Heterogeneity in Price Elasticities of Urban Water Demand: The Case for Albuquerque, New Mexico

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Keywords: Fixed effect regression, price elasticity, sectoral demand, urban water

DEPARTMENT OF ECONOMICS

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1. Executive summary

This report investigates the heterogeneity in price elasticities of urban water demand in Albuquerque, New Mexico. By analyzing water usage and billing data from the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), the study estimates how sensitive water usage is to changes in price across various sectors and socioeconomic groups, including differences by race and income. ABCWUA serves the largest urban area in the state, providing approximately 100,000 acre-feet of water annually to more than 200,000 customer accounts that support over 600,000 water users across the metropolitan area (ABCWUA, 2016).

New Mexico faces significant challenges regarding the imbalance between water demand and available supply. Albuquerque, the state's most populous city, is especially vulnerable due to its large population and limited water resources. The arid climate and periodic droughts exacerbate water scarcity, making efficient water management critical (Barlow & Leake, 2012). Over-reliance on groundwater sources and the declining flow of the Rio Grande River further strain the region's water resources (Gutzler & Robbins, 2011). Climate change exacerbates these challenges, intensifying the need for effective water management strategies. Rising temperatures and shifting precipitation patterns reduce snowpack in the surrounding mountains, leading to lower river flows and diminished water supply (Overpeck & Udall, 2020). Increased evaporation rates and prolonged drought conditions place additional stress on both surface and groundwater resources (Udall & Overpeck, 2017). Consequently, there is a heightened urgency for comprehensive water management strategies that address both current demands and future uncertainties, promoting sustainable usage, conservation, and efficient and equitable distribution of water resources across all sectors.

This report estimates the price elasticities of urban water demand across various dimensions—different sectors, income groups, and race—to inform the design of effective water pricing strategies for managing increasingly scarce water resources. Focusing on the service area of ABCWUA, the study provides a detailed analysis of water usage patterns and their responsiveness to price changes. Our research expands the current knowledge base by examining a variety of sectors, including multi-family, commercial, institutional, and city sectors in addition to single-family residential. This comprehensive approach allows for a nuanced understanding of how different sectors respond to price changes. Additionally, the investigation delves into various socioeconomic factors, such as race and income level, within the residential and multi-family sectors. By analyzing these factors, the study offers insights into the heterogeneity of water demand responsiveness across different demographic groups.

Key Findings

- The top five water consuming sectors in the service area of ABCWUA are single-family residential, multi-family, commercial, institutional, and city sectors, accounting for over 97% of annual total water usage. All the sectors exhibit inelastic price elasticities of water demand, i.e., changes in average water price have a relatively small effect on the volume of water consumed.

- Among the sectors and on an annual basis, the multi-family residential sector exhibits the highest price elasticity of water demand, with a value of -0.76 (water usage reduces by 0.76 percent for each one percent increase in average water price), followed closely by the single-family residential sector with a value of -0.73. The commercial, institutional, and city sectors exhibit lower price elasticities of water demand, with a price elasticity of -0.56, -0.59, and -0.63, respectively. These differences in the price elasticity across the sectors highlight the varying degrees of water use responsiveness to water pricing.
- The price elasticity of water demand differs in the irrigation (April to October) and non-irrigation seasons for all the sectors. Irrigation periods consistently show lower price elasticities, indicating lower sensitivity to price increases, possibly due to the essential nature of water use for irrigation purposes during these periods.
- Water usage patterns vary across different income levels, with higher incomes associated with higher sensitivity to average water price. Water usage patterns also differ by race in addition to income. Households in non-white-majority zip codes show a stronger response to average water price across all income levels, demonstrating greater sensitivity to price changes compared to households in white-majority zip codes. This highlights the potential unequal impacts, including water insecurity and water limiting behavior in households, of changes in water rates or pricing structures on different ethnoracial and socioeconomic populations.
- Temperature and precipitation also influence water usage across all sectors. The city sector shows the highest sensitivity to temperature changes, with substantial positive coefficients indicating increased water usage during hotter periods. Precipitation, conversely, has a strong negative impact on water usage, particularly in the city and single-family residential sectors.

Implications for Water Management

- The study underscores the need for sector-specific approaches in water management. Tailoring pricing strategies and conservation policies to the unique characteristics of each sector can lead to more efficient and sustainable water use.
- The differential impact of water pricing on consumption behavior across income levels highlights the importance of considering income heterogeneity when designing water pricing policies. Tailoring pricing strategies to account for varying price elasticities across income groups can enhance the effectiveness of such policies in promoting water conservation and ensuring equitable access to water resources.
- Recognizing the impact of race and income heterogeneity in the single-family and multi-family sectors is crucial for developing equitable water pricing policies. This understanding is essential for informed decision-making and long-term water resource management in urban settings like Albuquerque, addressing the challenges posed by climate change and resource scarcity.
- These variations highlight the need for tailored pricing and conservation strategies to address the unique characteristics and water use patterns of each sector effectively.

In conclusion, our findings provide critical insights for water utility managers and policymakers to develop targeted and equitable water management strategies in Albuquerque. Addressing the challenges posed by climate change and resource scarcity requires informed decision-making and long-term planning to ensure sustainable water resources for future generations.

2. Introduction

Climate change is profoundly impacting global water resources, causing more frequent extreme weather events and significantly affecting the availability and quality of freshwater. It alters water availability in two primary ways: changing precipitation patterns leading to floods, droughts, and scarcity, and increasing global temperatures which affect both surface and groundwater resources (IPCC, 2023 Bates et al., 2008). Concurrently, rapid population growth is exacerbating water scarcity, with projections indicating that by 2040, about a quarter of all children worldwide will live in regions experiencing severe water stress (UNICEF, 2023).

Water stress, defined as the imbalance between water demand and available supply, is largely a localized issue. For instance, while the United States does not face water stress at a national level, the southwestern states, which rely heavily on the Colorado River, do (Wang & Chermack, 2021; WRI, 2019). New Mexico is one of these states, with Albuquerque, its most populous city, particularly vulnerable due to its large population and limited water resources.

Understanding how different factors influence water demand elasticity is crucial for developing pricing policies that promote sustainable water use. Previous studies have shown significant variations in price elasticity due to sector, season, and demographic factors (Hanemann, 1998; Nataraj & Hanemann, 2011; Yoo et al., 2014). This study aims to investigate the heterogeneity in the price elasticity of water demand in Albuquerque, New Mexico. By estimating the price elasticities of urban water demand across various dimensions—such as different sectors, income levels, race groups, etc.—we seek to inform the design of effective water rate structures to manage increasingly scarce water resources. Utilizing recent data collected by the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), this study provides a detailed analysis of water usage patterns and their responsiveness to price changes.

Our research broadens the current knowledge base by exploring a variety of sectors, including multi-family, commercial, institutional, and city sectors in addition to single-family residential. Furthermore, our investigation expands across various socioeconomic factors, such as race and income level, within the single-family residential and multi-family sectors. The insights gained from this study can aid water utility managers and policymakers in developing and implementing strategies to promote sustainable water usage in Albuquerque and similar regions grappling with similar water management challenges.

3. Literature review

*3.1. **Range of Price Elasticities***

The price elasticity of water demand plays a crucial role in assessing how different water rate structures influence both water consumption and utility revenue. Previous literature suggests that water demand is generally inelastic to price changes. For example, studies in North America between 1951 and 1991 reported price elasticity estimates for urban areas ranging from -0.1 to -1.63, depending on water usage sectors, seasons, data aggregation levels, and modeling approaches (Hanemann, 1998). Bruno and Jessoe (2021) expanded on this by reviewing price elasticities for agricultural and urban water demand in North America from 2003 to 2021, finding a narrower range of -0.10 to -0.76 across 13 studies. Sussane et al. (2006) conducted a meta-analysis of agricultural irrigation water demand elasticity, drawing from 24 studies since 1963, and found a mean price elasticity of -0.48, but long-run elasticities, which are most relevant for policymaking, are expected to be larger than the mean estimate. These findings highlight the variability of price elasticity across different sectors and time periods.

Espey et al. (1997) also used meta-analysis to examine factors affecting price elasticity estimates in studies of residential water demand in the United States. They found that the inclusion of income, rainfall, and evapotranspiration significantly influenced elasticity estimates. Similarly, Sebri (2014) conducted a meta-analytical regression to explore factors such as price, income, and household size, and found significant variations in price elasticity due to seasonal changes and indoor/outdoor water use. These studies collectively underscore the importance of sector-specific and context-specific analyses when assessing the price elasticity of water demand.

3.2. Heterogeneity of Price Elasticities

The price elasticity of water demand exhibits significant heterogeneity across various factors such as sectors, seasons, drought conditions, income levels, and lot sizes. Nataraj and Hanemann (2011) found that households in Santa Cruz responded to changes in marginal prices with an elasticity of -0.12. Mansur and Olmstead (2012) reported a higher elasticity of -0.36 for urban households in the United States and Canada. Yoo et al. (2014) observed an elasticity of -0.66 in Phoenix, Arizona, indicating a higher sensitivity to price changes in areas susceptible to climate change. Moreover, Baerenklau et al. (2014) estimated an elasticity of -0.76 in Southern California, further illustrating the variability across regions and climate conditions.

Studies have also explored the impact of income levels on water demand elasticity. Yoo et al. (2014) found that lower-income users were more sensitive to price increases than higher-income users. This finding aligns with Sebri (2014), who reported that elasticities vary across regions and between developed and developing countries, emphasizing the need for tailored policymaking. In addition, Lee and Tanverakul (2015a) noted that water users with larger lot sizes were more responsive to water prices, highlighting the importance of property characteristics in elasticity estimates.

The heterogeneity of price elasticities is not confined to water demand alone. Research on electricity and natural gas demand has also shown variability. For instance, Bell and Griffin (2008) found that the price elasticity of electricity changes with climatic variables like precipitation and temperature. Similarly, Arévalo et al. (2021) examined natural gas demand elasticity across different demographic aggregations and found significant variations. These studies suggest that sector-specific factors, such as income, household size, and climatic conditions, play crucial roles in determining price elasticity.

While significant research has been conducted on the heterogeneity of price elasticities across various factors, gaps remain, particularly in studies focusing explicitly on racial demographics in the context of water demand. Panagopoulos (2014) and Schleich and Hillenbrand (2009) indirectly addressed this aspect by considering broader socioeconomic indicators or geographic areas with specific racial compositions. Further research is needed to explore the interplay between racial demographics and price elasticity more thoroughly.

3.3. Structure and Functional Forms of the Demand Function

The structure and functional form of the demand function are critical in accurately modeling water demand and estimating price elasticity. Most studies use econometric models that incorporate micro-level data and dynamic panel data estimation to capture the responsiveness of consumers to price changes. For example, Arbués et al. (2004) developed an econometric model combining micro-level data with dynamic panel data estimation, finding that residential users are more responsive to lagged average prices. This approach allows for a more accurate reflection of consumer behavior over time, considering both short-term and long-term responses to price changes.

Nonlinear models are often preferred for their ability to capture complex consumption behaviors. For instance, Gaudin (2006) employed a double-log model to analyze residential water demand, which allowed for capturing the diminishing marginal utility of water consumption. Similarly, Olmstead, Hanemann, and Stavins (2007) used a discrete/continuous choice model to estimate water demand, emphasizing the importance of accounting for block rate pricing in understanding consumer behavior.

In addition to the nonlinear models that capture complex consumption behaviors, the choice between fixed-effect and random-effect models is crucial in accurately modeling water demand. While random-effect models can account for unobserved heterogeneity across households, as demonstrated by Hewitt and Hanemann (1995) who used a random utility model to study water consumption under block rate pricing and found significant differences in price sensitivity across households, this study focuses on the fixed-effect panel model. The fixed-effect model is particularly suited for this analysis as will be discussed in Section 4, because it effectively controls for time-invariant characteristics within each household, providing a more precise estimate of the impact of price changes on water demand. This approach allows for capturing the unique, unobserved attributes of each household that remain constant over time, thereby isolating the effect of price and other variables of interest on water consumption.

3.4. Price Variable Selection

Selecting the appropriate price variable is crucial for accurately estimating the price elasticity of water demand. Researchers typically choose between average price, marginal price, or developing new indices tailored to specific contexts. The choice depends on the objective of the study and the behavior being modeled. Nataraj and Hanemann (2011) used a regression discontinuity design to analyze the impact of marginal price changes, finding that consumers respond to marginal price rather than average price. This suggests that marginal price may be more relevant for studies aiming to understand consumer behavior under tiered pricing structures.

However, average price can also be informative, particularly in studies where the focus is on overall expenditure rather than marginal consumption decisions. For example, Espey et al. (1997) found that average price, when combined with other factors like income and rainfall, significantly influenced price elasticity estimates. Developing new indices, such as a quasi-difference marginal price index as used by Bell and Griffin (2008), can offer a more nuanced understanding of consumer responses to price changes by capturing temporal variations and climatic influences. Several recent studies further illuminate the roles of marginal and average prices in water demand. Wichman (2014) investigates how households respond to both marginal and average prices. This study highlights that consumer perception of price plays a significant role in water demand, suggesting that both marginal and average prices can provide valuable insights depending on the context of the analysis. Wichman's findings emphasize the need to consider average price, which can significantly influence water consumption behaviors. Wichman and Brent (2022) explore how nudges and economic incentives jointly influence water consumption. This study provides evidence that consumers are responsive to both types of pricing signals depending on the context of the intervention.

There are also similar studies on the price elasticity of electricity and gas. For example, Ito (2014) finds that, in the residential energy sector, consumers respond to average price rather than marginal or expected marginal price under nonlinear pricing. Rubin and Auffhammer (2024) exploited a spatial discontinuity in two natural gas utilities' service territories—combined with variation in their block-rate pricing structure and a difference in how prima facie determined wholesale prices are differentially passed through to consumers—to identify average, seasonal, and income-specific own-price elasticities of residential natural gas demand. They estimated an average elasticity ranging from -0.15 to -0.19 depending on the measure of price used. Furthermore, they found that this elasticity varies substantially across seasons, income groups, and their interaction. Their study found no significant difference in consumers' responses to average versus marginal prices.

The justification for the chosen price variable in our study is based on the context and specific objectives of the analysis. Given the focus on understanding consumer behavior under different socioeconomic groups, average price is selected as the primary variable. This choice aligns with previous findings that the focus is on overall expenditure rather than marginal consumption decisions.

4. Methodology

4.1. Fixed-Effect Model

The fixed-effect model is a widely used econometric technique in panel data analysis. It is particularly valuable in studies where the objective is to control unobservable heterogeneity across entities. According to Wooldridge (2010), fixed-effect models are effective in controlling for time-invariant characteristics that might otherwise confound the estimates of the impact of the variables of interest. This technique has been extensively applied in various fields, including economics, social sciences, and environmental studies. Greene (2003) highlights that fixed-effect models are preferable when the omitted variables are correlated with the independent variables, a common scenario in observational studies. This approach helps in obtaining unbiased and consistent estimates, making it a robust tool for causal inference.

In the context of water demand, studies such as those by Olmstead and Stavins (2009) have utilized fixed-effect models to analyze the determinants of residential water demand. Their work demonstrates how fixed-effect models can effectively control household-specific factors, allowing for a more accurate estimation of the price elasticity of water demand.

The fixed-effect model was chosen for several reasons. First, it controls for unobserved heterogeneity by accounting for unobserved variables that are constant over time but vary across entities, in this case, different sectors. These unobserved factors could include household-specific characteristics such as preferences for water usage, efficiency of water appliances, or long-term habits. By controlling for these time-invariant factors, the model isolates the impact of time-varying variables like price and weather conditions on water demand. Second, the fixed-effect model mitigates omitted variable bias. In the context of water demand, omitted variable bias can arise if there are unobserved factors that influence both the independent variables, such as water price, and the dependent variable, water usage. The fixed-effect approach mitigates this bias by differencing out these unobserved factors. Third, the model focuses on within-entity variation by using only within-entity variation over time to estimate the effects of the independent variables. This is particularly useful when the primary interest lies in understanding how changes in explanatory variables, such as water prices or weather conditions, influence changes in water usage within the same household over time. Additionally, the model incorporates time-fixed effects, such as month and year fixed effects, to control for time-specific factors that could affect water consumption. Month fixed effects capture seasonal and monthly variations (e.g., holidays) in water usage, while year fixed effects account for any time-specific shocks or trends (e.g., economic conditions and the COVID pandemic) that impact water usage across all households. By including these time-fixed effects, the model further refines its ability to isolate the effects of the primary independent variables on water usage.

4.2. Model Specification

The baseline model is represented by the following equation:

$$ln(q_{it}) = \alpha ln(p_{i,t-1}) + \beta w_{it} + \gamma \eta_{it} + z_i + Month\_FE_m + Year\_FE_y + \varepsilon_{it} \quad (1)$$

In this equation, i and t index different sectors and time, respectively. The dependent variable q_{it} represents the water usage or the quantity of water demanded. The variable $p_{i,t-1}$ denotes the lagged average water price, with α being the key coefficient indicating the price elasticity of water demand. The vector w_{it} includes weather variables, and η_{it} encompasses other control variables, such as socioeconomic factors. The term z_i captures household fixed effects. The month and year fixed effects, represented by $Month\_FE_m$ and $Year\_FE_y$, respectively, account for seasonal and temporal variations in water usage. The residual error term is denoted by ε_{it}. This study will run this model for each sector to capture sector-specific variations in water demand and the effects of different factors on water usage.

5. Data

The dataset for this study comprises account-level data, detailing monthly water consumption, water bills, and weather conditions spanning six years (from 2018 to 2023). This comprehensive dataset is further enriched annually with socioeconomic data at the zip code level. The data sources include the Albuquerque Bernalillo County Water Utility Authority (ABCWUA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Census Bureau.

Water account information sourced from ABCWUA includes account ID, account type (i.e., residential/single-family, multi-family, commercial, city, and institutional), address, monthly water usage, billing start and end dates, and total monthly bill. The average price is calculated by dividing the total bill by water usage for each billing period. ABCWUA serves as a critical supplier for the largest urban area in New Mexico, providing approximately 100,000 acre-feet of water annually to more than 200,000 customer accounts. This service supports over 600,000 water users across the metropolitan area, including more than 155,000 single-family residential accounts (ABCWUA, 2016). Accounts lacking sufficient billing information were systematically excluded from the analysis to maintain data integrity and analytical rigor.

Weather data was obtained from NOAA, encompassing monthly mean precipitation and temperature records. Because each account has its own billing cycle that can start on any day of the month, monthly averages of the weather variables were calculated for each account based on the start and end date of billing cycles. To enhance the spatial and temporal relevance of weather data, geographical interpolation methods were employed based on the geodesic distance to three prominent weather stations (Albuquerque International Airport, Albuquerque Foothills NE, and Petroglyph National Monument) in the Albuquerque area. This interpolation technique utilized a weighted average approach, where weights were inversely proportional to the distance from each station. Missing weather data points were addressed through imputation using historical averages specific to corresponding time periods, ensuring data completeness and reliability.

Socioeconomic factors crucial for understanding demographic influences were derived from the U.S. Census Bureau, providing median household income and race/ethnicity statistics at the zip code level. Annual zip code-level socioeconomic data was integrated into the dataset from 2018 to 2023, providing a comprehensive socio-demographic context.

Figure 1 illustrates the total urban water usage across five sectors— single-family residential, multi-family, commercial, city, and institutional —from 2018 to 2023. The data, represented in million gallons, reveals distinct trends in water consumption patterns for each category over the six-year period. The residential sector, denoted by a dark blue line, consistently shows the highest water usage among all categories, fluctuating around 14,000 to 15,000 million gallons annually. Notably, there is a slight peak in 2020, followed by a gradual decline through 2023. This uptick can probably be attributed to the COVID-19 pandemic, as more people stayed home due to lockdowns and remote work arrangements, thereby increasing residential water consumption. This category exhibits the most significant volume of water usage, indicating the predominant role of residential consumption in urban water demand.

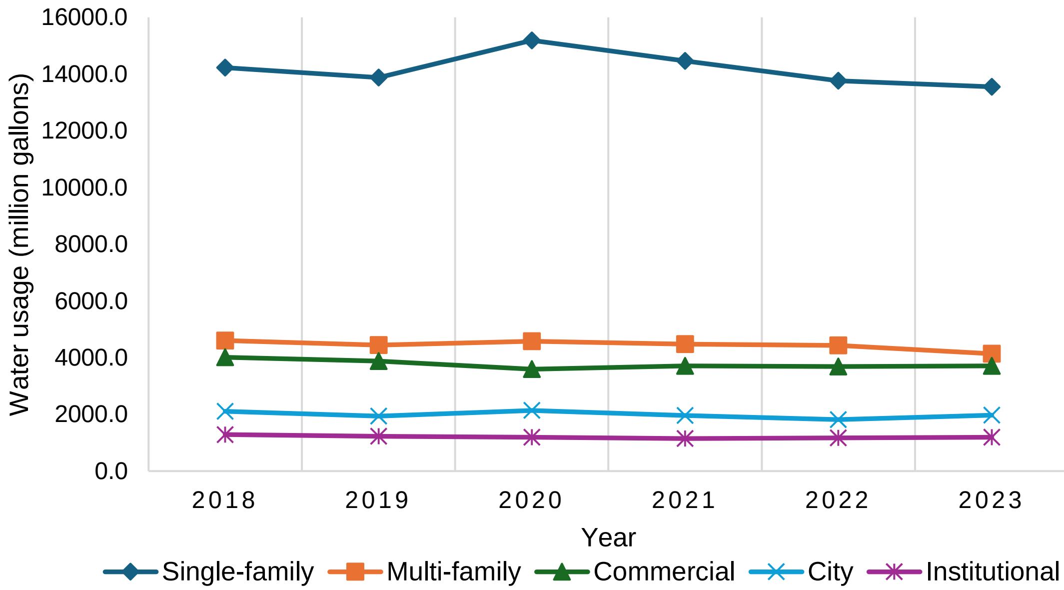

Figure 1 Total urban water usage of five major sectors in Albuquerque, New Mexico from 2018 to 2023.

Conversely, the commercial category, shown by a green line, saw a decrease in water usage in 2020. Commercial water consumption dropped from approximately 3,500 million gallons in 2018 to below 3,000 million gallons by 2020. This decline reflects the reduced activity in commercial spaces, as many businesses operated at limited capacity or were temporarily closed during the pandemic. The multi-family category, represented by an orange line, maintains a relatively stable usage of approximately 4,000 million gallons per year. There is minimal variation observed in this category over the first few years, suggesting a steady demand for water in multi-family housing units and, going down in the last 2-3 years. Institutional water usage, indicated by a light blue line, and city water usage, denoted by a purple line, are the lowest among the categories, each hovering around 1,500 to 2,000 million gallons annually. Both categories exhibit relatively stable trends with minor fluctuations, suggesting a consistent but relatively lower demand compared to residential and multi-family sectors. Overall, the figure underscores the dominant water usage by the residential sector, followed by multi-family and commercial sectors, with institutional and city categories contributing the least to total urban water consumption.

Figure 2 depicts the monthly water usage of the five major sectors from 2018 to 2023. The data reveals seasonal variations in water consumption across all the sectors, with a noticeable increase during the warmer months, likely due to heightened irrigation and cooling needs. The residential sector consistently demonstrates the highest water usage, reaching peaks exceeding 2,000 million gallons during peak months. In contrast, the other sectors, including multi-family, commercial, institutional, and city, show relatively lower and more stable consumption patterns, with peak values typically under 500 million gallons. These findings highlight the substantial contribution of the residential sector to overall water demand in the city, particularly during the irrigation season from April to October. The clear cyclical trend across all the sectors underscores the influence of seasonal factors on water usage patterns.

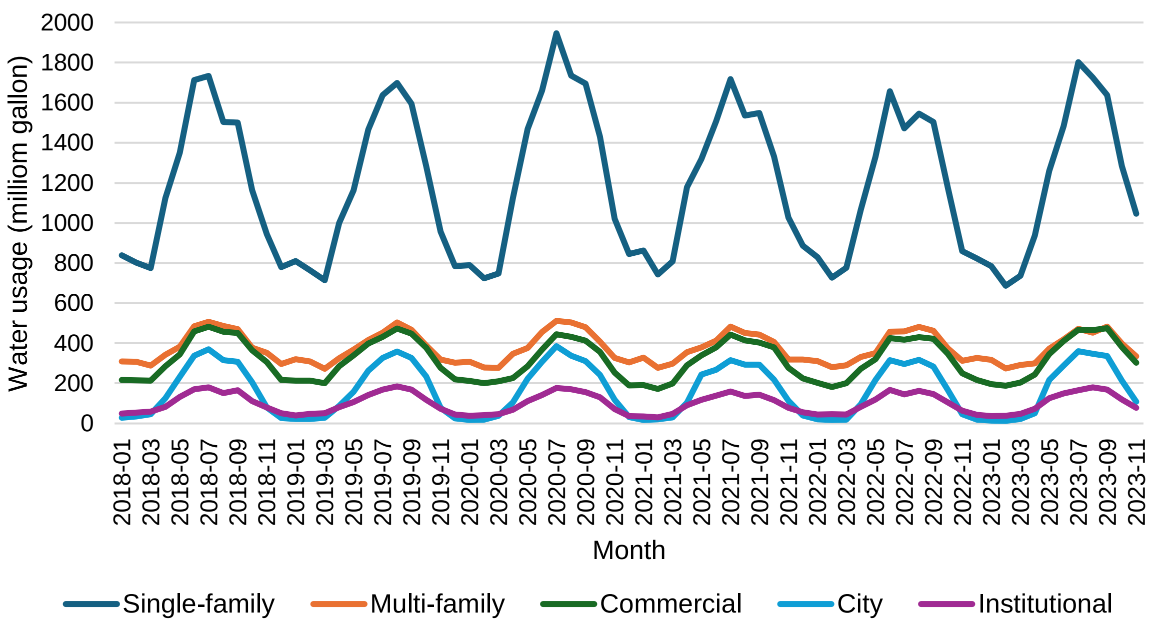

Figure 2 Monthly water usage of five major sectors in Albuquerque, New Mexico from 2018 to 2023.

Figure 3 presents the average daily water usage per account across various sectors, measured in gallons. The city sector has the highest usage, nearing 5,000 gallons per day, indicating significant water demand due to the irrigation of public parks and golf courses that are managed by the city of Albuquerque. Institutional usage follows, averaging around 3,000 gallons daily, reflecting the needs of schools, hospitals, and government buildings. The multi-family sector has a moderate average usage of about 1,500 gallons daily, driven by the collective water use of multiple households. The commercial sector shows a lower average of around 1,000 gallons per day, possibly due to more efficient water practices or less intensive needs. The single-family sector, with the lowest usage of 280 gallons per day, highlights the smaller water demand per household. Compared to Figure 1, which indicates that the residential sector exhibits the highest water usage on an urban level, the primary reason is the number of accounts or consumers in this sector. The high number of individual households and residential units leads to a greater cumulative demand for water, even if each individual account may consume less water on average than accounts in other sectors. This highlights the impact of population density and the number of consumers on total water usage in urban areas.

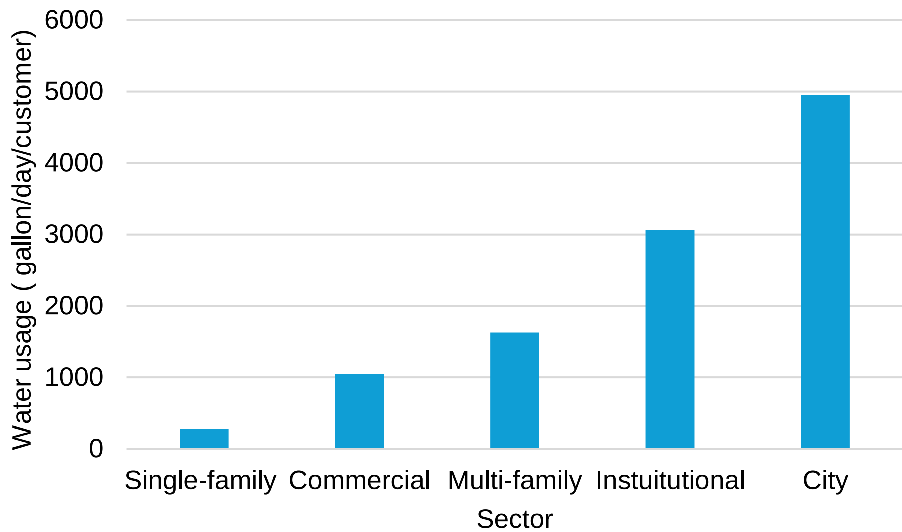

Figure 3 Average daily water usage per account by five major sectors in Albuquerque, New Mexico.

Figure 4 illustrates water consumption across different zip codes within the ABCWUA service area in 2023, with Panel (a) representing all sectors and Panel (b) focusing specifically on the residential sector. Both maps use a color gradient to denote varying levels of water usage, ranging from 0 to 3562 gallons per capita per day. Notable differences in water consumption patterns between the two maps can be observed. In Panel (a), which encompasses all sectors, there is a broader range of water consumption, with some areas, such as the central and northern parts, showing usage levels reaching the highest category (149-3564 gallons per capita per day). This indicates a high level of water demand across multiple sectors, possibly including city, commercial, and institutional uses. The darkest shades on the map represent the areas with the highest water usage, highlighting significant consumption in zip codes like 87113 87109, and 87131.

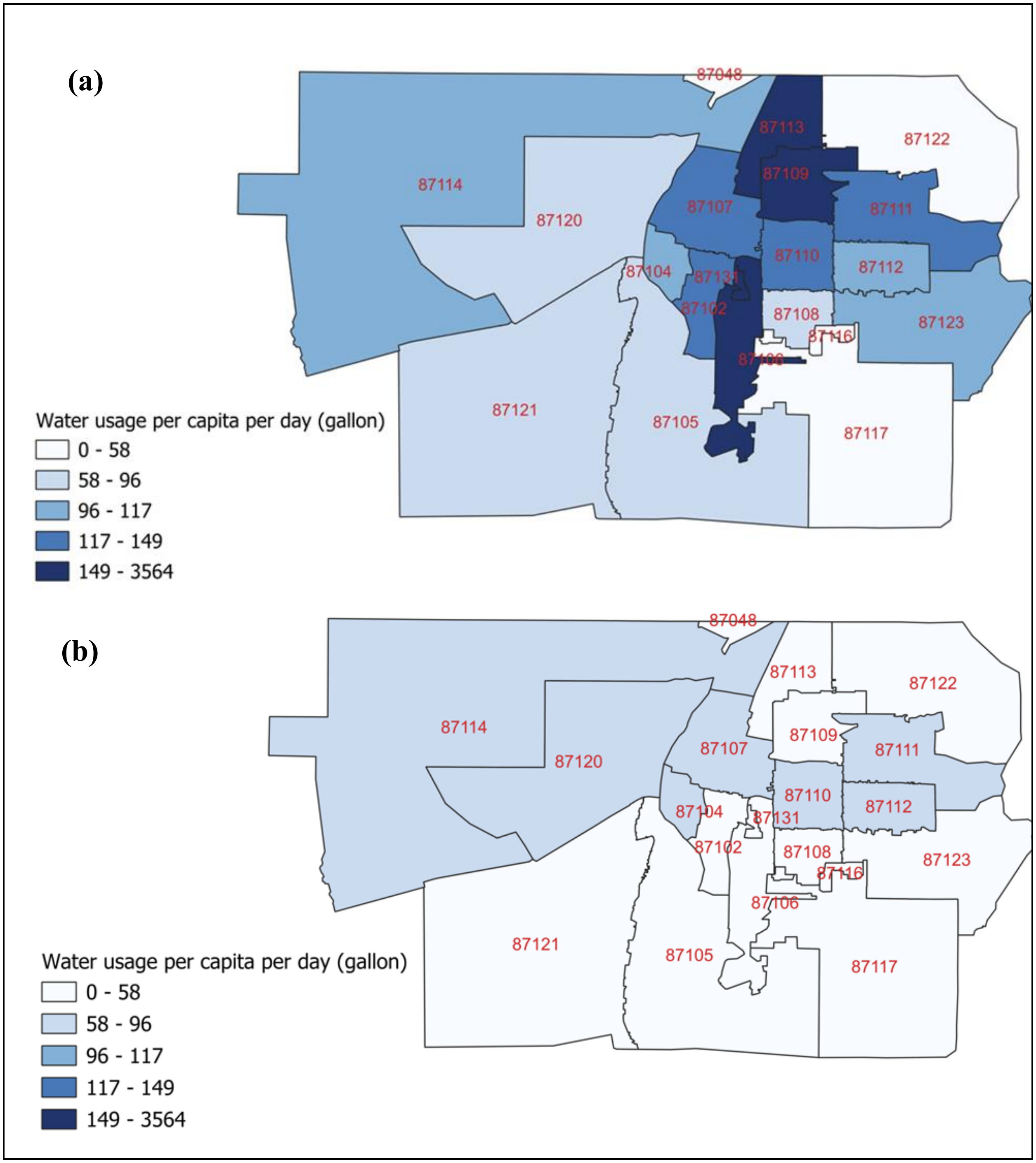

Figure 4 Water usage by zip codes in Albuquerque, New Mexico in the year 2023. Panel (a) water usage of five major sectors (residential, multi-family, commercial, institutional, and city); Panel (b) water usage of the residential sector.

Panel (b), on the other hand, presents a more concentrated and slightly lower range of water consumption, focusing solely on the residential sector. Here, the highest category reaches only up to 96 gallons per capita per day. This map reveals a slightly different distribution, with areas like

87120 and 87114 still showing higher usage but to a lesser extent than in the comprehensive all-sectors map. The north eastern and south parts of the city exhibit less residential water usage. Overall, the comparison between these two figures indicates that while the residential sector is a major contributor to water consumption, the inclusion of other sectors in the all-sectors map results in a higher and more varied range of water usage across the city. This disparity underscores the importance of considering all sectors when assessing urban water demand, as different sectors contribute variably to the overall consumption profile. Additionally, the visual differences between the maps highlight the spatial variability in water use, suggesting that targeted water management strategies may be needed for different areas and sectors to ensure sustainable water use.

Table 1 presents summary statistics for various sectors annually and during irrigation (irrig) and non-irrigation (non-irrig) seasons, covering single-family residential (RES), multi-family (MF), commercial (COM), institutional (INS), and city (CITY) sectors. The variables analyzed include average price per gallon, water usage per day, days of observation, monthly bill, temperature, precipitation, and sample size (N). The annual average price per gallon of water remains relatively low across all sectors, with the highest being \$0.039 for the institutional sector. During the irrigation season, average prices slightly decrease, reflecting the economies of scale given the relatively high monthly fixed charge. Water usage varies significantly, with the city sector showing the highest annual average usage at 4952.50 gallons/day, followed by the institutional sector at 3060.75 gallons/day. Water usage peaks during the irrigation season, especially in the city sector, which reaches 8597.28 gallons/day, while it drops during the non-irrigation season, particularly in the commercial and institutional sectors.

The number of days observed is consistent across sectors, averaging around 30.41 annually, with minor fluctuations between irrigation and non-irrigation periods. The average monthly water bill also varies, with the city sector incurring the highest at \$719.01. During the irrigation season, the total bill increases significantly, particularly in the city sector, which sees a bill of \$1037.28. In contrast, non-irrigation season bills are lower across all sectors due to reduced water consumption.

Temperature averages are similar across sectors, with an annual average of approximately 58.78°F. Higher temperatures are recorded during the irrigation season, averaging around 72.84°F, while the non-irrigation season sees lower temperatures, around 48.04°F. Precipitation is relatively uniform, with an annual average of 0.75 inches. During the irrigation season, precipitation is slightly higher at around 0.98 inches compared to the non-irrigation season. The sample size (N) varies greatly across sectors, with the highest being 14,355,345 for the residential sector and the lowest being 85,454 for the institutional sector.

Table 1 Summary statistics of the major sectors

Variable	Season	Sectors				
		RES	MF	COM	INS	CITY
Average price ($/gallon)	Annual	0.018	0.016	0.038	0.039	0.035
		(0.013)	(0.039)	(0.070)	(0.133)	(0.101)
	Irrigation	0.015	0.014	0.033	0.031	0.023
		(0.01)	(0.02)	(0.06)	(0.11)	(0.05)
	Non-irrigation	0.021	0.017	0.041	0.046	0.050
		(0.01)	(0.04)	(0.07)	(0.14)	(0.13)
Water usage (gallon/day)	Annual	279.58	1626.31	1050.31	3060.75	4952.50
		(1279.9)	(6043.4)	(6244.5)	(11960.9)	(28743.2)
	Irrigation	287.44	1927.36	1302.98	4504.71	8597.28
		(306.66)	(7159.51)	(8087.47)	(15535.46)	(39956.19)
	Non-irrigation	173.12	1401.72	799.87	1980.91	2224.29
		(190.58)	(5041.15)	(3729.89)	(8175.48)	(14545.51)
Days	Annual	30.41	30.42	30.41	30.42	30.42
		(2.17)	(2.22)	(2.17)	(2.58)	(2.09)
	Irrigation	30.70	30.78	30.72	30.68	30.68
		(1.99)	(2.12)	(2.07)	(2.98)	(1.94)
	Non-irrigation	30.21	30.15	30.18	30.23	30.22
		(2.22)	(2.26)	(2.21)	(2.21)	(2.17)
Monthly bill ($)	Annual	78.35	431.23	322.90	781.83	719.01
		(46.16)	(1292.46)	(784.61)	(1986.46)	(2544.61)
	Irrigation	87.54	471.39	362.15	968.70	1037.28
		(58.79)	(1434.24)	(925.16)	(2413.45)	(3403.56)
	Non-irrigation	70.98	401.27	298	642.07	480.78
		(31.28)	(1174.72)	(633.64)	(1579.71)	(1565.9)
Temperature (F)	Annual	58.66	58.87	58.78	58.88	58.81
		(14.95)	(15.08)	(15.01)	(15.07)	(15.03)
	Irrigation	72.84	72.94	72.88	72.86	72.80
		(6.69)	(6.97)	(6.81)	(6.82)	(6.95)
	Non-irrigation	48.04	48.38	48.23	48.20	48.32
		(9.76)	(10.17)	(9.97)	(9.97)	(10.13)
Precipitation (inch)	Annual	0.76	0.72	0.75	0.75	0.75
		(0.62)	(0.60)	(0.61)	(0.60)	(0.61)
	Irrigation	1.02	0.96	0.99	0.99	0.98
		(0.71)	(0.69)	(0.69)	(0.70)	(0.69)
	Non-irrigation	0.57	0.55	0.56	0.57	0.57
		(0.46)	(0.46)	(0.45)	(0.46)	(0.46)
N		14,355,345	589,191	804,299	85,454	88,402

Table 2 presents a summary of various monthly water account variables within the residential sector. The average price of water is 1.8 cents per gallon. On average, daily water usage is 221.94 gallons, with a billing period of approximately 30.42 days. The mean monthly bill is $78.05. The average annual temperature within this sector is 58.63°F, and the mean annual precipitation is 0.77

inches. The average income in the residential sector is $59,334. Regarding demographic distributions, Hispanic or Latino individuals represent an average of 44% of the population. White individuals constitute about 40%, Black or African American individuals make up approximately 3%, and Native American individuals account for around 5%. This table highlights key statistics related to water use, billing, and demographic composition in the residential sector.

Table 2 Summary statistics of water accounts in the residential sector with monthly water data at the account level and annual socioeconomic data at the zip code level

Variable	Unit	Mean	Std. Dev.	Min	Max
Average price	Cent/gallon	1.14	1.3	0.3	3.6
Water usage	gallon/day	221.94	253.33	0	81,093.52
Billing days	day	30.42	2.14	0	62
Bill total	$	78.05	45.87	0.96	17,359.63
Temperature	Fahrenheit	58.63	14.97	34.66	85.10
Precipitation	inches	0.77	0.62	0	10.70
Income	$	59,334	16,974	28,476	160,740
Hispanic or Latino	%	44	3.1	37	52
White	%	40	5	26	51
Black or African American	%	3	1	0.06	6.4
Native American	%	5	1	0.75	10.3
Others	%	8	1	0.87	16.2

6. Results

6.1. Baseline model

Using the baseline model framework presented in equation (1), we examine the main factors affecting water usage, with a focus on the responsiveness of water usage to water price, i.e., the price elasticity of water demand. Equation (2) presents the econometric models.

$$ln(q_{it}) = \alpha ln(p_{i,t-1}) + \beta_1 \text{TEMP}_{it} + \beta_1 \text{PPECIP}_{it} + \gamma\eta_{it} + z_i + Month\_FE_m + Year\_FE_y + \varepsilon_{it} \quad (2)$$

In this equation, $\ln(q_{it})$ represents the natural logarithm of water usage for sector i at time t. The term α captures the price elasticity of water demand, with $\ln(p_{i,t-1})$ being the natural logarithm of the lagged water price. The variables $TEMP_{it}$ and $PPECIP_{it}$ account for temperature and precipitation, respectively, and their coefficients, β_1 *and* β_2, measure their impacts on water usage. η_{it} encompasses other control variables, such as socioeconomic factors. The term z_i captures household fixed effects. The month and year fixed effects, represented by $Month\_FE_m$ and $Year\_FE_y$, respectively, account for seasonal and temporal variations in water usage. The residual error term is denoted by ε_{it}.

Regression results, detailed below, are presented separately for each sector. These results will provide insights into how water usage responds to price changes, temperature fluctuations, precipitation, and other factors, highlighting the unique characteristics and sensitivities of different sectors.

Table 3 presents regression results for the single-family residential sector. All models incorporate household fixed effects (Household FE) and month fixed effects (Month FE) except model (1). Model (3) includes year fixed effects (Year FE), while model (4) incorporates zipcode-year fixed effects (Zip-Year FE). The results consistently show a statistically significant negative relationship between average water price and water consumption. Specifically, in all four model specifications, the coefficient of average water price ranges from -0.693 to -0.727, indicating that a 1% increase in average water price leads to a reduction in water usage by approximately 0.69% to 0.73%. This negative elasticity suggests a responsiveness of residential water usage to price changes. The water demand here is price inelastic.

Table 3 Results for the single-family residential sector

	Dependent variable: Ln(q)					
	(1)	(2)	(3)	(4)	(4) Irrigation season	(4) Non-irrig. season
$ln\ (AP_{t-1})$	-0.693***	-0.726***	-0.727***	-0.725***	-0.614***	-0.687***
	(0.0009)	(0.0008)	(0.0008)	(0.0008)	(0.0013)	(0.001)
TEMP	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***
	(0.00002)	(0.00006)	(0.00006)	(0.00006)	(0.00007)	(0.00006)
	-0.07***	-0.04***	-0.04***	-0.05***	-0.06***	-0.03***
PPECIP	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0004)
Household FE	Y	Y	Y	Y	Y	Y
Month FE		Y	Y	Y	Y	Y
Year FE			Y			
Zip-Year FE				Y	Y	Y
N	13,128,301	13,128,301	13,128,301	13,128,301	5,644,899	7,483,402
adj. R^2	0.5583	0.5733	0.5724	0.5744	0.5664	0.5470

Note: Standard errors in parentheses are clustered at the household level.
$***p < 0.01$, $** p < 0.05$, $* p < 0.1$.

The coefficient for the lagged average price $ln\ (AP_{t-1})$ is -0.614 during the irrigation season, showing a statistically significant negative relationship between previous water prices and current consumption. This suggests that higher past prices lead to reduced water usage during irrigation. In the non-irrigation season, the coefficient is even more negative at -0.687, indicating a stronger response to price changes. These findings highlight the varying impact of water pricing on consumption behavior across different seasons.

Temperature (TEMP) has a positive and significant impact on water consumption across all models, with coefficients of 0.01. This implies that higher temperatures increase water usage, likely due to a greater need for outdoor watering and cooling. The impact of precipitation is also significant, with a larger negative coefficient during the irrigation season (-0.06) compared to the non-irrigation season (-0.03), emphasizing the heightened responsiveness of water usage to precipitation during the irrigation season. The adjusted R^2 values range from 0.5583 to 0.5744, indicating a good fit of the models.

Table 4 summarizes the regression results for the multi-family sector, which has a similar pattern as the single-family sector. The coefficient of $ln\ (AP_{t-1})$ is negative across all models, ranging from -0.75 to -0.76. This indicates that a 1% increase in average water price results in a decrease in water usage by 0.75% to 0.76%, highlighting the slightly higher price sensitivity of the multi-family sector compared to the single-family sector.

Table 4 Results for the multi-family sector

	Dependent variable: Ln(q)					
	(1)	(2)	(3)	(4)	(4) Irrigation season	(4) Non-irrig. season
$ln\ (AP_{t-1})$	-0.748***	-0.760***	-0.762***	-0.760***	-0.676***	-0.766***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.008)	(0.006)
TEMP	0.006***	0.006***	0.006***	0.006***	0.011***	0.005***
	(0.00008)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0003)
PPECIP	-0.039	-0.030***	-0.030***	-0.031***	-0.050***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Household FE	Y	Y	Y	Y	Y	Y
Month FE		Y	Y	Y	Y	Y
Year FE			Y			
Zip-Year FE				Y	Y	Y
N	566,430	566,430	566,430	566,430	243,127	323,303
adj. R^2	0.3275	0.3261	0.3145	0.3357	0.3278	0.3287

Note: Standard errors in parentheses are clustered at the household level.
***$p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Temperature (TEMP) again shows a positive and significant relationship with water consumption. This suggests that higher temperatures lead to increased water usage in multi-family dwellings. Precipitation (PPECIP) shows a negative and significant impact on water usage, with a much larger coefficient during the irrigation season (-0.050) compared to the non-irrigation season (-0.003), highlighting that water usage is significantly more responsive to precipitation during the irrigation season.

The coefficient for the lagged average price $ln\ (AP_{t-1})$ is -0.676 during the irrigation season, showing a statistically significant negative relationship between previous water prices and current consumption. This suggests that higher past prices lead to reduced water usage during irrigation. In the non-irrigation season, the coefficient is even more negative at -0.766, indicating a stronger response to price changes, with a more significant reduction in water usage. These findings highlight the varying impact of water pricing on consumption behavior across different seasons.

Overall, the findings in Tables 3 and 4 suggest that water demand in both single-family and multi-family sectors is generally less elastic during the irrigation season, reflecting a reduced sensitivity to price changes. The substantial increase in responsiveness to precipitation during the irrigation season underscores the potential impact of climate change on urban water demand.

In comparison with previous studies, the estimates for price elasticity in both the single and multi-family sectors are closely aligned with Baerenklau et al. (2014), who estimated a price elasticity of −0.76 in Riverside, California. Similarly, Yoo et al. (2014) reported a price elasticity of −0.66 for residential water demand in Phoenix, Arizona. Unlike Baerenklau et al. (2014) and Yoo et al. (2014), who did not differentiate between single-family and multi-family sectors, this study distinguishes between these two subgroups within the residential sector. All three studies focus on residential water demand in the southwestern United States, providing a robust comparison of price elasticity estimates across similar climatic and geographic contexts.

Table 5 shows the regression results for the commercial, institutional, and city sectors, which reveal sector-specific influences on water consumption patterns. Across all three sectors, average price consistently shows a statistically significant negative relationship with water consumption. The coefficients range from -0.556 to -0.563 in the commercial sector, -0.566 to -0.597 in the institutional sector, and -0.535 to -0.6312 in the city sector. This pattern indicates a robust trend where a higher average price correlates with lower water consumption, possibly reflecting conservation efforts following periods of high usage.

The coefficient for the lagged average price $ln\ (AP_{t-1})$ for commercial, institutional, and city sectors are respectively, -0.493, -0.457, and -0.498 during the irrigation season, showing a statistically significant negative relationship between previous water prices and current consumption. This suggests that higher past prices lead to reduced water usage during irrigation. In the non-irrigation season, the coefficients are even more negative, indicating a stronger response to price changes, with a more significant reduction in water usage. These findings highlight the varying impact of water pricing on consumption behavior across different seasons.

Temperature (TEMP) consistently has a positive relationship with water consumption across all sectors, though the magnitude of this effect varies. In the commercial sector, temperature coefficients range from 0.007 to 0.01, indicating a modest impact. In the institutional sector, positive coefficients in Models 1, 4, and 5 range around 0.019 to 0.02. The city sector shows a more pronounced impact, with coefficients ranging from 0.02 to 0.03, suggesting that water consumption in the city sector is more sensitive to temperature changes compared to the other sectors.

Precipitation (PPECIP) generally exhibits a negative relationship with water consumption, but the effect size and significance vary across sectors. In the commercial sector, coefficients are small, ranging from -0.003 to -0.0014. The institutional sector shows a wider range, with coefficients from -0.006 to -0.0026. In contrast, the city sector demonstrates larger and more consistently negative coefficients, ranging from -0.05 to -0.08, indicating that precipitation significantly affects water consumption in this sector more than in the others.

Table 5 Results for the commercial (COM), institutional (INS), and city (CITY) sectors

Sector		Dependent variable: Ln(q)					
		(1)	(2)	(3)	(4)	(4) Irrigation season	(4) Non-Irrig. season
COM	$ln\ (AP_{t-1})$	-0.556***	-0.564***	-0.562***	-0.563***	-0.493***	-0.548***
		(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
	TEMP	0.010 ***	0.007***	0.007***	0.007***	0.011***	0.006***
		(0.0001)	(0.0003)	(0.0003)	(0.0003)	(0.0005)	(0.0004)
	PPECIP	-0.003**	-0.004**	-0.014***	-0.006***	-0.024***	0.013***
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
	N	641,140	641,140	641,140	641,140	283,371	357,641
	adj. R^2	0.3723	0.3751	0.3743	0.3747	0.3968	0.3607
INS	$ln\ (AP_{t-1})$	-0.566***	-0.597***	-0.590***	-0.594***	-0.457***	-0.560***
		(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
	TEMP	0.02***	0.02***	0.02***	0.019***	0.014***	0.021***
		(0.0006)	(0.01)	(0.001)	(0.001)	(0.001)	(0.001)
	PPECIP	-0.016***	-0.006*	-0.026***	-0.014***	-0.038***	0.016***
		(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.009)
	N	71,190	71,190	71,190	71,190	32,018	39,172
	adj. R^2	0.3191	0.3297	0.3280	0.3291	0.3303	0.2813
CITY	$ln\ (AP_{t-1})$	-0.535***	-0.629***	-0.631***	-0.629***	-0.498***	-0.596***
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
	TEMP	0.03***	0.03***	0.02***	0.03***	0.02***	0.04***
		(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.003)
	PPECIP	-0.08***	-0.05***	-0.05***	-0.05***	-0.04***	-0.05***
		(0.006)	(0.007)	(0.007)	(0.007)	(0.006)	(0.015)
	N	52,464	52,464	52,464	52,464	28,714	23,167
	adj. R^2	0.3623	0.4082	0.4098	0.4081	0.4718	0.3294
	Month FE		Y	Y	Y	Y	Y
	Year FE			Y			
	Zip-Year FE				Y	Y	Y

Note: Standard errors in parentheses are clustered at the household level.
***$p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The models incorporate various fixed effects, enhancing their explanatory power. The commercial sector includes month, year, and zip-year fixed effects. The institutional sector includes year, month, and zip-year fixed effects, while the city sector includes month, year, and zip-year fixed effects. The adjusted R-squared values are highest in the city sector, ranging from 0.3623 to 0.4098, compared to 0.3723 to 0.3747 in the commercial sector and 0.3191 to 0.3297 in the institutional sector. This indicates that the explanatory variables and fixed effects in the city sector models better account for the variance in water consumption.

In conclusion, while the negative impact of average water price on water usage is consistent across sectors, the sensitivity to temperature and precipitation varies significantly. The city sector is particularly responsive to changes in these variables, highlighting the need for sector-specific approaches in water consumption analysis and policy formulation. The inclusion of fixed effects enhances the models' explanatory power, with the city sector models showing the highest adjusted R-squared values, underscoring their robustness.

Figure 5 illustrates the price elasticity of water demand, with their confidence intervals, across the five sectors of water consumers in Albuquerque, New Mexico, based on the regression results from model (4). The figure shows that among annual price elasticities the multi-family residential sector exhibits the highest price elasticity, with a value of -0.76. This indicates that multi-family households significantly reduce their water consumption in response to price increases. The single-family residential sector also demonstrates high price elasticity, though slightly less than the multi-family sector, with a value of -0.73. In contrast, the commercial, institutional, and city sectors exhibit lower price elasticities. The commercial sector has a price elasticity of approximately -0.56, indicating moderate responsiveness to price changes. The institutional sector shows higher responsiveness, with a price elasticity around -0.59. The city sector demonstrates the highest sensitivity to price changes, with a price elasticity near -0.63. These differences in price elasticity across sectors highlight the varying degrees of responsiveness to water pricing. Residential sectors, both single-family and multi-family, are more responsive to price changes, suggesting that water pricing strategies could be particularly effective in managing water demand within these sectors. Conversely, the lower price elasticity in the commercial, institutional, and city sectors indicates that alternative strategies may be needed to effectively manage water demand in these areas.

Several factors could contribute to these differences. For instance, multi-family and single-family residential sectors may have more discretionary water use compared to commercial and institutional sectors, which might have more essential or fixed water usage patterns. Residential consumers might also be more directly impacted by water bills and thus more responsive to price changes. In contrast, commercial and institutional users might have less flexibility to reduce water usage without affecting their core operations. Additionally, the city sector's lower sensitivity could be attributed to budget constraints or policy-driven efficiency measures that make it harder to adjust water consumption based on price alone. This sector-specific variation in price elasticity underscores the importance of tailoring water management policies to the unique characteristics and sensitivities of each sector to achieve more efficient and sustainable water use.

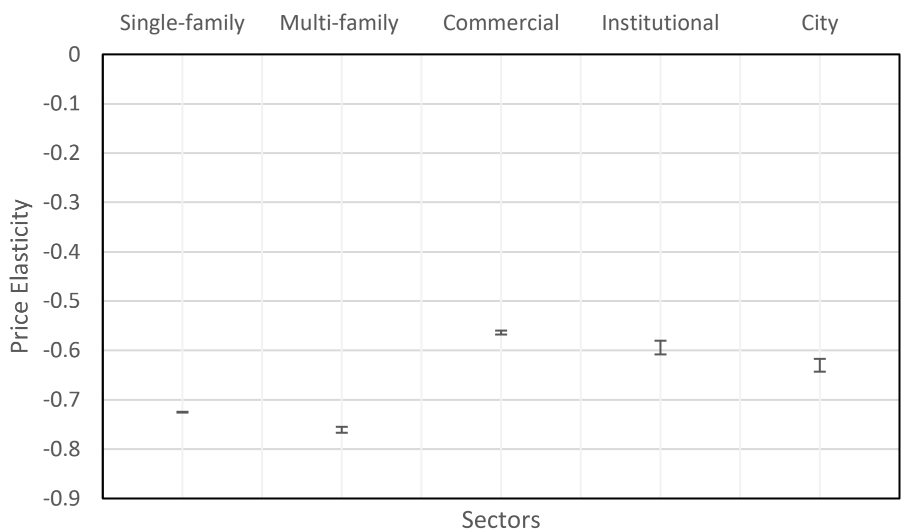

Figure 5 Price elasticity of water demand across five major sectors in Albuquerque, New Mexico

Figure 6 illustrates the price elasticity of water demand across five major sectors in Albuquerque, segmented by annual, irrigation, and non-irrigation seasons. Price elasticity is represented on the vertical axis. The five sectors analyzed are single-family, multi-family, commercial, institutional, and city, listed along the horizontal axis. Each sector shows different elasticity values for annual, irrigation, and non-irrigation periods, depicted by blue, orange, and green markers respectively. For single-family houses, price elasticity is relatively less negative during the irrigation season compared to non-irrigation and annual periods, suggesting a lower sensitivity to price changes when irrigation is needed. Multi-family sectors show a similar trend with irrigation elasticity being less negative, indicating less responsiveness to price changes during irrigation periods. Commercial sectors exhibit less variation between seasons, with non-irrigation elasticity slightly more negative, indicating a consistent sensitivity to price changes year-round. Institutional sectors show a notable difference; elasticity during irrigation season is less negative, indicating lower sensitivity to price changes compared to the annual and non-irrigation periods. The city sector follows a similar pattern, with the least negative elasticity during the irrigation season, reflecting lower price sensitivity when irrigation is required. Overall, the figure highlights how price elasticity of water demand varies significantly across sectors and seasons, with irrigation periods generally showing less negative elasticity values, indicating lower sensitivity to price increases during these times. This suggests that water demand in these periods is less elastic, potentially due to the essential nature of water use for irrigation purposes.

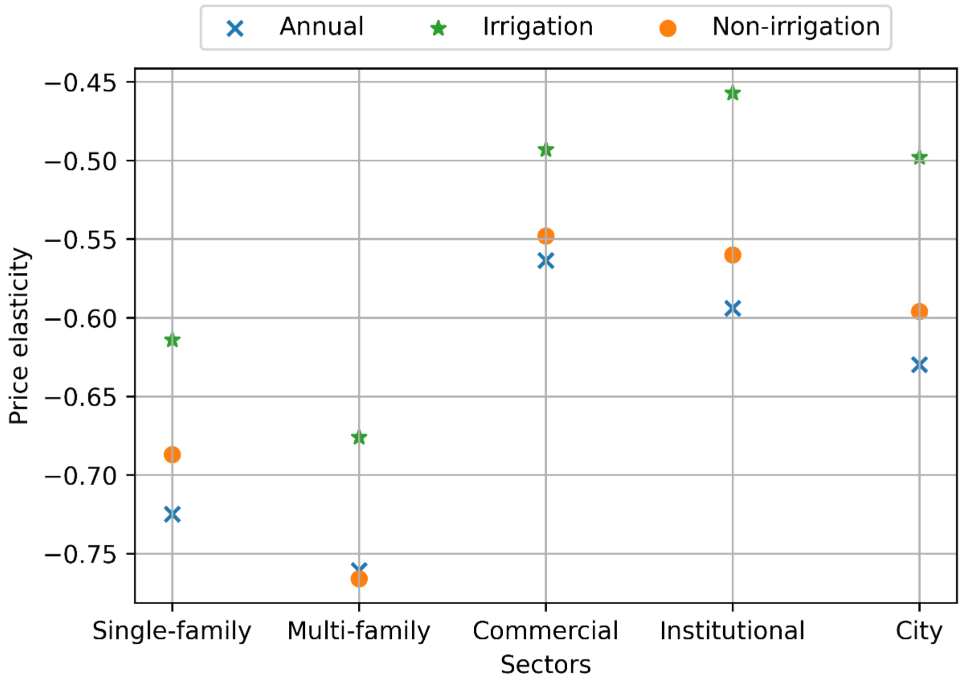

Figure 6 Price elasticity of water demand across five major sectors in Albuquerque: Annually, irrigation, and non-irrigation seasons

6.2. Heterogeneity

This section investigates the heterogeneity of price elasticity across different income levels and race/ethnicity groups. The analysis aims to uncover how variations in socioeconomic factors influence the responsiveness of water demand to price changes. By examining these disparities, we can gain a deeper understanding of the equity implications of water pricing policies. Additionally, this investigation helps identify which demographic groups are more vulnerable to price increases, allowing for more targeted and effective policy interventions

Table 6 presents the fixed-effect regression results for the residential single-family and multi-family sectors across different income levels. The tables highlight the relationship between water usage, average water price, temperature, and precipitation for low, moderate, and high-income groups. In terms of income levels, New Mexico generally exhibits lower incomes compared to the national average. This study developed localized income categories for Albuquerque. For instance, households within the bottom 25% of the sample average income were categorized as low income, while those in the top 25% were classified as high income, and the households between these two were considered moderate income. Specifically, if the median household income in a zip code is less than \$47,980, it is considered low income; if it ranges between \$47,980 and \$69,741 (inclusive), it is considered moderate income; otherwise (i.e., higher than \$69,741), it is considered high income.

The fixed-effect regression results for the single-family and multi-family sectors across different income levels reveal notable variations in the price elasticity of water demand. For single-family residential in low-income zip codes, the coefficients of the lagged average price are -0.63, -0.67 for moderate-income zip codes, and -0.76 for high-income zip codes. In the multi-family sector, the coefficients are respectively -0.726, -0.725, and -0.877 for low to high-income zip codes. These coefficients indicate a significant negative relationship between average water price and water consumption across all income groups. The magnitude of the coefficients suggests that higher water prices lead to reduced water consumption, with high-income households in high-income zip codes exhibiting the greatest responsiveness to price changes. Specifically, in the single-family residential sector, a one percent increase in the lagged average price results in approximately a 0.73 percent decrease in water consumption for low and moderate-income zip codes. In contrast, for high-income zip codes, the same price increase leads to a nearly 0.88 percent decrease in water consumption.

Table 6 Results for single-family residential and multi-family sectors across different income levels

Sector		Dependent variable: Ln(q)		
		Low income	Moderate income	High income
Single-family	$ln\ (AP_{t-1})$	-0.636***	-0.670***	-0.760***
		(0.001)	(0.001)	(0.001)
	TEMP	0.008***	0.011***	0.013***
		(0.0001)	(0.0001)	(0.0001)
	PPECIP	-0.04***	-0.05***	-0.04***
		(0.0005)	(0.0003)	(0.0004)
	N	2,990,995	6,582,080	3,555,226
	adj. R^2	0.5144	0.5658	0.6214
Multi-family	$ln\ (AP_{t-1})$	-0.726***	-0.725***	-0.877***
		(0.007)	(0.01)	(0.042)
	TEMP	0.006***	0.006***	0.008***
		(0.0003)	(0.0004)	(0.001)
	PPECIP	-0.03***	-0.03***	-0.007***
		(0.001)	(0.002)	(0.004)
	N	326,525	211,001	28,904
	adj. R^2	0.3275	0.3261	0.3145
	Household FE	Y	Y	Y
	Month FE	Y	Y	Y
	Zip-Year FE	Y	Y	Y

Note: Standard errors in parentheses are clustered at the household level.
***$p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

These findings highlight the differential impact of water pricing on consumption behavior across income levels. Households in the high-income zip codes are more sensitive to price changes, potentially due to greater financial flexibility allowing them to adjust their water usage more readily. In contrast, households in the low and moderate-income households, while still responsive to price changes, exhibit slightly lower price elasticity, which may reflect budget constraints or less discretionary water use. Overall, the analysis underscores the importance of considering income heterogeneity when designing water pricing policies. Tailoring pricing strategies to account for varying price elasticities across income groups can enhance the effectiveness of such policies in promoting water conservation and ensuring equitable access to water resources.

Table 7 introduces race into the analysis for single-family and multi-family residential sectors, respectively, allowing for a comparison of the impact of race and income on water consumption. We categorized the zip codes into white-majority and non-white-majority groups based on the demographic composition of their populations. Zip codes where more than fifty percent of the population is white are labeled as white-majority (White), while those with less than fifty percent white population are designated as non-white-majority (Non-White) zip codes. The main changes in water consumption patterns observed across income levels in Table 6 are consistent with those in Table 7. In both sets of tables, higher income levels are associated with a stronger negative relationship between average water price and water consumption. For example, in Table 6, price elasticity becomes more negative with increasing income. Similarly, in Table 7, this pattern holds true across both White and Non-White groups, indicating that income level significantly impacts water consumption behaviors regardless of race.

Table 7 Heterogeneity by race and income: results for single-family residential and multi-family

Sector		Dependent variable: Ln(q)					
		Low income		Moderate income		High income	
		White	Non-white	White	Non-white	White	Non-white
Single-family	$ln\ (AP_{t-1})$	-0.536***	-0.652***	-0.668***	-0.642***	-0.726***	-0.774***
		(0.003)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)
	TEMP	0.011***	0.008***	0.013***	0.008***	0.014***	0.008***
		(0.0003)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
	PPECIP	-0.068***	-0.039***	-0.052***	-0.051***	-0.055***	-0.024***
		(0.001)	(0.0006)	(0.0004)	(0.0006)	(0.0006)	(0.0007)
	N	563,017	2,427,978	4,337,165	2,244,915	2,027,238	1,527,988
	adj. R^2	0.4920	0.5198	0.5668	0.5643	0.5976	0.6531
Multi-family	$ln\ (AP_{t-1})$	-0.641***	-0.736***	-0.711***	-0.745***	-0.903***	-0.677***
		(0.012)	(0.008)	(0.012)	(0.016)	(0.042)	(0.1)
	TEMP	0.004***	0.006***	0.006***	0.008***	0.009***	0.007***
		(0.0008)	(0.0003)	(0.0004)	(0.0007)	(0.001)	(0.002)
	PPECIP	-0.027***	-0.032***	-0.032***	-0.031***	-0.008	-0.031***
		(0.003)	(0.001)	(0.002)	(0.003)	(0.005)	(0.011)
	N	84,880	241,645	143,713	67,288	21,939	6,965
	adj. R^2	0.3750	0.3810	0.3216	0.3480	0.2296	0.2146
	Household FE	Y	Y	Y	Y	Y	Y
	Month FE	Y	Y	Y	Y	Y	Y
	Zip-Year FE	Y	Y	Y	Y	Y	Y

Note: Standard errors in parentheses are clustered at the household level.
***$p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

While income levels appear to be the main driver of changes in water consumption patterns, race also plays an important role. In Table 7, price elasticity (the coefficients for the average price variable) are different between White and Non-White groups within each income category. For instance, price elasticity for low-income households in the single-family residential sector are -0.536 for the White group and -0.652 for the Non-White group, and in the multi-family sector are -0.641 for White and -0.736 for Non-White. This similarity indicates the heterogeneity of the price elasticity of water demand across races. Households in Non-White zip codes exhibit a stronger response to water price compared to households in White zip codes across all income levels, except for moderate-income households in the single-family sector and high-income households in the multi-family sector. This suggests that households in Non-White zip codes generally demonstrate greater sensitivity to price changes.

It is important to note that in the multi-family sector, the higher price elasticity might be influenced by the relatively small number of high-income households, as indicated by the larger standard deviation. Additionally, multi-family residences often have property managers who tend to manage water use more efficiently, especially for outdoor water use. This efficient management likely contributes to the higher price elasticity observed across all income groups in this sector.

The temperature and precipitation coefficients also show consistent patterns across racial groups within each income category, further indicating that the main changes in water consumption are driven by income levels rather than race. For example, in Table 7, the temperature coefficients for moderate-income households are 0.013 for White and 0.008 for Non-White, showing a similar positive impact. The precipitation coefficients for the same group are -0.052 for White and -0.051 for Non-White, indicating a similar negative impact.

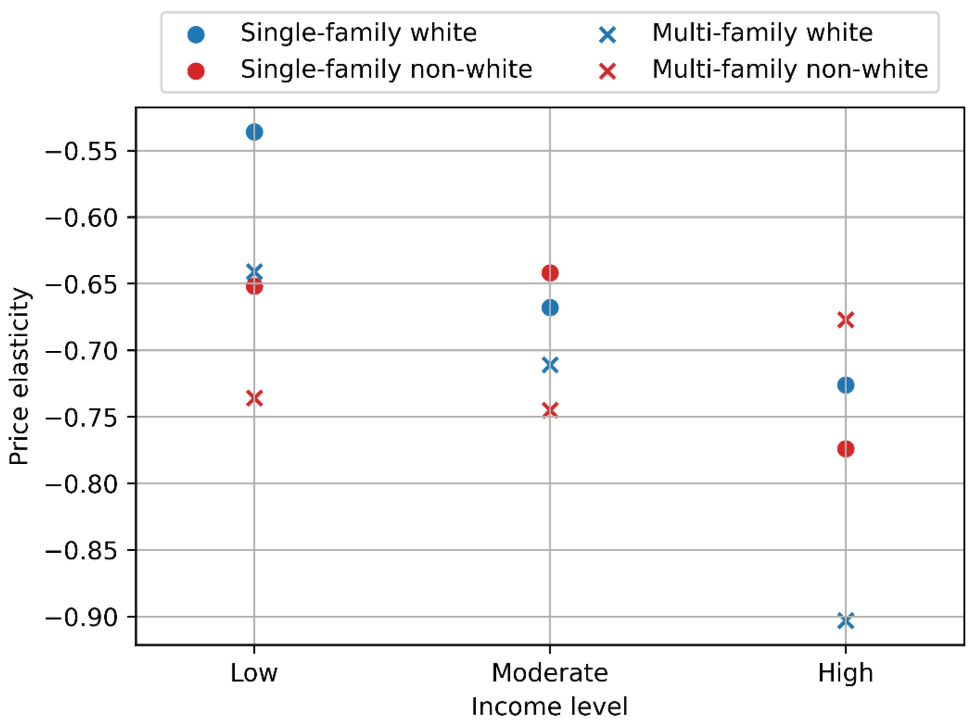

Figure 7 Price elasticity across different income levels and race groups in single-family residential and multi-family sectors

Figure 7 illustrates the estimated price elasticities from Table 7. The x-axis categorizes income into three levels: Low, Moderate, and High, while the y-axis measures the price elasticity of water demand. The figure shows the relationship between the price elasticity of water demand across various income levels and different racial groups within the single-family and multi-family sectors. The results confirm the findings from Table 6, highlighting that income levels have a significant impact on water consumption patterns, with higher incomes associated with higher price elasticity and a greater influence of temperature and precipitation. The impact of race is also significant and does substantially alter the observed patterns across different income levels. Households in Non-White zip codes show a stronger response to average water price across all income levels, demonstrating greater sensitivity to price changes compared to households in White zip codes.

7. Conclusion

Climate change is profoundly impacting global water resources, causing more frequent extreme weather events and significantly affecting the availability and quality of freshwater. Understanding the price elasticity of water demand is crucial for policymakers and water utilities to set appropriate pricing strategies to manage resources more efficiently. In this study, we investigated the heterogeneity in the price elasticity of water demand in Albuquerque, New Mexico by estimating the price elasticities of urban water demand across different sectors and socioeconomic factors.

The inclusion of various fixed effects in our models enhances their explanatory power, capturing unobserved heterogeneity and improving model fit. The single-family residential sector models exhibit the highest adjusted R-squared values, indicating a superior fit compared to other sectors. This highlights the effectiveness of household, month, year, and zip-year fixed effects in accounting for the variance in residential water consumption. The city sector also shows relatively high adjusted R-squared values, underscoring the robustness of its model fit.

Our findings reveal that while all sectors exhibit a negative relationship between average water price and water consumption, the residential sectors, both single-family and multi-family, display a higher price elasticity compared to commercial, institutional, and city sectors. Specifically, the residential sectors' price elasticity indicates a higher responsiveness to changes in average water price, suggesting that pricing strategies could be particularly effective in these sectors for managing water usage.

Temperature and precipitation also influence water usage across all sectors. The city sector shows the highest sensitivity to temperature changes, with substantial positive coefficients indicating increased water usage during hotter periods. Precipitation, conversely, has a strong negative impact on water usage, particularly in the city and single-family residential sectors. As climate change is affecting the Southwest, including rising temperatures and more frequent, intense, and longer droughts, our results call for attention to and long-term planning for managing potential increasing water demand in all sectors, particularly in the city and single-family residential sectors.

Investigating the heterogeneity of price elasticity across income and race in the single-family and multi-family sectors shows that water usage patterns vary across different income levels, with higher incomes associated with higher sensitivity to average water price and a greater influence of temperature and precipitation. Water usage patterns also differ by race in addition to income. Households in non-white-majority zip codes show a stronger response to average water price across all income levels, demonstrating greater sensitivity to price changes compared to households in white-majority zip codes. This highlights the potential unequal impacts, including water insecurity and water limiting behavior in households, of changes in water rates or pricing structures on different ethnoracial and socioeconomic populations. Overall, the analysis underscores the importance of considering income and race heterogeneity when designing water pricing policies. Tailoring pricing strategies to account for varying price elasticities across income and race groups can enhance the effectiveness of such policies in promoting water conservation and ensuring equitable access to water resources.

This study highlights the necessity of sector-specific approaches and the importance of considering ethnoracial and socioeconomic factors when designing water pricing policies. Recognizing the distinct sensitivities and responses of different sectors, income levels, and race groups to key determinants of water use allows for the development of more targeted and effective water management strategies. Tailoring water pricing strategies and conservation programs to the unique characteristics of each sector, income level, and race group in single and multi-family sectors can help achieve more efficient and sustainable water use, addressing the pressing challenges posed by climate change and water scarcity in the Southwest. This nuanced understanding is essential for informed decision-making and long-term water resource management in urban settings like Albuquerque.

8. References

Barlow, P. M., & Leake, S. A. (2012). Groundwater Depletion and Sustainability of Groundwater Use in the Western United States. U.S. *Geological Survey*. Retrieved from https://pubs.usgs.gov/fs/fs-103-03/

Baerenklau KA, Schwabe KA, Dinar A. (2014). The residential water demand effect of increasing block rate water budgets. Land Econ. 90(4):683–99

Bell, D. R., & Griffin, R. C. (2008). An annual quasidifference approach to water price elasticity. *Water Resources Research*, *44*(8). https://doi.org/10.1029/2007WR006233

Bruno, E. M., & Jessoe, K. (2021). Using Price Elasticities of Water Demand to Inform Policy. *Annual Review of Resource Economics*, *13*(1), 427–441. https://doi.org/10.1146/annurev-resource-110220-104549

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. https://doi.org/10.2307/3146872

Espey, M., Espey, J., & Shaw, W. D. (1997). Price elasticity of residential demand for water: A meta-analysis. *Water Resources Research*, *33*(6), 1369–1374. https://doi.org/10.1029/97WR00571

Flores Arévalo, Y., Ponce Oliva, R. D., Fernández, F. J., & Vásquez-Lavin, F. (2021). Sensitivity of Water Price Elasticity Estimates to Different Data Aggregation Levels. *Water Resources Management*, *35*(6), 2039–2052. https://doi.org/10.1007/s11269-021-02833-3

Gaudin, S., Griffin, R. C., & Sickles, R. C. (2001). Demand Specification for Municipal Water Management: Evaluation of the Stone-Geary Form. *Land Economics*, *77*(3), 399–422. https://doi.org/10.2307/3147133

Greene, W. H. (2003). *Econometric Analysis* (5th ed.). Prentice Hall.

Gutzler, D. S., & Robbins, T. O. (2011). Climate Variability and Projected Change in the Western United States: Regional Downscaling and Drought Statistics. Water Resources Research, 47(4). doi:10.1029/2010WR009930.

Hanemann, W. M. (1998). Determinants of urban water use. , 31-76. *Urban Water Demand Management and Planning*, 31–76.

Hewitt, J. A., & Hanemann, W. M. (1995). A Discrete/Continuous Choice Approach to Residential Water Demand under Block Rate Pricing. *Land Economics*, *71*(2), 173. https://doi.org/10.2307/3146499

Hoyos, D., & Artabe, A. (2017). Regional Differences in the Price Elasticity of Residential Water Demand in Spain. *Water Resources Management*, *31*(3), 847–865. https://doi.org/10.1007/s11269-016-1542-0

Hung, M.-F., & Chie, B.-T. (2013). Residential Water Use: Efficiency, Affordability, and Price Elasticity. *Water Resources Management*, *27*(1), 275–291. https://doi.org/10.1007/s11269-012-0185-z

Ito, K., (2014). Do consumers respond to marginal or average price? Evidence from nonlinear electricity pricing. *Am. Econ. Rev*. 104, 537–563

IPCC. (2023). Climate Change 2023: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Lee, J., & Tanverakul, S. A. (2015a). Price elasticity of residential water demand in California. *Journal of Water Supply: Research and Technology-Aqua*, *64*(2), 211–218. https://doi.org/10.2166/aqua.2014.082

Martínez-Espiñeira *, R., & Nauges, C. (2004). Is all domestic water consumption sensitive to price control? *Applied Economics*, *36*(15), 1697–1703. https://doi.org/10.1080/0003684042000218570

Miyawaki, k., omori, y., & hibiki, a. (2011). Panel data analysis of japanese residential water demand using a discrete/continuous choice approach*. *Japanese Economic Review*, no-no. https://doi.org/10.1111/j.1468-5876.2010.00532.x

Nieswiadomy, M. L. (1992). Estimating urban residential water demand: Effects of price structure, conservation, and education. *Water Resources Research*, *28*(3), 609–615. https://doi.org/10.1029/91WR02852

Olmstead, S. M. (2009). Reduced-Form Versus Structural Models of Water Demand Under Nonlinear Prices. *Journal of Business & Economic Statistics*, *27*(1), 84–94. https://doi.org/10.1198/jbes.2009.0007

Olmstead, S. M., Michael Hanemann, W., & Stavins, R. N. (2007). Water demand under alternative price structures. *Journal of Environmental Economics and Management*, *54*(2), 181–198. https://doi.org/10.1016/j.jeem.2007.03.002

Overpeck, J. T., & Udall, B. (2020). Climate Change and the Aridification of North America. Proceedings of the National Academy of Sciences, 117(22), 11856-11858. doi:10.1073/pnas.2006293117.

Reynaud, A., Renzetti, S., & Villeneuve, M. (2005). Residential water demand with endogenous pricing: The Canadian Case. *Water Resources Research*, *41*(11). https://doi.org/10.1029/2005WR004195

Rinaudo, J.-D., Neverre, N., & Montginoul, M. (2012). Simulating the Impact of Pricing Policies on Residential Water Demand: A Southern France Case Study. *Water Resources Management*, *26*(7), 2057–2068. https://doi.org/10.1007/s11269-012-9998-z

Schleich, J., & Hillenbrand, T. (2009). Determinants of residential water demand in Germany. *Ecological Economics*, *68*(6), 1756–1769. https://doi.org/10.1016/j.ecolecon.2008.11.012

Sebri, M. (2014). A meta-analysis of residential water demand studies. *Environment, Development and Sustainability*, *16*(3), 499–520. https://doi.org/10.1007/s10668-013-9490-9

Shin, J.-S. (1985). Perception of Price When Price Information Is Costly: Evidence from Residential Electricity Demand. *The Review of Economics and Statistics*, *67*(4), 591. https://doi.org/10.2307/1924803

Taylor, R. G., McKean, J. R., & Young, R. A. (2004). Alternate Price Specifications for Estimating Residential Water Demand with Fixed Fees. *Land Economics*, *80*(3), 463. https://doi.org/10.2307/3654732

Udall, B., & Overpeck, J. (2017). The Twenty-First Century Colorado River Hot Drought and Implications for the Future. Water Resources Research, 53(3), 2404-2418. doi:10.1002/2016WR019638.

UNICEF. (2023). Water scarcity. UNICEF. Retrieved August 5, 2024, from https://www.unicef.org/wash/water-scarcity

Wang J. & Chermak J. M. (2021). Is less always more? Conservation, efficiency and water education programs. Ecological Economics, Volume 184.

Wichman, C. J. (2014). Perceived price in residential water demand: Evidence from a natural experiment. *Journal of Economic Behavior & Organization*, *107*, 308-323. https://doi.org/10.1016/j.jebo.2014.02.017

Wooldridge, J. M. (2010). *Econometric Analysis of Cross Section and Panel Data* (2nd ed.). MIT Press.

World Resources Institute (2019). "Updated Decision-Relevant Global Water Risk Indicators." WWW Document. Accessed August 5, 2024. https://www.wri.org/publication/aqueduct-30

Yoo, J., Simonit, S., Kinzig, A. P., & Perrings, C. (2014). Estimating the Price Elasticity of Residential Water Demand: The Case of Phoenix, Arizona. *Applied Economic Perspectives and Policy*, *36*(2), 333–350. https://doi.org/10.1093/aepp/ppt054

9. Appendix

Table A1 provides a comprehensive breakdown of water consumer accounts across different sectors, revealing notable disparities in account numbers among the sectors. Residential consumers (RES) dominate the distribution with 180,292 accounts, comprising an overwhelming 89.24% of the total consumer base. This signifies a predominant reliance on water services by residential households within the studied area.

In contrast, other sectors such as Commercial, City, and Multi-Family exhibit significant but relatively smaller shares of consumer accounts, ranging from 3.8% to 5.18%. Sectors like FIRE (Fireline) and IND (Industrial) account for the smallest proportions, each representing less than 0.2% of the total accounts.

Such distribution underscores the residential sector's importance in water consumption patterns, reflecting a crucial focus for water resource management and planning. Policymakers and utility providers may consider these insights when devising strategies to allocate resources and optimize service delivery across various consumer segments.

Table A1 The number and percentage of water consumers across different sectors (Jan 2023)

Sector	Number of accounts	Percent
Residential	180,292	89.24
Commercial	10,456	5.18
Multi-family	7,677	3.8
City	1,164	0.58
Institutional	1,114	0.55
KAFB (Kirtland Airforce)	843	0.42
Fireline	237	0.12
JV (Journal Voucher)	154	0.08
Industrial	99	0.05
Other	4	0
Total	202,040	100

Table A2 provides a summary of various statistics related to water use and billing across different sectors, including Residential (RES), Multi-Family (MF), Commercial (COM), Institutional (INS), and City (CITY). It details mean annual water use in billion gallons, with the residential sector showing the highest usage at 14.18 billion gallons, followed by the multi-family sector at 4.45 billion gallons, the commercial sector at 3.76 billion gallons, the institutional sector at 1.2 billion gallons, and the city sector at 1.99 billion gallons. The percentage of total water use reveals a similar trend, with the residential sector accounting for 55.43%, the multi-family sector for 17.38%, the commercial sector for 14.72%, the institutional sector for 4.7%, and the city sector for 7.77%. In terms of water billing, the mean annual water bill in million dollars is highest for the residential sector at 169.41 million dollars, followed by the commercial sector at 42.52 million dollars, the multi-family sector at 40.38 million dollars, the institutional sector at 10.82 million dollars, and the city sector at 9.87 million dollars. The percentage of the total water bill further confirms this distribution, with the residential sector at 62.05%, the commercial sector at 15.58%, the multi-family sector at 14.79%, the institutional sector at 3.96%, and the city sector at 3.62%. Additionally, the mean average price of water in cents per gallon is highest for the residential sector at 1.19 cents per gallon, while the multi-family sector is at 0.91 cents per gallon, the commercial sector at 1.13 cents per gallon, the institutional sector at 0.90 cents per gallon, and the city sector at 0.50 cents per gallon. This table highlights significant variations in water use, billing, and pricing among different sectors, emphasizing the dominant water consumption and associated costs within the residential sector.

Table A2 Annual summary statistics by sector

Variable	Unit	Sector				
		RES	MF	COM	INS	CITY
Mean annual water use	Billion gallons	14.18	4.45	3.76	1.2	1.99
	%	55.43	17.38	14.72	4.7	7.77
Mean annual water bill	Million $	169.41	40.38	42.52	10.82	9.87
	%	62.05	14.79	15.58	3.96	3.62
Water bill per unit	Cents/gallon	1.19	0.91	1.13	0.90	0.50
N		180,292	7,677	10,456	1,114	1,164