	1	1	0	12

Notes: Summary statistics are for years 2001-2016 and come from the Assessor data.

The 1,633 premises matched with Assessor data yielded 99 different business types, listed in the Appendix. From these 99 business types, we created 13 broad commercial categories.[7] The categories, and the more specific business types included in each category, are listed in Table 2.

[6] Includes premises that may not have a building on the parcel

[7] This was done primarily for two reasons. First, for ease of analysis—13 elasticity estimates versus 99 elasticity estimates. Second, the local utility requested larger commercial categories to match the analysis done by other utilities in the west and helped guide the decision on which business types to include in each category.

Table 2: Business Types in Each Commercial Category

Category	Business Types Included
Eating/Drinking	Bar/Tavern, Fast Food Restaurant, Restaurant
Industrial	Distribution Warehouse, Equipment Building, Industrial Light Manufacturing, Industrial Engineering & Research, Light Commercial Utility, Loft - Industrial
Car wash	Car Wash - Automatic, Car Wash - Drive thru, Car Wash - Self Service
Storage	Equipment Storage, Lumber Storage - Horizontal, Material Storage Sheds, Mini Warehouse, Storage - Material, Storage Garage, Storage Warehouse
School/Church/Rec	College - Classrooms, School - Classroom, School - Elementary/Secondary, School - Gymnasium, Auditorium, Community Recreation Center, Bowling Alley, Library - Public
Offices	Office Building, Government Building, Medical Offices, Post Office, Administration Building, Bank
Cars	Mini Lube Garage, Service Garage, Service Station, Automotive Center
Retail	Market, Mini Mart Convenience Stores, Supermarket, Convenience Store, Community Shopping Center, Discount Store, Dispensary, Mixed Retail w/ Office Units, Mixed Retail w/ Residential Units, Neighborhood Shopping Center, Regional Shopping Center, Retail Store, Warehouse Discount Store
Living spaces	Rooming Houses, Studio Loft, Dormitory Residence Halls, Fraternity, Home for the Elderly, Hotel - Full Service, Hotel - Limited Service, Jail - Correctional Facility, Motel, Multiple - Residential, Multiple - Senior Citizens, R V Parks
Animals	Kennel, Veterinary Hospital, Veterinary Office
Medical	Convalescent Hospital Nursing Home, Hospital, Mortuary, Surgical Center - Out patient, Group Care Homes
Gathering Places	Clubhouse, Bath Houses, Drive In Theatre, Health Club, Recreational Pool Enclosure, Theatre - Motion, Theatre - Stage
Other	Armory, Barber/Beauty Shop; Commuter Terminal, Airline, Bus; Day Care Center, Drive-up Mini Banks, Fire Station Staffed, Fraternal Building, Golf Course, Greenhouse Shade Shelters, Laboratories, Miscellaneous OB, Nursery/Greenhouse, Parking Lot, Parking Structure, Restroom Building/Concessions, Showroom, Supplemental Values, Underground Parking Garage, Church, Farm Utility Building, Barn, Shed - Equipment

Descriptive statistics for billed (approximately monthly) water consumption associated with each commercial category are listed in Table 3. The largest water consumers by monthly volume are medical, industrial, and car wash commercial business types while the smallest water consumers are auto repair shops, office buildings, and storage facilities.

Table 3: Descriptive Statistics on Billed Consumption Variable (gallons) by Commercial Category

Category	Obs.	# Premises	Mean	Std. Dev.	Min	Max
Eat/Drink	27,096	167	60,218	61,630	10	1,059,700
Industrial	8,593	65	274,804	1,149,292	10	30,000,000
Car Wash	4,037	26	116,711	121,566	20	934,600
Storage	20,177	131	37,441	123,965	10	2,421,800
School/Rec	11,029	73	101,269	241,060	10	4,518,700
Offices	72,108	456	31,409	67,204	10	2,160,800
Cars	14,878	94	20,091	49,005	10	624,100
Retail	55,877	353	48,298	97,783	10	2,985,000
Living Spaces	9,091	67	88,957	115,139	10	1,552,950
Animals	1,472	12	39,509	61,392	100	531,560
Medical	3,869	33	278,731	412,368	30	3,697,500
Gath. Places	3,884	30	113,782	175,699	10	2,546,900
Other	19,610	126	47,393	145,208	10	4,585,500

Notes: Summary statistics are for years 2001-2016.

As shown in Figure 1, average billed consumption varies among the 13 commercial categories. Interestingly, water usage is roughly constant for most commercial categories from 2001-2016. However, water use in the industrial category grew by roughly one hundred percent between 2014 and 2016. Analysis of average billed consumption by year suggests this increase is due to intensive growth (increased consumption of existing facilities) rather than extensive growth (new water-intensive industrial facilities entering the database).

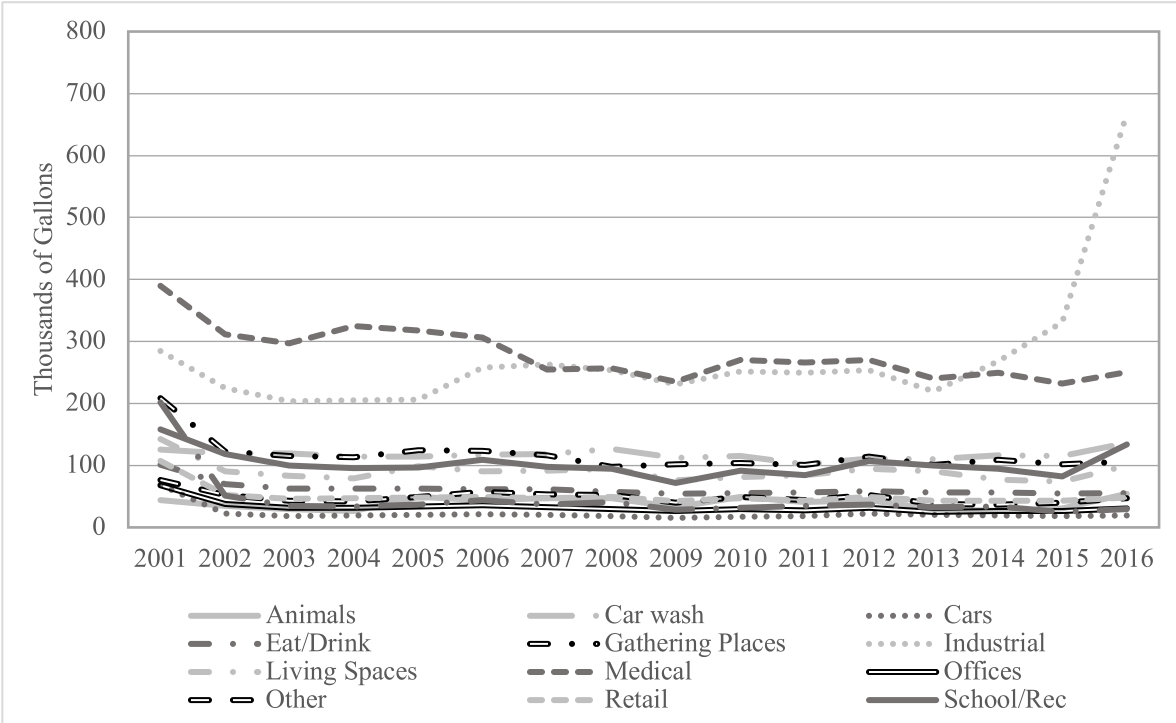

Figure 1: Average Billed Consumption (gallons) by Commercial Category

Next, we assign businesses to consumption variance groups based on variance in billed consumption from 2001-2005. This was done to determine whether variance level can be a useful method to identify users that would be particularly responsive to conservation policies. For example, a low-variance customer likely relies on using a relatively constant amount of water across billing periods and therefore may not have the ability to make adjustments, while the opposite may be true for high-variance users. If this is the case, and the utility anticipates growth in the less price-responsive low-variance group, the utility will know they must develop effective non-price conservation policies to control growing demand. To create the variance groups, we calculate each firms' consumption variance between 2001-2005. Firms with variance in the bottom 33rd percentile in this period were assigned to the low-variance group, firms with variance in the middle 33rd percentile to the mid-variance group, and firms with variance in the top 33rd percentile to the high-variance group. Because variance groups were created using a firm's 2001-2005 water consumption, the demand estimations for these groups will use a sample of observations from 2006 onwards. Table 4 shows the number of firms (premises) in each variance group, along with select descriptive statistics on the consumption variable. Notably, low-variance users have the lowest mean use.

Table 4: Descriptive Statistics on Consumption Variable by Variance Group

Variance Level	Obs.	# Premises	Mean	Std. Dev.	Min	Max
Low	56,666	720	7,916	13,598	10	544,050
Mid	56,670	720	30,101	34,326	10	1,088,000
High	53,017	825	200,908	502,887	10	12,800,000

Notes: Summary statistics are for years 2006-2016.

As is common in utility pricing, all commercial users face (1) a base charge, and (2) a marginal rate per 1000 gallons (kgals) consumed, with the base charge and marginal rate varying by meter size. The local utility utilizes an increasing block rate structure that has two blocks for most meter sizes (6" and 8" meters are the exception and have only one block). The width of the first block (the number of gallons consumed before jumping to the second price block) varies by meter size. Summer rates are higher than winter rates in both blocks. A total of 8,378 of our observations consumed enough to move into the higher pricing block during a billing period. During the study period, the local utility implemented 9 increases in the marginal rates and fixed charge for all meter sizes. The average of the individual rate increases was $0.015.[8]

Finally, we matched the water consumption data with climate data from NOAA. This data included readings on maximum temperature and total precipitation from multiple climate stations in the local city. All stations' maximum temperature and total precipitation observations were averaged for a given month and assigned to a water consumption observation based on the

[8] Detailed pricing schedules are available upon request from the authors.

meter read date. All observations were also assigned the percentage of the local city under a level 3 drought according to the United States Drought Monitor at the meter read date. A level 3 drought indicates a severe drought where there are major crop losses and widespread shortages or restrictions.

CHAPTER 3: MODEL AND IDENTIFICATION

We develop a model of commercial water demand following Moeltner and Stoddard (2004). Similar to Moeltner and Stoddard (2004), we acknowledge several major identification challenges with our data. First, water consumption is likely correlated with unobserved time-invariant firm characteristics, including building size, cooling or heating system used, square footage requiring irrigation, and more. Second, the increasing block rate pricing schedule employed by the local utility means that consumption and marginal or average price are simultaneously determined. Together, these issues, if not addressed, result in biased OLS parameter estimates.

We address the first of these challenges by employing a fixed effects model of demand. Specifically, we include year fixed effects to control for time varying unobservables that are common across firms such as annual demand fluctuations. We also include firm fixed effects to control for firm specific time-invariant unobservables such as firm-specific water usage patterns and physical parcel characteristics. Finally, we include irrigation season (May through October) fixed effects to control for irrigation season unobservables that are common across firms, like irrigation tech or amount of irrigable land. In contrast, a random effects specification addresses this problem in the same manner, but importantly random effects assumes the unobserved effects are uncorrelated with the regressors employed in the model. If the unobserved effects *are* correlated with any regressors, fixed effects must be employed.[9] This specification has been applied in the residential water demand literature (see Kenney et al. (2008)), but is much less common in the commercial sector (see Angulo et al. (2014)).

[9] A Hausman using an OLS specification of our model test strongly rejects the null hypothesis that random effects is a better fit than fixed effects with p=0.00

We address simultaneity of price and consumption using an instrumental variables strategy. To date, the water demand literature has not achieved a consensus on appropriate price variables and instrument choice. Moeltner and Stoddard (2004) use listed per unit charges for each tier, applicable tier threshold, and marginal sewer price as instruments, while Renzetti (1992) uses the average of the marginal price blocks, number of blocks, and the difference between first and last blocks as instruments. Angulo et al. (2014), on the other hand, use a one-period lag of the price variable as an instrument. Following Kenney et al. (2008) and others in the residential water demand literature, we use the one-period lagged average price as our price variable of interest.[10] Lagged average price is used to reflect the fact that utility consumers do not receive their bill until after they their billing period has ended.[11] We instrument the lagged average price with the log of the listed per unit charges for each tier (similar to Moeltner and Stoddard (2004)) and the days of service lagged by one period. The lag of the days of service is a valid instrument if it is correlated with the lag of the average price (the price variable of interest) and plausibly uncorrelated with current period water consumption. The latter assumption would be violated if, for example, a firm used less water in the current period because their previous period bill was greater than average due to a longer than average billing period. However, the meter read dates are random, which implies the billing period is random across time and customers. Although other commercial water demand estimation studies have used the listed per unit charges for each tier as instruments, we are the first commercial study to use the lag of the days of service as an instrument.

[10] We believe the lagged average price is more appropriate as billed water use in a given month is likely responsive to previous period water bills not current water bills.

[11] Lagged average price is defined as the previous billing period's total bill divided by the previous billing period's total consumption

Commercial water demand can be modeled as a function of price, firm characteristics, and either weather or time of year. However, the fixed effects specification absorbs any variables that are fixed within a firm across time such as parcel characteristics, or any variables that are constant within a year. We model demand for water by firm *i* during billing period *t* as:

$$lnw_{it} = \alpha + \beta_1 ln\bar{p}_{i,t-1} + \beta_2 prcp_t + \beta_3 tmax_t + \beta_4 dos_{i,t} + \beta_5 drought_t + irr_t + \eta_i + m_t + \varepsilon_{it}, \quad (1)$$

where $ln\, w_{it}$ is the log of water consumption for business i in period t, $ln\bar{p}_{i,t-1}$ is the one-period lag of the logged average price for business i in period t, $prcp_t$ is the mean daily precipitation in the month the meter was read, $tmax_t$ is the mean daily maximum temperature in the month the meter was read, $dos_{i,t}$ is the length of the billing period for business *i* in period *t*, $drought_t$ is the percentage of the local city land under a category 3 drought in time period *t*, n_i is a firm fixed effect, m_t is a year fixed effect, and irr_t is a dummy for the irrigation season of May-October (or the irrigation fixed effect).[12] In each model, standard errors are clustered at the firm level to control for potential correlation in the errors within firms and at the year level to control for partial correlation in the errors within a year (for example, errors may be correlated in drought and non-drought years).

Very few commercial water demand studies have employed a formal test to assess whether firms respond to average or marginal price. To address this shortcoming, and to confirm that customers in our sample are indeed responding to our chosen lagged average price term, we employ a test developed by Shin (1985).[13] Specifically, we model commercial water consumption as a function of the perceived price of water (P^*_{it}). Perceived price is modeled as a function of average price, marginal price, and a price perception parameter *k*:

[12] We find the results are fairly robust to alternative specifications including alternative definitions of drought and varying sets of fixed effects.

[13] The Shin (1985) analysis was focused on the electricity sector rather than the water sector.

$$P^*_{it} = MP_{it}\,(AP_{it} / MP_{it})^{\,k} \qquad (2)$$

where MP_{it} is marginal price for customer i in period t and AP_{it} is the non-logged lagged average price for customer i in period t, our primary price variable in equation 1. Given equation (2), if the consumer only responds to *MP*, then k=0; if the consumer responds only to *AP*, k=1; if $0 < k < 1$, then the consumers respond to a price between average and marginal; if $k < 0$, then consumers respond to a price above both marginal and average price; finally, if $k > 1$, then consumers respond to a price below both marginal and average price (for more details see Nieswiadomy and Molina (1991)).

Further, if we assume water demand is a double logarithmic function of explanatory variables, we can estimate demand using the following equation: [14]

$$lnw_{it} = \beta_0 + \beta_1 ln(MP_{it}\,(AP_{it} / MP_{it})^k) + \boldsymbol{X\beta_2} + \varepsilon_{it} \qquad (3)$$

where $\boldsymbol{X}$ is the vector of explanatory variables. With algebraic manipulation, equation (3) can be re-written as:

$$lnw_{it} = \beta_0 + \beta_1 ln\, MP_{it} + \delta ln(AP_{it} / MP_{it})) + \boldsymbol{X\beta_2} + \varepsilon_{it} \qquad (4)$$

where $\delta = \beta_1 k$. Clearly, δ is not identified, though we can use equation (4) to test the hypothesis that $\beta_1 = \delta$. Failing to reject the joint hypothesis that $\beta_1 = \delta$ implies that k=1 and the marginal price terms cancel out in equation (2), indicating that firms respond to average rather than marginal price. Applying these equations to our data, we estimate the following equation to test if a customer responds to the marginal water price or the one-period lag of the average price:

[14] Note that Shin (1985) separates the explanatory variables into separate terms in the original paper. For ease of presentation, we have presented these variables as a vector X.

$$lnw_{it} = \alpha + \beta_1 \ln(mp_{i,t}) + \beta_2 k\, ln(\frac{\bar{p}_{i,t-1}}{mp_{i,t}}) + \beta_3 prcp_t + \beta_4 tmax_t + \beta_5 dos_{i,t} + \beta_6 drought_t + irr_t + \eta_i + m_t + \varepsilon_{it}, \qquad (5)$$

where $mp_{i,t}$ is the marginal price of water for customer *i* in billing period *t*.

In addition to estimating demand for all firms, we split the sample by commercial categories and estimate equation (1) separately for each category. This approach allows us to see how elasticity varies among commercial categories, which is useful information for a utility anticipating growth in a certain sector.

Finally, we split the sample into low, mid, and high-variance groups and again re-estimate equation (1) for each group. The variance groups were created using a firm's 2001-2005 water consumption, so the demand estimations for these groups are created using only observations from 2006 onwards. As far as we know, ours is the first study to estimate separate elasticities among variance groups. Again, this information would be particular valuable for a utility anticipating growth in the number of premises in one of these variance categories.

CHAPTER 4: RESULTS AND DISCUSSION

In the following section, we first present the results of estimating equation (1) for all firms using lagged average price. In addition, we present results from equation (5), or the Shin (1985) test. Then, we estimate separate elasticities for 13 different categories of commercial businesses. Finally, we examine how price responsiveness depends on consumption variability.

4.1 Primary Results for All Firms

Table 5 displays the results of estimating equation (1) and equation (5)—our full demand model with lagged average price as the price term, and the Shin test to assess whether firms respond to lagged average or contemporaneous marginal price.

Table 5: Primary Estimation Results

Dependent Variable: lnw_{it}	**Equation 1**	**Equation 5**
Variable		
$ln\bar{p}_{i,t-1}$	-0.80 (0.20)***	-
$lnmp_{i,t}$	-	-0.68 (0.34)*
$ln(\frac{\bar{p}_{i,t-1}}{mp_{i,t}})$	-	-1.16 (0.25)***
$prcp_t$	-0.08 (0.19)	0.26 (0.27)
$tmax_t$	0.01 (0.00)***	0.01 (0.00)***
$dos_{i,t}$	0.03 (0.00)***	0.03 (0.00)***
$drought_t$	-0.00 (0.00)	-0.00 (0.00)
irr_t	0.24 (0.05)***	0.06 (0.10)
R^2	0.77	0.78
Observations	364979	364979

Notes: Standard errors are clustered at the firm and year level.
*Significant at 10%; **significant at 5%; ***significant at 1%.

As shown in column 2 of Table 5, the main demand model using lagged average price performs well. All significant variables apart from the precipitation and drought variables are significant at p=0.01, all significant variables have the expected sign, and the R-squared is high.

The price elasticity of demand for all firms is represented by the coefficient on the price variable. In equation (1), we find a significant and negative price elasticity of -0.80. This means that given a 10% increase in price, we expect consumption to decrease by 8.0%, all else equal. This elasticity is on the higher end of the range of estimates in the literature.

Not surprisingly, equation (1) suggests that firms consume more water when temperatures are higher—specifically, a 1 degree increase in mean maximum temperature in the month the meter was read is associated with a 1% increase in consumption for the firm in their billing cycle.

The days of service (billed days) variable and the dummy variable for irrigation season both behave as expected—a one day increase in days of service increases consumption by 3% and the irrigation season is associated with a 27% increase in consumption.[15]

Column 3 displays the results of estimating equation 5. Of particular interest are the coefficients on $lnmp_{i,t}$ and $ln(\frac{\bar{p}_{i,t-1}}{mp_{i,t}})$. Using these coefficients, we find a *k* value *k*=1.70, which would imply firms respond to a price below both marginal and lagged average price. However, we perform an F-test to determine whether the coefficients are statistically different from one another. The F-test marginally rejects the null with p-value 0.098. We consider this suggestive evidence that the coefficients are equal, implying that $k \approx 1$ in equation (2) and the marginal price terms in equation (2) cancel out. Therefore, we have suggestive evidence that firms in our sample are responding to lagged average price rather than marginal price. Although we are not the first to employ the Shin (1985) method in the commercial sector, we are the first to find evidence that firms respond to lagged average price rather than marginal price.

[15] The instruments consistently pass underidentification tests.

This result—that firms respond to lagged average price and not marginal price—is not completely unexpected. Although the literature has found significant marginal price relationships in many cases, the average business owner may not be aware of their marginal cost of water in a tiered rate structure. Responding to lagged average price is more realistic.

This result also has important implications for utilities considering price changes. It is possibly for a utility to increase marginal price without increasing average price. If a utility believes firms are responding to marginal price, the would expect this type of price change to lower consumption. However, if firms are responding only to average price as we have found, then there would be no price response. In this case, a utility would instead need to change their pricing structure in a way that increases average price. This can be done, for example, by simply raising the fixed charge of every customer. This type of price increase may even face less backlash than an increase in the per-gallon rates.

4.2 Estimating Demand by Commercial Category

Table 6 displays the price elasticity results from estimating equation (1) separately for each commercial category. As we are primarily interested in how price elasticity varies among categories, Table 6 only reports elasticity estimates and overall model performance.[16]

[16] Full regression results are available from the authors upon request.

Table 6: Elasticities by Commercial Category

Category	$\boldsymbol{ln\overline{p}_{i,t-1}}$	**Decrease in Consumption from 10% Increase in Price**	$\boldsymbol{R^2}$	**Obs.**
Eat/Drink	-0.08 (0.16)	0.8%	0.76	27,096
Industrial	-0.66 (0.17)***	6.6%	0.82	8,593
Car Wash	-0.98 (0.38)**	9.8%	0.77	4,035
Storage	-0.73 (0.19)***	7.3%	0.81	20,175
School/Rec	-0.45 (0.22)**	4.5%	0.66	11,029
Offices	-0.71 (0.21)***	7.1%	0.77	72,104
Cars	-0.56 (0.14)***	5.6%	0.82	14,877
Retail	-0.36 (0.18)*	3.6%	0.80	55,876
Living Spaces	-0.27 (0.36)	2.7%	0.81	9,091
Animals	-1.18 (0.07)***	11.8%	0.72	1,472
Medical	-0.37 (0.36)	3.7%	0.87	3,869
Gathering Places	-0.69 (0.25)**	6.9%	0.72	3,884
Other	-0.79 (0.17)***	7.9%	0.72	19,609

Notes: School/Rec category standard errors were clustered only at the firm level (rather than the firm and year level) due to few observations within clusters.
*Significant at 10%; **significant at 5%; ***significant at 1%.

Elasticity estimates are negative and significant in 10 of our 13 commercial categories. The lowest (in absolute value terms) significant elasticity estimate is in the Retail category (-0.36) and the highest is in the Animals category (-1.18). Our elasticities fluctuate but remain relatively centered around the all-firm elasticity estimate of -0.80.

The two most elastic categories in descending order are Animals and Car Wash, while the two least elastic categories in descending order are School/Rec and Retail. It is unsurprising that School/Rec and Retail are relatively inelastic. Retail locations are one of the lower water consumers in terms of monthly consumption (see Table 3) which suggests that most water is for essential uses. Schools, on the other hand, use a larger amount of water per month on average, but this water use is still likely primarily for essential uses (drinking or cooking, for example). Furthermore, most schools do not operate on profit-maximization principles, but rather are responding to parent and taxpayer desires. As a result, the decision to use non-essential water for purposes such as watering school fields is probably based more on these external factors than an internal response to price.

On the other hand, it is somewhat surprising that car washes and businesses in the Animals category are relatively elastic. The businesses in the Animal category include kennels, veterinary hospitals, and veterinary offices. Kennels and veterinary hospitals likely only use essential amounts of water, which would usually suggest low elasticity. The same is true for car washes, where water use is integral to the basic functioning of the business. We have several possible explanations for these unexpected results. First, Animals and Car washes are our two smallest categories in terms of number of premises. It is possible that the groups are too small to capture an accurate elasticity. Second, it is possible the high elasticity in the Animal category is being driven by a kennel(s) with large, watered grassy areas that can choose not to irrigate when prices increase. Third, it is likely that car washes, in the long term, respond to price increases with more efficient washing technology. Knowing that they can adapt in the long term, car washes may choose to absorb the short term increased costs rather than lowering consumption.

Notably, we also find that some commercial categories—Living Spaces, eating and drinking establishments (Eat/Drink), and medical establishments (Medical)—do not have a significant response to price, indicated by statistically insignificant coefficients.[17] Two potential explanations exist for these findings. First, these businesses may be able to more completely pass-through water costs to consumers than other business types. Second, water may be an integral part of operations for these categories. Overall, utilities can use this information to more accurately predict demand response to price changes if they anticipate growth in a certain sector.

[17] An alternative explanation is insufficient variation in prices and consumption to identify an elasticity for some commercial categories. However, the elasticity point estimates in each of the insignificant categories is low relative to the significant point estimates.

4.3 Estimating Demand by Variance Group

Table 7 displays estimation results of equation (1) applied to each variance group separately. Again, we are primarily interested in how price elasticity varies among categories, so Table 7 only reports elasticity estimates and overall model performance.

Table 7: Elasticities by Variance Group

Variance Level	$\boldsymbol{ln\overline{p}_{i,t-1}}$	Decrease in Consumption from 10% Increase in Price	R^2	Obs.
Low	-0.13 (0.16)	1.3%	0.65	56,659
Mid	-0.82 (0.26)**	8.2%	0.73	56,666
High	-0.95 (0.50)*	9.5%	0.70	53,013

Note: Variance group demands estimated with a sample of observations from 2006-2016.
*Significant at 10%; **significant at 5%; ***significant at 1%.

Elasticity estimates are negative and significant in the mid- and high-variance groups, and insignificant in the low variance group. High-variance firms (elasticity=-0.95) are more elastic than mid-variance firms (elasticity=-0.82). Notably, the point estimates of elasticity are different and significant in the mid- and high-variance categories, but we cannot say the estimates are statistically different from each other. These results are intuitive in that firms with higher variance in water use are likely more able to lower their consumption in response to price changes, possibly because their water consumption is not solely for essential uses. With this result, utilities anticipating growth in the number of high- or mid-variance firms would know they can use price policies to control increasing demand. On the other hand, the utility would have to utilize non-price conservation policies to handle growth in the number of low-variance firms.

This result also has interesting implications for utility revenue. If, for example, a utility anticipates an increase in the number of high-variance users (who are relatively more elastic), they can expect future increases in average prices will effectively lower demand but will increase revenue by a smaller amount than if the same price increase was applied to the more inelastic mid-variance firms. On the other hand, the utility sacrifices some conservation gains for greater revenue gains if they choose to raise prices for mid-variance firms instead of high-variance firms. However, growth in the high-variance group will also lead to less revenue *stability* for the utility. Since public utilities often operate on cost-recovery principles, the ability to anticipate future revenue is important for planning purposes. The utility may be relieved that growth in the high-variance group means more effective price policies but concerned over the implications of that growth for revenue stability.

CHAPTER 5: CONCLUSION

This paper estimates commercial water demand elasticities for businesses served by a local utility. We then test whether firms respond to lagged average or contemporaneous marginal price and explore whether price responsiveness varies by commercial category or within-firm consumption variability. Using lagged average prices, we estimate an average elasticity across all businesses of -0.80. In addition, we find suggestive evidence that firms respond to lagged average price and not marginal price.

We also find that firms that exhibit low consumption variability are unresponsive to prices, and that there is heterogeneity in price elasticity by business type. Estimating demand by variance group is a novel approach in the literature and our result is useful for utilities anticipating growth in one of the variance groups.

Our results suggest several potential avenues for future research. First, there is a clear need for further investigation into the most appropriate price term to use in demand models. Many commercial studies use an instrumented marginal price, but our results suggest firms may not respond to marginal prices. Lagged average price may be the stronger choice, but further investigation is needed to determine if there is yet a better option. In addition, future studies should consider how other utility policies—namely usage restrictions—impact demand estimates.

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APPENDICES

Table 8: List of Commercial Demand Estimation Studies

Author	Elasticity Range
Lynne et al. (1978)	-0.17 (Motels/Hotels) to -1.07 (Department Stores)
Grebenstein and Field (1979)	-0.32 to -0.80
Babin et al. (1982)	-0.54 (Electric/Electronic) to -0.66 (Paper and Allied)
Schneider and Whitlatch (1991)	-0.23 (Commercial, short run)
Renzetti (1988)	-0.12 (Petrochemicals) to -0.54 (Light Industry)
Renzetti (1992)	-0.15 (Plastics and Rubber) to -0.58 (Pulp and Paper)
Renzetti (1993)	-0.30 (Manufacturing) to -1.14 (Metals)
Malla and Gopalakrishnan (1999)	-0.31 to -0.39 (Food Processing)
Dupont and Renzetti (2001)	-0.77 (Canada)
Wang and Lalla (2002)	-1.00 (China)
Reynaud (2003)	-0.09 (Alcohol) to -0.73 (Extractive)
Moeltner and Stoddard (2004)	-0.23 (Eat and Drink) to -0.63 (Amusement/Recreation)
Kumar (2006)	-0.30 (Drug and Pharmaceutical) to -0.94 (Leather)
Angulo et al. (2014)	-0.38 (Hotels), insignificant in Bars/Cafes, Restaurants
Deya-Tortella et al. (2016)	Insignificant

Table 9: Full List of Matched Business Types

Business Type	# Premises
Administration Bldg	1
Armory	1
Auditorium	1
Automotive Center	12
Bank	35
Bar/Tavern	24
Barber/Beauty Shop	2
Barn	1
Bath Houses	5
Bowling Alley	1
Car Wash - Automatic	3
Car Wash - Drive thru	12
Car Wash - Self Service	11
Church	63
Clubhouse	8

College - Classrooms	2
Community Recreation Center	2
Community Shopping Center	33
Commuter Terminal, Airline, Bus	1
Convenience Store	48
Convlsnt Hosp Nursing Home	19
Day Care Center	15
Discount Store	40
Dispensary	4
Distribution Warehouse	4
Dormitory Residence Halls	3
Drive In Theatre *Code	1
Drive-up Mini Banks	4
Equipment Building	1
Equipment Storage	6
Farm Utility Building	3
Fast Food Restaurant	44
Fire Station Staffed	8
Fraternal Building	3
Fraternity	13
Golf Course *Code	2
Government Building	4
Greenhouse Shade Shelters	1
Group Care Homes	3
Health Club	6
Home For the Elderly	3
Hospital	7
Hotel - Full Service	6
Hotels - Limited Service	9
Indust Light Manufacturing	19
Industrial Engineering & Research	26
Jail - Correctional Facility	1
Kennel	1
Laboratories	3
Library - Public	2
Light Commercial Utility	2

Loft - Industrial	13
Lumber Storage - Horizontal	2
Market	1
Material Storage Sheds	1
Medical Offices	108
Mini Lube Garage	8
Mini Warehouse	9
Mini-Mart Convenience Stores	1
Miscellaneous OB	1
Mixed Retail w/ Office Units	14
Mixed Retail w/ Res Units	2
Mortuary	2
Motel	5
Multiple - Residential	21
Multiple - Senior Citizens	3
Neighborhood Shopping Center	48
Nursery/Greenhouse	1
Office Building	305
Parking Lot	5
Parking Structure	2
Post Office	3
R V Parks *Code	1
Recreational Pool Enclosure	3
Regional Shopping Center	4
Restaurant	99
Restroom Building/Concessions	2
Retail Store	141
Rooming Houses	1
School - Classroom	14
School - Elementary/Secondary	47
School - Gymnasium	4
Service Garage	73
Service Station	1
Shed - Equipment	2
Showroom	2
Storage - Material	2

Storage Garage	7
Storage Warehouse	102
Studio Loft	1
Supermarket	15
Supplemental Values *Code	5
Surgical Center - Out patient	2
Theatre - Motion	4
Theatre - Stage	3
Underground Parking Garage	1
Veterinary Hospital	9
Veterinary Office	2
Warehouse Discount Store	2