Pricing for water conservation and equity consideration: the case of Texas

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Abstract

Water utility providers in Texas have been trying to coordinate demand for and supply of water to ensure a stable source of water given the state's recent rapid population growth and persistent drought-like conditions. Their efforts, however, vary across municipalities throughout Texas. The paper provides a broad analysis of pricing practices in 423 municipalities across Texas from 2014 to 2020 and their impact on residential water consumption. We also assess how other socio-demographic and climatic conditions may influence water use and water rates decisions across municipalities. Besides investigating the potential determinants of water demand, the paper also looks at several supply side variables and the income gap to address the endogeneity of water block prices. Our results shed light on how current water pricing practices in Texas incorporate aspects of the Integrated Water Management Practices that have been shaping water management for decades.

JELcodes: Q2, D4

Keywords: residential water demand, Texas water rates, dynamic panel data

1 Introduction

Proper water resource management is an important issue in Texas, especially for regions with growing population and constrained water resources. According to Phillips and Teng (2020), two economists at the Federal Reserve Bank at Dallas, it is projected that the Texas' population may grow more than 70 percent, from 29.5 million in 2020 to 51 million in 2070, close to double the current population. Texas also has a long history of regular and severe droughts. More recently, for example, during the years of 2011, 2012, and 2014, Texas experienced serious drought conditions, with the western region of Texas being the most affected. Currently as of February 2020, the Edwards Plateau and South Central climate divisions are two of ten divisions in Texas experiencing moderate drought conditions.[1] The challenge posed by a growing population under periodic droughts point to the importance of coordinating growing water demand with potentially restricted water supply.

Figure 1: Population change

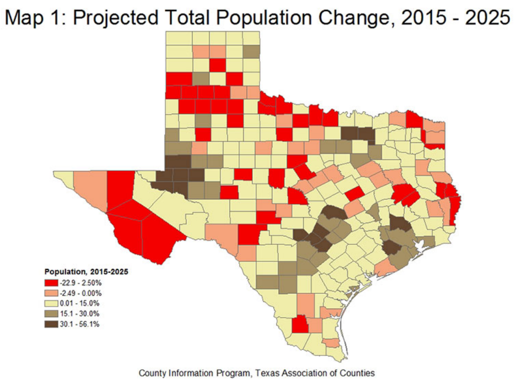
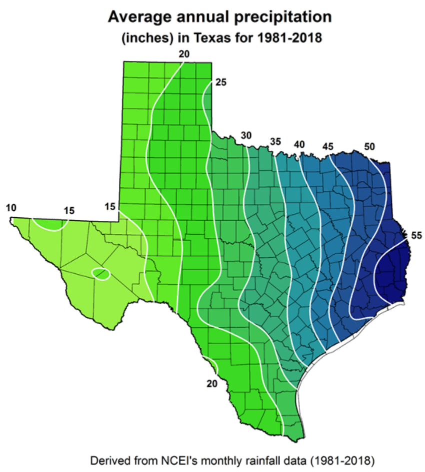


Figure 2: Precipitation



From Figure 1, which shows projected population changes for different Texas counties, we see numerous counties projected to experience moderate to rapid population growth. Figure 2, on the other hand, shows that average annual precipitation has been mostly sufficient for regions in East Texas. Thus even if average annual precipitation remains the same across various regions in Texas, despite the possible future impact of global warming, the possible problem of coordinating residential water demand and water supply across various regions in Texas remains.

There have been a number of surveys of the literature concerning the role water rates have over water use including Espey et al. (1997), Hewitt and Hanemann (1995), and Olmstead et al. (2003). Water pricing generally varies from fixed rate, uniform pricing, to an increasing block, use-based, pricing structure. Despite its possible effectiveness in addressing water conservation goals, the utilization of use-

1. Phillips and Teng, Federal Reserve Bank of Dallas, 2020.

based water rates, especially with respect to the use of increasing block rates, may have unintended consequences of potentially making water less affordable for larger sized but lower income households.[2] Consequently, water utility providers may feel obligated to take into account both revenue, conservation, and equity concerns as they continually adjust their pricing schemes.

In addition, pricing practices have also been supplemented by other methods and concerns such as public education and conservation programs. Indeed, many water utility providers have sought to integrate the economic aspect of water management into a more encompassing concept of sustainable water resources management, an approach that follows the Dublin Principles on managing water resources.[3] More specifically, Integrated Water Resource Management, is a process that attempts to simultaneously manage water and balance the use of land and related resources in order to equitably maintain economic and social welfare while also ensuring the sustainability of ecosystems as a whole.[4]

Integrated water management practices have been established for several decades across the world, getting support and acknowledgment from different countries in the United Nations, and may be especially relevant to Texas given the growing population and persistent drought conditions. Indeed, the Texas Water Development Board have constructed guidelines regarding the Best Water Management Practices that align with Integrated Water Management practices. Our paper, therefore, aims at evaluating how current pricing practices in Texas follow the principles of integrated water resource management. Indeed, throughout the paper, we investigate how pricing practices and water consumption may or may not adjust to a variety of socio-economic background characteristics and climate conditions. Our analysis focuses on residential water use and water rates across different municipalities in Texas from 2014 to 2020 while also accounting for other determinants of demand.

There have been various articles focusing on water rates in Texas: Nieswiadomy and Molina (1989), Griffin (2001), Griffin and Characklis (2002), Hewitt and Hanemann (1995), and Gaudin et al (2001). More specifically, Griffin (2001) and Griffin and Characklis (2002) provide a general picture of the issues and trends in Texas water marketing and effective pricing while Nieswiadomy and Molina (1989) and Hewitt and Hanemann (1995) provide more detailed water demand estimates with household water consumption data in Denton, Texas using OLS, IV and 2SLS. For example, Nieswiadomy and Molina (1989) look at household data in Denton from 1976 to 1985 and estimate residential water demand under decreasing and increasing block rates. Gaudin et al. (2001), on the other hand, utilize a a probabilistic model

2. Dahan and Nisan (2007).
3. Global Water Partnership (2000).
4. Global Water Partnership (2000).

to estimate water demand across different pricing structures using water use per capita and average prices from 221 Texas communities during the period 1981-1985. Most of the previous articles on water demand estimation in Texas date back over twenty years, while in the meantime, Texas has seen rapid growth in population. Our paper, therefore, provides a more recent and extensive analysis into residential water demand using the Arellano-Bond approach.[5]

The structure of the paper is as follows: Section Two reviews the literature on water pricing together with a brief introduction into current residential pricing practices in general and in Texas specifically. Section Three describes the data set and details the empirical methods utilized in the paper while Section Four presents the results, and Section Five concludes.

2 Literature Review

In general, when researchers analyze residential water pricing they need to consider a variety of issues: the price structure, the authorities' pricing objectives, the responsiveness of demand to water prices, which functional forms to use for estimating demand, what contributing factors to use, and which types of data sets to utilize. There have been numerous papers addressing some or all of these aspects, each with a different approach.

With regard to the design of water pricing schemes, Griffin (2001) provides a theoretical framework on how to design one that serves the multiple goals of revenue neutrality and efficiency. Revenue neutrality can be achieved by setting a fixed billing threshold, which balances the financial surpluses and deficits across various users. Moreover, in order to be efficient, water rates need to reflect scarcity originating from different sources such as competition among different uses of water, depletion, and limited infrastructure (Griffin, 2001).

The recent literature on water pricing also tries to account for the interaction between pricing choices and water consumption: while households alter their water use based on the prices they face, household water consumption may in turn shape the water rates that are chosen by providers. This two-way relationship may make it difficult to separate out the impact of price on water consumption. Several authors have tried a variety of models in order to address this problem. Reynaud et al. (2005) uses a probabilistic model which utilizes a two-step selection bias correction method to capture pricing selection across Canadian communities. Using given pricing thresholds that have been chosen to maximize a municipality's social surplus, Reynaud et al. (2005) take a multinomial logit approach together with the probabilistic model to determine consumer responses to those different prices. This

5. Arrelano and Bond (1991).

approach is not only able to capture pricing differences across municipalities but also to derive price elasticities for each.

Hewitt and Hanemann (1995) address the two-way relationship by categorizing water consumption into different pricing blocks. Then using a discrete-continuous choice model and by constructing a probability statement for the blocks separately, the authors are able to obtain unique price elasticities for each pricing block. Other researchers like Gaudin, Griffin and Sickles (2001) and Martinez-Espineira (2003a) use generalized least squares (GLS) and include additional variables to control for the relationships between price and the original explanatory variables. By utilizing this approach, they can also obtain specific price elasticities within each pricing block.

Finding accurate and meaningful measures of price elasticity of demand is an essential starting point for understanding how water users respond to different price signals. However, estimates vary across the literature. Hewitt and Hanemann (1997) and Espey et al. (1997) provide a broad analysis on the price elasticity of water demand and find a mean elasticity of only around -0.51. Nonetheless, they suggest that price elasticities might be higher for alternative pricing structures such as increasing block rates without giving a detailed explanation why. In addition, past studies of elasticity may not have estimated price elasticity accurately since most used current prices without paying much attention to possible lagged responses from consumers to past water price signals. They also did not allow for possible direct impacts of differing water rates. More recent literature have tried to address these problems by including a wider variety of water rates over time together with a comparison of impacts on residential water demand across varying pricing structures. Olmstead et al. (2007) analyzes the influence of different pricing structures on residential water consumption. They also conclude that estimates of price elasticity are higher for increasing block rates compared to traditional flat rates. Moreover, they provide possible explanations for this higher price responsiveness. For example, households that trigger a higher marginal price for use beyond some level of consumption may pay more attention to price and water use since they expect to see a higher water bill than households who do not trigger the higher price.

Studies of water consumption also include other contributing factors besides price. Although, researchers have used different contributing factors for water demand, the key variables that influence residential water consumption boil down to weather conditions and household-related variables.[6] Temperature, precipitation, and the evaporation rate, for example, are important contributing factors as they can potentially affect pricing decisions and affect water use. Additionally, according to Maidment and Miaou (2008), the response to rainfall can depend more on

6. Hall (2009); Hoffman and Worthington (2008); and Olmstead et al. (2007).

its occurrence than on its magnitude while there appears to be a non-linear and monotonically positive relationships between water use and temperature changes, specifically when temperature rising above 21 Celsius degree.

In addition, Hall (2009) sheds light on how pricing design may vary over time to account for different climatic conditions in the case of Los Angeles county. During years with normal precipitation, the higher block price should equal the long-run marginal cost so as to achieve economic efficiency. During drought years, the rate ordinance should include automatic increases for the second-tier price and an accompanying reduction in the threshold, with the magnitude of these adjustments specific to the severity of the shortage.

Household characteristics might also affect water consumption, as have been shown in Hoffman and Worthington (2008) and Olmstead et al. (2007). Household size is a potential contributing factor in terms of determining the level of water consumption but is time-invariant within a short period of time. However, there may be a variation in household size across municipalities. As a result, including household size in the regression may help explain residential water demand.

The level of income has also been used as one of the possible factors affecting water consumption. Previous studies by Olmstead et al. (2007) and Gaudin et. al (2001) indicate that the estimated income elasticity of demand for water is small. Nonetheless, these studies do not employ samples of multiple regions with income-diverse populations. The inclusion may be relevant since, when considering larger municipalities, income levels may matter as well as income differences among individuals within those communities may matter as well. Therefore, we investigate whether local communities try to adjust water rates to account for differences in distribution of income, so as to ensure that basic water use is affordable to all households. Accounting for the distribution of income may thus help us explain demand as well as make sense of how municipalities with large variation in incomes may try and incorporate this concern in their water rates.

In addition to using use-based water rates, many water utilities have tried to engage consumers using a variety of public information and conservation programs in order to encourage water saving in the long run. Public information refers to the programs that inform water users about the current structure and design of the water rates, while conservation programs provide water consumers with information regarding how to use water more efficiently. Even though these programs aspire to the similar goal of water conservation, their different approaches may affect water consumption differently. The effects of public education and water conservation, however, have not been shown to be statistically significant for different regions of the US. Nieswiadomy (1992) analyzes water demand in different regions across the United States using the data from the American Water Works Association (1984) and concludes that public education appears to have reduced water consumption only in the West while conservation programs do not appear to reduce water use for the time period of interest in any of the regions studied.

With regard to the modeling of residential water demand, the choice of functional forms is still not clearly defined in the literature. There is a variety of functional forms that have been used to specify water demand and to compute demand elasticities. Linear demand functions are the most straightforward while a non-linear demand function allows for changing incremental responses at different prices. Among the non-linear functional forms, the double log model is a common specification in the residential water demand literature. Olmstead et al (2003), Baerenklau et al. (2014) use Cobb-Douglas, while Arbues et al. (2003) and Gaudin et al. (2001) use the Stone-Geary utility function, with the justification based on the theory that consumers are more sensitive to changes in price when price is high. Instead of using specific functional forms for their estimation, some researchers use more general forms to allow for higher variation with respect to water rates. For example, Nuauges and Blundell (2010) nonparametrically estimate price and income elasticities of residential water consumption using variation in the block pricing structure and tariff rates for different areas in Cyprus. They argue that this approach of not assigning a specific form for the parameters of the explanatory variables, reduces the potential biases inherent in the parametric-structural and more reduced-form approaches and thus more accurately estimates what the data infers.

A variety of data sets, from cross-sectional to time series and panel data, have been employed to evaluate residential water pricing. The use of panel data has become standard practice due to its ability to address both time and space dimensions for water demand. However, most of the panel data literature has either focused on micro-household data within a certain region or focused on comparing several cities/regions on a similar scale. These micro household data sets provide a detailed look into water user behavior for different types of households with respect to water policies. However, they may not reflect how behavior differs across different regions with varying populations. Our paper uses panel data from most Texas municipalities with varying sizes and socio-demographics characteristics in order to shed light not only on water use but on how different cities may adjust their prices based on socio-economic characteristics and water supply conditions and on how they adapt to these changes over time.

In relation to the above literature, my paper attempts to make contributions in several ways. First, we investigate how water rates may address conservation and potential equity concerns associated with income differences. The paper also highlights the differences in terms of statistical significance and elasticity between the second and first block prices for differing groups of municipalities based on population sizes. Furthermore, the paper addresses the potential endogeneity of water rates and water use by analyzing how rates may be influenced by supply and demand side variables. The paper also attempts to investigate the impact of water conservation and public information programs specifically in the case of Texas.

3 Addressing current water pricing practices

In this paper, we focus on investigating the use of pricing practices in Texas in conserving water resources while taking into account each municipality's differences in climate and socio-demographic conditions. In order to better assess the effectiveness of pricing practices, there are several issues we need to address first.[7]

Before evaluating the effectiveness of current pricing practices, it is important to acknowledge different types of price structures that may be implemented by water utility managers. Residential water pricing typically takes one of the two forms in the United States: (1) uniform rates or (2) increasing block rates. Each of these price structures also includes a fixed base water service fee to ensure revenue stability. Uniform rates charge a single volumetric marginal price at any level of consumption while increasing block rates charge higher marginal prices for higher quantities consumed beyond a given threshold.

Uniform pricing encourages users to use according to their own needs with no pricing differences across different groups of water users. The advantage of this practice stems from its equality in price: there will be no undesirable constraint on large low-income households with higher water use if the uniform price is not set too high.

Increasing block rates are used by more and more water utilities across the country due to its use-based characteristics and its potential for conservation pricing. By setting higher prices for higher amounts of water consumption, increasing block rates try to restrain water use to within the amount deemed as desirable for serving essential needs. Nevertheless, defining what amount of water use is deemed essential and what is considered excessive is difficult. Indeed, defining the quantity for each block in the price structure and setting the number of blocks varies across municipalities. The traditional increasing block pricing scheme defines each block based on a fixed quantity of consumption. In recent years however, in cities within the Los Angeles area, each block can vary depending on the socio-demographic conditions of each household. Nonetheless, this method has not been adopted widely since information regarding the socio-demographic conditions of each household are not always known to utility providers.

7. Olmstead et al. (2007).

In Texas, most cities adopt the traditional increasing block price where the first block is normally classified for basic water use while the second block is classified for discretionary or for the luxury use of water. Indeed, based on the guidelines from the Texas Water Development Board, to qualify as conservation pricing, the price of the higher block should be associated with discretionary and seasonal outdoor water use. Specifically, as recommended by the Texas Water Development Board (TWDB), the first block is designated for the use of 5,000 gallons and below annually while the second block is associated for water use between 5,000 and 10,000 gallons annually, with the first block price considered as the base price. To get a better idea where the threshold stands in terms of typical consumption, the average water usage throughout the municipalities we consider from 2014 to 2021 is around 6,204 gallons annually. Nevertheless, despite the unity we see in the water-use threshold, municipalities in Texas utilize a variety of block prices. These price differences thus may reflect differences in the socio-demographic and climate characteristics of various municipalities and regions across Texas.

4 Data set and empirical methods

4.1 Data set

Each year, the Texas Municipal League conducts a survey of water and wastewater charges of the state's municipalities. The data set includes water consumption and prices for cities with a wide range of population and income levels. The annual water consumption and water cost data is from 2014 to 2020. The number of municipalities in the Texas Municipal League varies over time as the data set does not always include the same municipalities' water rates and consumption for the years covered. Thus, in order to retain the characteristics of panel data, we only utilize the data from municipalities that have the water rates and consumption data for three years or more in the period of interest. Based on this criteria, the final data for residential water use consists of 423 municipalities in Texas. The data set includes both residential and commercial use but we only focus on residential water use. The data set includes population, total number of customers, average usage, and the price for each block of usage. Although all of the municipalities included use increasing block rates and the same water usage thresholds, the price for each block varies across municipalities.

Evaluating the impact of pricing practices on water use requires detailed information regarding the break down of the pricing structure. In the context of the data set, we have the price for each block as shown on the typical residential water bill which consists of a water service base price, a water usage price, and the total water bill. We use the water rates as a proxy for the costs consumers face in their water bills.

In addition, we consider other potential contributing factors for water use, of which annual data is also collected. The data on household size and median and average household income is obtained from the US Census and the World Population Review. Both median and average household income are included as a proxy for the possible income gap for each municipality, which might be helpful for explaining possible equity considerations built into the pricing structure.

We also consider other means that may influence water consumption such as public information and conservation programs that water utility providers offer water users in order to encourage more efficient water use. Information regarding public information and conservation programs are collected from the Texas Water Development Board, and dummy variables are created in order to reflect whether or not these programs are available in each municipality. Since conservation programs may come in many forms, we code the conservation program as being available for any municipality implementing one or more programs.

Additionally, we include regional climate-related variables like precipitation, evaporation rate, and temperature to reflect how they may affect water demand. Nieswiadomy and Molina (1989) account for the difference between the evaporation rate and precipitation rate as a proxy for the water replacement rate, which also helps reflect climatic fluctuation over time. Following previous literature, our paper also looks at the difference between evaporation and precipitation as a proxy for water replacement rate that may shape water consumption, as water use may vary depending on the changes in climate. The climate data is from the National Weather Service Forecast Office. Precipitation and evaporation rate data are in inches while temperature is in Fahrenheit.

4.2 Model specification

In this paper, we follow the double log model specification from Olmstead et al (2007) and Baerenklau et al. (2014). The double log model with respect to prices and water consumption allows parameter estimates to be directly interpreted as elasticities of demand (Schleich and Hillenbrand (2009)). The residential water demand model in this paper is specified as follows:

$$\mathrm{lnw} = \mathrm{f}(\mathrm{lnpfb}, \mathrm{lnpsb}, \mathrm{Popgrowth}, \mathrm{Medinc}, \mathrm{evapordiff}, \mathrm{temp}, \mathrm{HouSi}, \mathrm{Pubedu}, \mathrm{Conserv}) \tag{1}$$

Although demand may also be influenced by lagged prices, we use lagged prices as instruments for the current price rather than including them directly in the model. We also include the lagged residential water demand in the model as following the Arellano-Bond dynamic panel data method.

Table 1: Variables explanation

Variable	Definition
w	Average annual water consumption (gal/year)
lnpfb	natural log of price of the first block
lnpsb	natural log of price of the second block
Popgrowth	Population growth (percent)
Medinc	Median household income
evapordiff	Total annual difference between evaporation rate and precipitation rate (inches)
temp	Average annual temperature (F)
HouSi	Average household size
IncGap	The gap between average and median household income
Pubedu	The dummy variable for public education program regarding water billing
Conserv	The dummy for the availability of water conservation program
rwlevel	reservoir water level (ft)
Pdindex	Palmer drought index
qrestrict	Dummy variable for water use restriction

Table 2: Summary statistics

Variable	Mean	Std. Dev.	Min	Max	N
Population	32226.766	149529.541	114	2325502	2551
lnpfb	3.476	0.374	1.092	4.824	2551
lnpsb	3.949	0.361	1.459	5.894	2551
Preci	42.226	17.608	7.67	105.3	2242
Temp	66.707	4.267	31.3	86.4	2548
MedInc	55291.128	28542.763	17422	250001	2240
HouSi	2.79	0.338	1.76	3.9	2546
AvgInc	71705.573	37901.922	27623	386300	2240
IncGap	16430.98	13483.909	6319	165788	2237
Evaporationrate	54.851	8.459	32.19	85.28	2227
Popgrowth	0.011	0.057	-0.725	0.959	2136
evapordiff	12.526	22.873	-61.16	67.61	2226
lnpop	8.745	1.486	4.736	14.659	2551
ln_use	8.663	0.428	6.114	10.976	2551
Pubedu	0.31	0.463	0	1	2551
Conserv	0.067	0.25	0	1	2551
rwlevel	782.23	765.01	27.8	4468	2539
Pdindex	1.15	2.28	-4.92	5.99	2551
qrestrict	0.35	0.48	0	1	2551

Table 1 shows a detailed list of the variables used in our estimation while Table 2 highlights their summary statistics. From Table 2, we can see the difference between block prices, population, median household income, and precipitation vary widely. These findings emphasize the differences not only in terms of socio-economic factors but also in weather and climate conditions from one municipality to another.

Note that in Table 2 there are two variables that change signs: the difference between evaporation and precipitation rates which is a proxy for the water replacement rate and population growth. If the difference between evaporation and precipitation is positive, then evaporation outweighs the precipitation rate, which might increase the outdoor water use. On the other hand, if the variable is negative, the outdoor water use might decrease thanks to higher precipitation. The change in sign for population growth further emphasizes the fact that some municipalities see decreases in population while others see population growth. These sign-changing variables may complicate the interpretation of our coefficients, and requires further explanation in the results section of this paper.

Since the amount of water usage for each block is already uniformly defined by the Texas Water Municipal League, water utility providers can only adjust prices of the two blocks when responding to water use or other factors. Consequently, water prices may be endogenous and in order to obtain proper estimates, we need to correct for their endogeneity while also taking into account that water rates may also be used to address possible equity and conservation concerns. We address these concerns by looking at how supply-side variables and how the income gap may affect water rates. Although there are alternative tools for public administrators to address income inequality, we focus on the possibility that providers may adjust their pricing structure in response to income differences. As the first block is designed to represent basic water use and possibly priced accordingly, so that water is available to all, pricing changes in the first block price are the most likely to reflect equity concerns. To measure the possible presence of income inequality we use the difference between average and median household income and label this term as the income gap. A positive income gap may result in there being some concerns for equity since it reflects a skewed distribution toward higher incomes. Although this measure might not be as good when compared to the Gini index, given data constraints, the income gap can serve as an appropriate indicator for the possible presence of equity concerns being priced into the water pricing structure. If, on the contrary, average household income is less than median household income, then there may be no equity concerns. From the summary statistics table, we see that the income gap is always positive and this observation further highlights the need to check for potential equity pricing. To do this, we create an interaction term between the current first block price and income gap and analyze its impact. For a robustness check on our specification, we also look at how results might differ if the second block price is used instead of the first block price in the interaction term.[8]

In addition, the second block price may serve as a tool for conservation since going beyond the threshold may signal water use beyond what is considered necessary. Therefore, we consider three supply side variables in the regression as instruments for the second block price: the Palmer Drought Index, the reservoir water level, and a dummy variable indicating whether water-use restrictions have been implemented by the municipality over the study period. We expect the use of a quantity restriction to be positively related to the water rates as the imposition of a quantity restriction may be used in conjunction with a rise in price. The Palmer Drought Index varies from negative to positive values with negative values indicating the presence of drought, with a more negative number signifying a more severe drought. Since positive values of the index refer to times of high precipitation, we expect the drought index to be negatively related to water rates since higher the index, the better the water availability and lower the price. With regard to the measure of reservoir water levels, we also expect it to have a negative impact on water rates since higher the water level, the more supply, and lower the price.

With regard to public information and conservation programs, the Texas Water Development Board provides detailed guidelines concerning information each water utility might provide to consumers. The conservation programs, tailored specifically to residential water use, include the Residential Clothes Washer Incentive Program, Residential Toilet Replacement Programs, and Custom Conservation Rebates.[9] Each of these programs are designed to serve home or apartment units depending on their size and date of construction. The implementation of these conservation programs vary across Texas as some municipalities provide one or more while others do not. In addition, public information programs may help conserve water by educating water users on the structure of water rates and how water conservation is important for meeting the goals of sustainably managing local water resources.[10]

4.3 Hypotheses

The hypotheses below formerly focuses on further explaining the impacts of different factors on water demand as addressed. First, as Olmstead et al. (2007) has shown, price signals can play a role in restraining water demand and thus we would expect the sign of price coefficients to be negative. Nonetheless, we have two different prices for each block and these two price signals may have an effect on each other and as a result, may potentially give us mixed results. The significance may

8. See Appendix D: Robustness check.
9. TWDB Report 362 (2004).
10. TWDB Report 362 (2004).

vary depending on which price users react to.

Second, the lagged residential water consumption should be positively related to current residential water use as consumers would not deviate too far from past uses.

Third, since the evaporation rate less precipitation variable may capture variation over time in climatic conditions, it may impact water use especially with respect to discretionary/outdoor use. We would expect a decrease in discretionary water use for negative values of the variable and an increase in discretionary water use for positive values. Even though the variable ranges from negative to positive values, we can see that discretionary water use and the variable move in the same direction. As a result, we expect a positive relationship between residential water use and the difference between evaporation and precipitation rates.

Fourth, as mentioned previously with regard to the municipality average household size indicator, that although it may not vary much over the time period, it may vary across municipalities and we expect it to have a positive impact on water consumption.

Fifth, population growth should have a positive coefficient with respect water use. Even though the variable varies in sign, positive values of population growth should have a positive impact on water consumption while negative values should have a negative impact.

Sixth, we would expect median household income to be positively related to water consumption. Higher income means a higher budget for water consumption and the ability to use more water for a variety of uses, regardless of the changes in water rates. Olmstead et al. (2007) find a weak positive relationship between income and water use.

Seventh, we expect temperature to have a positive relationship with water consumption. However, there might be a mixed sign relationship between temperature and water consumption. Higher temperature might encourage consumers to use more water, however this might put more pressure on current water resources which in turn may result in restricted water use.

Eighth, although the interaction between the first block price and the income gap is expected to be negative since the higher the income gap, the water utility providers might consider the need to adjust the first block to ensure the basic supply of water for all, the overall impact of the interaction term on water consumption may be positive as both the first block price and income gap may move in the same direction when shaping residential water consumption.[11] For example, the higher the income gap, the larger the reduction in the first block price. On the other hand, the lower the income gap, the lower the reduction of first block price.

Finally, we investigate the possible impact on public information and conser-

11. Williams (2015).

vation programs on water use. We expect the sign of both to be negative, which is consistent with Nieswiadomy (1992)'s analysis of the impact of public information and conservation programs in different regions across the US. The variables used here indicate whether or not the municipalities in the data set utilize public information and conservation programs to influence water use throughout the time period studied. Thus the significance of the coefficients may indicate whether these programs aimed at educating people about the current water rates and other water conservation methods are effective or not.

4.4 Methodology and Estimation

First, we focus on the residential water demand analysis where the two block water rates are used in the dynamic panel data model for residential water use along with other socio-demographic and climate variables. We conduct the analysis using the Arellano-Bond dynamic panel data approach with the presence of lagged terms based on the General Method of Moments (GMM), following Kumaradevan (2013)'s method, to address the potential relationship between explanatory variables and the dynamic characteristics of the data.

$$\begin{aligned}\mathrm{lnw_{it}} = \vartheta_{\mathrm{it}} + \beta_1 \mathrm{lnpfb_{it}} + \beta_2 \mathrm{lnpfb_{it-1}} + \beta_3 \mathrm{lnpsb_{it}} + \beta_4 \mathrm{lnpsb_{it-1}} + \beta_5 \mathrm{lnw_{it-1}} + \beta_6 \mathrm{evapordiff_{it}} \\ + \beta_7 \mathrm{HouSi_{it}} + \beta_8 \mathrm{lnMedinc_{it}} \\ + \beta_9 \mathrm{popgrowth_{it}} + \beta_{10} \mathrm{temp_{it}} + \beta_{11} \mathrm{Pubedu_{it}} + \beta_{12} \mathrm{Conserv_{it}} \\ + \beta 13 \mathrm{lnpfb_{it}} \mathrm{xlnIncGap_{it}} + \mathrm{u_{it}} \quad (2)\end{aligned}$$

Prior to doing the regression, we conduct tests for heteroskedasticity and auto-correlation. From the results of our tests, we are able to conclude that there is a heteroskedasticity problem but no auto-correlation problem. We can clearly see that the heteroskedasticity problem lies with respect to population size.[12] To correct for this problem, we break the regression down to account for group-wise differences. This heterogeneity issue is also reflected in the literature. Rinaudo et al. (2012), for example, emphasizes the need to account for differences in municipal water demand due to variation in population characteristics. In the current data set, we see some municipalities associated with high variation in population as well as in median household income. Using a similar approach as in previous literature, we categorize municipalities according to population size which is divided up into five groups:(1) 100,000 and above (2) 100,000-50,000 (3) 50,000-10,000 (4) 10,000-1,000 and (5) 1,000 and below.

12. See Appendix A: Heteroskedasticity and auto-correlation tests.

As shown in the literature by Worthington and Hoffman (2006, 2008) and Olmstead et al. (2003), the relationship between water consumption and weather conditions are usually not linear but monotonically positive and Maidment and Miaou (1986) have pointed out that water users seem to only respond to certain ranges of temperature and precipitation. We follow their recommendation and set a threshold for temperature rather than include all temperature information in the data. Our threshold is based on the average temperature overtime for each population group.

5 Results

Table 3: Main results from dynamic panel model for water consumption

	(1) 100k+	(2) 100k-50k	(3) 50k-10k	(4) 10k-1k	(5) 1k-
lnpfb	-0.17032	0.50476	-0.82889**	0.21120	0.24445
	(0.62786)	(0.11713)	(0.01498)	(0.49824)	(0.18562)
lnpsb	-0.17706	-0.32810	-1.44905***	0.01079	-0.50118**
	(0.49083)	(0.26696)	(0.00008)	(0.97353)	(0.01108)
L.lnw	0.08336	0.31044	0.01932	0.56380***	0.27938*
	(0.66419)	(0.14962)	(0.95165)	(0.00474)	(0.09852)
evapordiff	0.00065	-0.00346	0.06665**	0.09900***	0.04570***
	(0.74821)	(0.14246)	(0.03625)	(0.00264)	(0.00295)
Temp	0.00239	0.05405***	0.00295	-0.01067	0.04505***
	(0.88466)	(0.00395)	(0.81174)	(0.12984)	(0.00058)
Popgrowth	0.18455	1.08516**	0.90551**	-0.03290	0.04742
	(0.88910)	(0.02630)	(0.03274)	(0.96686)	(0.87023)
lnmedinc	0.11085	0.60031***	0.42558***	0.31309***	0.05416
	(0.46803)	(0.00977)	(0.00001)	(0.00735)	(0.82159)
HouSi	0.10794	0.76475*	0.15318**	0.09179**	-0.08452
	(0.42741)	(0.06817)	(0.02580)	(0.01494)	(0.53270)
Pubedu	-0.16903*	-0.45745***	0.01966	0.19700	-0.26185
	(0.08734)	(0.00006)	(0.81656)	(0.12399)	(0.19385)
Conserv	-0.01063	-0.49106***	0.06072	-0.40135	
	(0.89603)	(0.00000)	(0.76751)	(0.34359)	
Observations	62	25	217	668	29
LR chi2	107589.48610	56574.51294	342098.88630	610177.29567	75131.56602

***p < 0.01, **p < 0.05, *p < 0.1

Table 3 gives the results of our regression by each population group. The table shows that the statistical significance of explanatory variables varying across the population groups. The population groups with the most significant results and of the right signs for the explanatory variables are population groups (3) and (4), with population group (4) having the largest number of observations.

The current first block price is not statistically significant for most of the population groups, except for population group (3), where it also has the right sign. The current second block price shows a negative relationship with respect to residential water use across most population groups except for population group (4). In addition, the current price of the second block is statistically significant for population groups (3) and (5). Moreover, we can see that the current second block price are less inelastic than the current first block price, in absolute terms, for population groups (1), (3), and (5).

With respect to the lagged residential water demand, it has positive coefficients for all the population groups with population groups (4) and (5) being statistically significant.

Regarding the results of evaporation difference, we mostly see positive coefficients, which is of the right sign for most population groups except for group (2). The results are statistically significant for population groups (3), (4) and (5).

Temperature has the expected positive relationship for most of the population groups except for population group (4), with population groups (2) and (5) being statistically significant.

Population growth is positive for most of the population groups except for population group (4), with population groups (2) and (3) being statistically significant.

Median household income has positive impact on water consumption across all groups. Moreover, the positive coefficient is statistically significant in population groups (2), (3), and (4). Demand is also income inelastic for all groups.

Household size also shows a positive relationship except for population group (5) with respect to residential water demand, with population groups (2), (3) and (4) being statistically significant.

Public information program has the right signs for population groups (1), (2) and (5), while also being statistically significant for population group (1) and (2). As conservation programs are only available for those cities with larger populations, the variable appears to not have significant impact on smaller towns although the coefficients have the right signs except for population group (3). Conservation program has a statistically significant impact for population group (2).

After conducting a dynamic panel data analysis on residential water demand with respect to potential explanatory variables, we see some puzzling results especially with respect to the current first block price. As a result, we want to investigate the possible endogeneity problem of water rates and analyze the potential correction for endogeneity. We first use the Hausman test to check whether there is an endogeneity problem with water rates and the test result suggests evidences of endogeneity.[13] Indeed, we are able to reject the null hypothesis of no systematic differences in the coefficients of water rates when evaluating water use at 5 percent significance level. To address this, we use the instrumental variable approach. The supply-side variables including Palmer drought index, reservoir water level and quantity restriction dummy are included as instruments since how water providers may respond to water supply and climate conditions can create endogeneity in water rates. Lagged price variables are also used since water rates are set by water utility providers through administrative procedures and thus prices may not be flexibly adjusted from time to time. The income gap is also included in the regression as an instrument for the two-block current water rates to help control for potential equity concerns. All these variables are chosen as instruments due to their potentially strong correlation with water rates and their no correlation with residential water use. Although it has been argued above that the first block price may be adjusted as a result of equity concerns while the second block price may reflect conservation concerns, we still consider how the both concerns may impact both water rates. The reason is that the current first and second block prices may potentially be used together in response to both.

$$\mathrm{p_{fb}} = \mathrm{f(L.p_{fb}, L.p_{sb}, rwlevel, lnincgap, Pindex, qrestrict)} \tag{3}$$

$$\mathrm{p_{sb}} = \mathrm{f(L.p_{fb}, L.p_{sb}, rwlevel, lnincgap, Pindex, qrestrict)} \tag{4}$$

From Table 4, we can see that reservoir water levels and the income gap (in logged terms) both significantly affect water rates. The reservoir water level should reflect water availability in each municipality, which is an essential input for conservation consideration. With respect to the other possible impacts, the Palmer drought index has a statistically significant impact on the two prices, and also the expected negative sign. The quantity restriction variable, on the contrary, is not statistically significant despite showing the expected positive sign. On the other hand, the income gap may reflect possible equity considerations if it showed a negative sign with respect to the water rates. Here, however, since the coefficient for the income gap is positive, it seems that the water pricing structure of providers may instead be regressive.

To address the endogeneity problem of water rates and in turn, to improve the model results for water consumption, supply-side variables that significantly influence water rates from Table 4 are also incorporated in the dynamic panel data for water consumption. After following the appropriate procedures to correct for possible endogeneity of the two current block prices, we see that the signs of both the current first and second block prices have been improved. Indeed, once we have

13. See Appendix B: Hausman test.

Table 4: Water rates and supply side and income variables

	(1) sb	(2) fb
L.lnpfb	0.1452***	0.0117
	(0.000)	(0.772)
L.lnpsb	0.0699*	0.1411***
	(0.077)	(0.000)
rwlevel	-0.0018***	-0.002***
	(0.000)	(0.000)
lnincgap	0.0259***	0.0253***
	(0.0038)	(0.0044)
Pdindex	-0.0371***	-0.0025
	(0.0019)	(0.118)
qrestrict	0.0513	0.0312
	(0.198)	(0.436)
Observations	1643	1643
F	32.38	25.09

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

combined the variables on both demand and supply side together with the interaction term, the impact of the current first block price becomes negative for more of the population groups while the current second block price now has negative impacts across all population groups. Moreover, the current first block price becomes statistically significance for both population groups (2) and (3). The current second block price also becomes statistically significant for population group (4) besides population groups (3) and (5). From Table 5, we also have results for the lagged block prices across all population groups. The lagged second block price shows consistently negative coefficients across the population groups, with two being statistically significant for population groups (2) and (5). However, the lagged first block price is not statistically significant across population groups but has negative coefficients for population groups (3) and (4).

With regard to other explanatory variables like population growth, temperature, and evaporation difference, we see that they become statistically significant for more population groups in the combined model. On the other hand, there is little improvement in the performance of other explanatory variables like household size, public information or conservation programs.

The income gap, in logged terms, has negative impact for most of the population groups except for groups (1) and (5), which further illustrates that a large income gap, indicating possibly large differences in income, may limit water demand for

Table 5: Main results from dynamic panel model combining supply and demand side

	(1) 100k+	(2) 100k-50k	(3) 50k-10k	(4) 10k-1k	(5) 1k-
lnpfb	0.92372	-0.95949**	-0.46480***	-0.24733	0.12862
	(0.43577)	(0.02312)	(0.00033)	(0.22987)	(0.11572)
lnpsb	-0.25603	-0.34866	-0.49644**	-0.98408***	-0.37501*
	(0.25444)	(0.18880)	(0.01149)	(0.00041)	(0.06105)
L.lnw	0.00172	0.17154	0.18001*	0.03185	0.43006***
	(0.99051)	(0.45544)	(0.09091)	(0.74132)	(0.00115)
L.lnpfb	0.15385	0.40078	-0.01771	-0.18346	0.53658
	(0.71056)	(0.16636)	(0.86693)	(0.46706)	(0.27474)
L.lnpsb	-0.26864	-1.33900***	-0.02148	-0.05640	-0.44048*
	(0.46161)	(0.00000)	(0.93213)	(0.81158)	(0.06295)
evapordiff	0.00170	0.00428**	0.00228*	0.00150*	0.00902***
	(0.39070)	(0.03978)	(0.05920)	(0.06113)	(0.00000)
Temp	0.00233	0.04132**	-0.01110	0.00955*	0.05145***
	(0.87268)	(0.03801)	(0.23729)	(0.09379)	(0.00009)
Popgrowth	0.05557	0.99316*	0.71862***	-0.33214	0.07657
	(0.96258)	(0.06699)	(0.00869)	(0.57566)	(0.79771)
lnmedinc	0.11085	0.60031***	0.42558***	0.31309***	0.05416
	(0.46803)	(0.00977)	(0.00001)	(0.00735)	(0.82159)
lnincgap	0.37930	-1.16368	-1.50641***	-0.67104	0.09911
	(0.45999)	(0.66381)	(0.00142)	(0.37547)	(0.62237)
lnpfb × lnincgap	-0.13428	0.34472	0.49385***	0.24212	-0.02213
	(0.41133)	(0.64242)	(0.00040)	(0.24504)	(0.67161)
HouSi	0.17857	-0.42981	0.13690*	0.08115*	-0.27816
	(0.29348)	(0.11479)	(0.06083)	(0.05341)	(0.13640)
Pubedu	-0.11369	-0.31794***	0.00870	0.17182	-0.09732
	(0.30823)	(0.00355)	(0.93453)	(0.22129)	(0.70818)
Conserv	0.01086	-0.30405**	0.28959	-0.51187	
	(0.90808)	(0.01094)	(0.10952)	(0.22353)	
Observations	53	20	198	599	28
LR chi2	85795.55319	159456.56138	326675.06908	566131.22891	66770.75342

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

households in need. From Table 5, we also see that the interaction term between income gap and block price has positive coefficients for most population groups except for groups (1) and (5), and is significant only for population group (3) between 10,000 and 100,000. The interaction term is positive with respect to water consumption and seems to suggest that changes in the income gap and the current first block price may combine to further strengthen their impact on residential water demand.

6 Concluding remarks

This paper contributes to the current literature on Texas residential water consumption by checking for potential equity and conservation concerns. More specifically, the paper provides an analysis of residential water consumption under current water pricing practices in Texas with consideration for various socio-economic and climatic variables.

Although the significance of explanatory variables vary across different population groups, there are a few things to emphasize concerning their general impact on residential water consumption. Increasing block rates signal scarcity and as a result can help reduce resource use, which is reflected by the significant impacts of the second block prices that we see in a few of our estimates. Public information and conservation programs should also be considered for water conservation consideration since they have a mostly negative impact on water use.

Regarding socio-demographic variables, median household income should also be considered when analyzing water consumption, as it shows a consistent positive impact. Beside median household income, the income gap also matters since it reflects the possible presence of income inequality among water users and its presence may affect pricing and demand. We have checked to see if we could verify this by including an interaction term between the first block price and the income gap. Our results were mixed with respect to our supply-side variables but in our combined estimates, the impact of interaction term is positive with respect to water consumption which demonstrates that the presence of income inequality may strengthen the pricing effects on water demand.

We have also found that climate-related variables like temperature and the evaporation difference variable, should also be considered in evaluating residential water demand, since they have a positive impact on residential water use.

As compared to the literature, this paper analyzes the impacts on municipalities' water consumption across different population sizes rather than studying specific household data or focusing on certain areas with fixed population size. This difference may affect the magnitude of our estimated coefficients. However, the results in this paper still align with the literature, specifically in terms of the current block prices' negative impacts on water consumption. To put the paper in the historical context of Texas residential water demand analysis with respect to increasing block prices, the paper shows that the second block price is relatively less inelastic and statistically significant than the first block price, especially for municipalities with populations of 50,000 and below, which adds to the previous literature by Nieswiadomy and Molina (1989), Hewitt and Hanemann (1995) and Gaudin et al (2001). Using past prices together with supply-side variables as instrumental variables also seems to achieve better results in terms of signs and significance for the second block price as compared Hewitt and Hanemann (1995) which lacked statistical significance for water prices in general. Nieswiadomy and Molina (1989) have statistically significant estimates but a mixture of positive and negative signs for the block prices. Moreover, Nieswiadomy and Molina (1989) do not analyze in detail any differences regarding potential variations in magnitude of their estimated coefficients between different block prices. Rather their interest is in comparing between decreasing and increasing block rate pricing impacts on water consumption. As our paper focuses on increasing block rate pricing, the analysis regarding the relative difference in elasticities between the different block prices is essential. In addition, our paper also utilizes the combination of supply- and demand-side variables to help improve the estimates for the first block price, which becomes more statistically significant and negative for more population groups in the combined model.

Furthermore, previous literature on Texas residential water demand did not allow for programs that encourage water conservation through public education and conservation programs. Our paper has highlighted the significant impact of public education and conservation programs specifically for municipalities with population between 50,000 and 100,000. Even though the number of observation for those municipalities in the dataset is not large, they are the municipalities that reflect relatively major residential water consumption. With the evidence of statistically significant and negative impacts of public education and conservation programs on those municipalities, there can be further application for the water providers in terms of conservation perspectives for higher population municipalities in the long term. Although there has been some work on the impact of increasing block rates on water consumption, the possibility of equity pricing has not been specifically addressed. Our paper has tried to contribute to the literature by considering the income gap variable together with several supply side variables in order to correct for this concern as well as the possible endogeneity of water prices. From our analysis, we can see that the interaction term has positive impacts on residential water demand for three of the population groups, which further suggests that municipal water providers may consider the impact of income inequality through their pricing structure as the presence of income gap strengthens the price effects on water consumption.

In this paper, however, we have not included details regarding the characteristics of water utility providers, which might also have an impact on water rates and in turn, water consumption. These details, if they were available, might be useful for further research into not just evaluating price elasticity but also water rate design. Additionally, in the years to come, we may see more unexpected changes in terms of climatic conditions. Water utility providers may need to look at those changing conditions more closely and plan on ways to adjust water rates and the thresholds for block rates accordingly. In addition, from a water utility provider's perspective, the reservoir water level should also be accounted for. As we have seen in our results, the variable significantly affects both water rates.

On a final note, although we have found some possible concerns for income inequality among water users, potential equity problems need not be addressed through pricing. For example, this may be better addressed through public redistribution programs for lower-income households regarding water use or through lump-sum payments. Such programs may take a less distortionary approach in addressing the problem between water accessibility and income inequality.

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A Heteroskedasticity and autocorrelation tests

Table 6: Heteroskedasticity and autocorrelation tests for population and income

	(1) Population	(2) Income
lnpop	0.90***	
	(0.00)	
lnmedinc		0.31***
		(0.00)
Observations	2551	2239
LR chi2	.	624.38
Panels	heteroskedastic	
Correlation	No autocorrelation	

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$

B Hausman test for endogeneity

```
             ---- Coefficients ----
         |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
         |     fixed        random       Difference          S.E.
---------+----------------------------------------------------------------
   lnpfb |   -.0815641    -.0519278       -.0296363         .0271009
   lnpsb |   -.0870978    -.1393572        .0522594         .0205073
---------+----------------------------------------------------------------
                          b = consistent under Ho and Ha; obtained from xtreg
           B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(2) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        6.87
                Prob>chi2 =      0.0323
```

Figure 3: Hausman test for endogeneity

C Effect size for the model results

Table 7: Effect size for the two-block prices FE model

Estimates	**First block**	**Second block**
Eta-squared	0.5342	0.5179
Omega-squared	0.3733	0.3514

D Robustness check for interaction term: considering the second block

Table 8: Main results from dynamic panel model instead with second block price in interaction term

	(1) 100k	(2) 50k	(3) 10k	(4) 1k	(5) Hundred
lnpfb	0.30708	-0.06688	0.29821*	0.42816	-0.20262
	(0.42591)	(0.82578)	(0.06503)	(0.42380)	(0.62302)
lnpsb	0.22394	7.77796	-1.46053	0.22982	3.42700*
	(0.89625)	(0.28011)	(0.74264)	(0.92893)	(0.08053)
L.lnw	-0.03945	0.16462	0.20934	0.02797	0.45499***
	(0.81594)	(0.16824)	(0.18328)	(0.83567)	(0.00026)
L.lnpfb	0.12072	0.37993	0.06952	0.18643	0.35738
	(0.78325)	(0.16725)	(0.66142)	(0.71503)	(0.44656)
L.lnpsb	-0.34421	-1.34671***	-0.41340	-0.03821	-0.17501
	(0.41902)	(0.00000)	(0.27991)	(0.93417)	(0.49204)
evapordiff	0.00060	-0.00322	0.00065	0.00101	0.04642***
	(0.76203)	(0.15272)	(0.65404)	(0.25894)	(0.002288)
Temp	0.00412	-0.05404***	0.00414	-0.01070	0.04022***
	(0.80109)	(0.00229)	(0.73580)	(0.11869)	(0.00192)
Popgrowth	-0.28579	0.90937*	-0.84677**	-0.03715	0.03071
	(0.82684)	(0.05725)	(0.04420)	(0.96262)	(0.91371)
lnmedinc	-0.02874	0.12009	0.05293	-0.04658	0.16058
	(0.90503)	(0.43290)	(0.66834)	(0.71062)	(0.53108)
HouSi	0.07712	-0.47111	0.21114**	0.11502**	0.06889
	(0.70040)	(0.10968)	(0.01259)	(0.02416)	(0.70898)
lnincgap	0.23604	3.02553	-0.53774	0.68074	1.55015*
	(0.70043)	(0.31247)	(0.75416)	(0.50619)	(0.05852)
lnpsb × lnincgap	-0.06002	-0.70911	0.14325	-0.11763	-0.37714*
	(0.71724)	(0.32584)	(0.75032)	(0.63916)	(0.06384)
Pubedu	-0.13215	0.19357*	0.15815	0.09695	-0.08251
	(0.34799)	(0.08058)	(0.25233)	(0.71171)	(0.72678)
Conserv	0.12561	-0.35507***	0.50160*	0.06861	
	(0.35657)	(0.00143)	(0.07529)	(0.92755)	
Observations	53	20	198	599	28
LR chi2	87793.58274	170350.50965	243082.90760	529315.15238	70242.79619

$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$