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

Hien Nguyen

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Abstract

The policy makers in Texas have been trying to coordinate demand 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 the current water pricing practices in Texas incorporate aspects of the Integrated Water Management Practices that have been shaping water management for decades and also address the potential equity considerations.

JELcodes: Q2, D4

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

1 Introduction

Proper water resources management is an important issue, especially for regions with growing population and constrained water resources like Texas. 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.[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

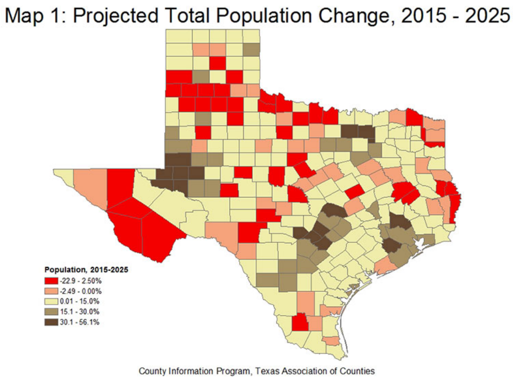
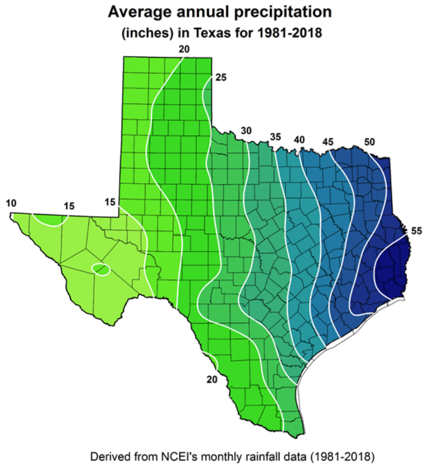


Figure 2: Precipitation



From Figure 1 that showing the population of different Texas counties, even though there are some counties that experiencing negative population growth, we can see a lot of the counties are actually seeing moderate to rapid population growth. Figure 2, on the other hand, shows that the precipitation would increase as moving from the West to the East Texas. Figure 1 and 2, together, better present how different regions across Texas has to deal with the problem of coordinating residential water demand and water supply.

There have been a number of papers surveying the literature studying the role water rates has 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 efficiency in addressing water conservation goals, the utilization of use-based water

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

rates, especially with respect to the use of increasing block rate, may have unintended consequences of potentially making water less affordable for larger sized but lower income households.[2] Consequently, water utility providers often have 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 measures 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 broadly, integrated water resource management is a process promoting the coordinated development and management of water, land, and related resources in order to maintain economic and social welfare in an equitable manner while ensuring the sustainability of vital ecosystems.

Integrated water management practices have been established for several decades and is especially relevant to Texas given the growing population and persistent drought conditions. Our paper, therefore, aims at evaluating how current pricing practices in Texas manage to 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 the water use of Texas residents and analyzes the 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 the 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, examine and utilize a functional form in order to estimate water demand across different pricing structures using water use per capita and average price from 221 Texas communities during the period 1981-1985. Most of the previous articles on water demand estimation

2. Dahan, M., and U. Nisan (2007), Unintended consequences of increasing block tariffs pricing policy in urban water, Water Resour. Res., 43.

3. The Dublin-Principles of the International Conference on Water and the Environment (ICWE) in Dublin, Ireland, 1992 (GWP 2000)

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.[4]

The structure of the paper is as follows: Section Two reviews the literature on water pricing together with an brief introduction into the current residential water pricing practices in general and in Texas specifically. Section Three presents the data set and the empirical methods of the paper while Section Four presents the results with explanations 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, which 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 aspects like inter-sectoral competition, 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 people 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. Through a multinomial logit approach, the probabilistic model helps reflect consumers' responses to different pricing thresholds chosen to maximize a municipality's social surplus. This approach is able to capture the pricing differences across the municipalities and to derive the price elasticities for each.

Hewitt and Hanemann (1995) address the two-way complication by categorizing

4. Arrelano, M., and S. Bond (1991), Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. Review of Economic Studies 58, 277-97.

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. Through this approach, they can also obtain specific price elasticities within each pricing block.

Finding an accurate and meaningful measure of price elasticity of demand is an essential starting point for the understanding of how water users respond to different price signals. In terms of the the price elasticity of water consumption, 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. However, they suggest that the price elasticities might be higher for alternative pricing structures such as increasing block rates without detailed explanation. In addition, past studies of elasticity may not have estimated the 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 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 across varying pricing structures. Olmstead et al. (2007) have analyzed the influence of different pricing structures on residential water consumption. They also concluded that the price elasticities estimates are higher for increasing block rates compared to traditional flat rates. Olmstead et al. (2007) provide some 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 the price since they see a higher amount on their bill than households who do not.

Studies of water consumption also include potential water use's contributing factors besides price. Although, over the years, 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.[5]

Temperature, precipitation, and the evaporation rate are theoretically considered as important contributing factors. These factors can potentially affect the pricing decision and in turn affect water use. According to Hoffman and Worthington (2008), the response to rainfall can depend more on its occurrence than on its magnitude while there appears a non-linear response of water use to temperature changes.

In addition, Hall (2009) also sheds light on how pricing design may need to vary

5. Hall, 2009; Hoffman and Worthington, 2008; and Olmstead et al. 2007.

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.

Some characteristics of the households might also affect the price choice, and in turn, water consumption, as have been shown in Hoffman and Worthington (2008) and Olmstead et al. (2007). First, 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. Furthermore, there may be a variation in household size across municipalities. As a result, including the household size in the regression may help account for possible indirect impact of pricing choices by providers on water use.

Secondly, income level 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 scale of municipalities, income levels may matter as well as income differences among individuals within those communities. Moreover, local communities often try to adjust water rates to account for the distribution of income, so as to ensure that basic uses of water are affordable to every household. Accounting for income distribution can therefore help us make sense of how municipalities with possible large variations of income level may try and incorporate this in their water rates.

In addition to using use-based water rates, many water utilities have tried to engage consumers using 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. On the other hand, conservation programs refer to those programs that 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 AWWA (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 all 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 are various 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 a changing incremental response 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 the Cobb-Douglas function, which is in double log form, for their demand studies. Arbues et al. (2003) and Gaudin et al. (2001), on the other hand, use the Stone-Geary utility function, which is also a log linear form, with the justification based on the economic theory that consumers are more sensitive to changes in price when the price is high. Instead of using specific functional forms for their estimation, some researchers assume more general forms to allow for higher variation with respect to water rates. For example, Nuauges and Blundell (2010) nonparametrically estimate the price and income elasticities of residential water consumption using variation in the pricing block structure and tariff rates for different areas in Cyprus. They argue that this nonparametric approach, assigning no 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 have become standard practice due to its ability to address both time and space horizons 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 provides 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 of 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 cities adapt to these changes over time.

In relate to the literature, my paper attempts to make contribution in several ways. First, the paper investigates the water rates from conservation perspective and how the water rates address potential equity concerns associated with income differences. The paper also highlights the differences in terms of statistical significance and the inelasticities between the second and first block prices for some population groups, which further reflects how water block pricing can help conserve water. Furthermore, the paper also tries to address the potential endogeneity of water rates in evaluating water use by analyzing how the rates may be affected by supply side variables. Moreover, the paper also attempts to investigate the impacts of water conservation and public information programs specifically in the case of Texas. Last but not least, my paper evaluates impacts of explanatory variables on water consumption of municipalities across different population sizes.

3 Addressing current water pricing practices

In this paper, we focus on investigating Texas's use of pricing practices in conserving water resources while also 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 complications we need to address.[6]

Before evaluating the effectiveness of the 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 typically 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 the information regarding the socio-demographic conditions of each household are not always known to utility providers.

6. 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 a 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, 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 further picture where the threshold stands in terms of typical consumption, the average water throughout the municipalities we consider over from 2014 to 2021 is around 6204 gallons annually. Nevertheless, despite the unity in water-use thresholds, cities in Texas utilize a variety of block prices. These price differences 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. The 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 the 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 prices rather than including them directly in the model.

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	2556
qrestrict	0.35	0.48	0	1	2555

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 from one to another.

There are also two variables that change sign in the data set: 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 the existing precipitation water. The change in sign for population growth further emphasizes the fact that some municipalities see decreases in population while others see high 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, the water utility provider can only adjust the prices of the two blocks in responding to water use or other factors. Water prices, as a result, may tend to be endogenous and so there is a need to correct for their endogeneity. Water rates may also be used to address possible equity and conservation concerns. We address these concerns by looking at how water supply side variables and how the income gap may affect water rates. There are alternatives for dealing with income inequality. However, within the scope of my study, I would focus on analyzing the impact of pricing structure and investigate the implementation of price discrimination in accounting for 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 may reflect equity concerns. To measure income inequality we use the sign of the income gap, average household income less median household income. A positive income gap may result in equity concerns and perhaps a lower water price since it reflects a skewed distribution toward higher income. This income gap variable might not be as good when compared to Gini coefficients when addressing income inequality. However, given the data constraint, the income gap is still appropriate to check for the potential equity concerns in pricing structure. On the contrary, if the average household income is less than median household income, 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 the robustness check purpose, we also look at how the results might be different if instead the second block price is instead used in the interaction term. [7]

On the other hand, 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, reservoir water level and a dummy variable indicating whether a water-use restriction has been implemented for the municipality over the study period. We would expect the availability of quantity restriction to positively affect 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. More specifically, negative values of the index would refer to the presence of drought, with a more negative number signifying a more severe drought. On the other hand, the positive values of the index would refer to times of high precipitation. We thus expect the drought index to have a negative impact on water rates since higher the index, the better the water availability, and lower the price. Regarding the reservoir water level, we would also expect a negative impact on water rates since higher the water level, the more supply, and the lower the price.

With regard to public information and conservation programs, the Texas Water Development Board provides detailed guidelines regarding what each water utility might provide for public information and conservation programs. The conservation programs, tailored specifically to residential water use, include the Residential Clothes Washer Incentive Program, Residential Toilet Replacement Programs, and Custom Conservation Rebates.[8] 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.[9]

4.3 Hypotheses

The hypotheses below are mainly focusing on explaining the impacts of different factors on water demand. The supply side variables would be investigated later once we talk more about the potential endogeneity of water rates. 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

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

have the 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 vary depending on which price users react to.

Second, I hypothesize the lagged residential water consumption to positively affect the current residential water use as consumers would not sway too far from their previous 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 evaporation less precipitation rate variable. On the contrary, we may expect an increase in discretionary water use for positive values of the variable. Even though the evaporation less precipitation rate variable ranges from negative to positive values, we can see that discretionary water use and the evaporation less precipitation variable move in the same direction. As a result, we would expect a positive relationship between residential water use and the difference between the evaporation and precipitation rates.

Fourth, regarding the average household size indicator of the municipality, even though it may not vary much over the time period, it may vary across municipalities. We would expect it to have a positive impact on water consumption.

Fifth, population growth might 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 value of population growth may affect water consumption negatively.

Next, we would expect the median household income to have a positive impact on water consumption. Higher income would mean a higher budget for water consumption and the ability to use more water, regardless of the changes in water rates. Olmstead et al. (2007) find a weak positive relationship between income and water use.

Moreover, we would expect temperature to have a positive relationship with water consumption. Even though the sign is expected to be positive, 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.

Furthermore, the interaction term 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 need to adjust the first block more considerably to ensure the basic supply of water for all, which should increase water use. The impact of the interaction term on water consumption may be positive showing that the the impact of both first block price and income gap are moving in the same direction when shaping residential water consumption. A positive interaction term means that the higher the income gap, the greater the impact of first block price on water consumption.[10] In this case, the higher the income gap, the larger the negative impacts of first block price on residential water demand. On the other hand, the lower the income gap, the lower the impact of first block price on residential water demand.

In addition, we investigate the possible impact on public information and conservation programs on water use. We would expect the sign of both to be negative, which is consistent with Nieswiadomy (1992)'s analysis over the impact of public information and conservation program in different regions across the US. The variables of interest here signal the implementation of public information and conservation programs, which are not available for all the municipalities in the data set. 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

Given our analysis of the water rates together with supply-side variables and the income gap, we turn now to our 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 Moment (GMM), following Kumaradevan (2013)'s method, to address the potential relationship between explanatory variables and the dynamic characteristics of the data.

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

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.[11] To correct for

10. Interaction effects between continuous variables. Richard Williams. 2015
11. See Appendix: Heteroskedasticity and auto-correlation tests.

this problem, we break the regression down to account for group-wise differences. This 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 can 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.

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 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 gives the results of our regression by each population group. The table shows that the significance of the 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 (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 the evaporation difference variable, 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).

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

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

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, 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).

Household size also shows a positive relationship except for population group (5) with respect to residential water demand, with population groups (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).

In order to address how water demand and water supply might align, the supply-side variables that significantly influence water rates from Table 3 are also incorporated in the dynamic panel data for water consumption. The purpose of this combination is to address the endogeneity problem of water rates and in turn aim at improving the model results for water consumption.

We use the Hausman test to check whether there is endogeneity problem with water rates and the test result suggests evidences of endogeneity.[12] To address the possible endogeneity of the block prices as mentioned above, we use the instrumental variable approach. The supply side variables are included as instruments because how water providers may respond to water use can create endogeneity in water rates. Besides, the lagged variables are used also as instrumental variables since all the water rates are set by water utility providers through administrative procedures and so prices may not too flexibly adjusted from time to time. Other variables in Table 3 are included in the regression as instruments for the two-block current water rates to help control for possible conservation and potential equity concerns. Alhough it has been argued above that the first block may tend to reflect equity concerns while the second block may reflect conservation concerns, we still consider both variables and how the other supply side variables may impact both water rates. The reason is that the first block price and the second block price may be used together in response to both concerns.

12. Appendix B: Hausman test

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

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

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

From Table 4, we can see that reservoir water level and income gap (in logged terms) both significantly affect water rates. The reservoir water level should reflect the water availability in each municipality, which is an essential input for conservation consideration. On the other hand, the income gap would 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 water providers' pricing structure may instead be regressive. With respect to water conservation, 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.

After including supply side variables to correct for possible endogeneity of the two block prices, we see that the signs of both current first and second block prices have been improved. Indeed, once we have combined the variables on both demand and supply side together with the interaction term, the impact of the current first

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

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

block price becomes negative for more of the population groups while the second block price has negative impacts for 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: 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.

With respect to the other variable introduced in the combined model, the income gap, in logged terms, has negative impacts for most of the population groups except for groups (1) and (5), which further illustrates that the larger income gap may limit water demand for 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 seems to suggest that changes in the two variables may combine to further strengthen the impact on residential water consumption.

6 Concluding remarks

The paper contributes further 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 the consumption under current water pricing practices in Texas with the consideration of many socio-economic and climatic variables.

Although the significance of the independent variables vary across different population groups, there are a few things to mention 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 the 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, which the paper addresses through introducing the interaction term between the current first block price and income gap. The impact of interaction term is positive with respect to water consumption further emphasizes that the presence of income inequality may strengthen the pricing effects on water demand.

Beside socio-demographic variables and other programs from the water utility providers, climate-related variables like temperature and evaporation difference, 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 analyze 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 affects the resulting coefficients' magnitude. However, the results in this paper still align with the literature, specifically in terms of the negative impacts the block prices on water consumption. On the other hand, the difference in analysis also adds to the literature of evaluating water pricing impacts. To put in the paper 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 population of 50,000 and below, which is an addition to the previous literature by Nieswiadomy and Molina (1989), Hewitt and Hanemann (1995) and Gaudin et al (2001). Indeed, using the past prices together with supply side variables as instrumental variables seem 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 the water prices in general. Nieswiadomy and Molina (1989) have statistically significant but a mixture of positive and negative results for the block prices. Moreover, Nieswiadomy and Molina (1989) does not analyze in details any differences regarding the potential variations of magnitudes of coefficients between the different blocks but rather comparing between decreasing block rate pricing's and increasing block rate pricing's impacts on water consumption. As our paper focus mainly on increasing block rate pricing, the analysis regarding relative difference in elasticities between the different block prices is essential. In addition, the paper also utilizes the combination of supply and demand side variables to help improve the result for the first block price, which becomes more statistically significant and negative for more population groups from the combined model.

Furthermore, previous literature on specifically Texas residential water demand did not allow for programs that encourage water conservation such as public education and conservation programs. Also, even though there have been some work on the impact of increasing block rate pricing on water consumption, the potential for equity pricing was not specifically addressed. Our paper has tried to contribute to this 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 the 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 might need to consider the impact of income inequality through their pricing structure as the presence of income gap can strengthen the price effects on water consumption.

In this paper, we have not included details regarding the characteristics of the water 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 their water rates accordingly. More specifically, from water utility providers perspective, the reservoir water level should also be accounted for since the variable significantly affect both water rates. This paper have highlighted that the current water pricing structure may not be necessarily address the income inequality concern or may not be progressive in nature regarding household income. Besides through pricing structure, potential equity problems may be addressed through public redistribution programs for lower-income households regarding water use or other lump-sum financial incentives. The main purpose of the paper is to investigate the response to potential income inequality concerns. The later research may take another step and also evaluate some alternatives dealing with the income inequality problems associated with water accessibility.

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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

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