Water rights market as a tool to redistribute water in Texas Rio Grande and Edwards Aquifer

Hien Nguyen

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Abstract

1 Introduction

Rising water supply uncertainties together with rapidly increasing population have sparked further interest into more sustainable water management methods in Texas. Water marketing has gathered a lot of discussion as the key to manage water in times of uncertain supply and increasing demand. It is, therefore, important to investigate the water market in the context of water policy in Texas. Water management across different regions depends heavily on the institutions currently implemented. There are multiple doctrines of water management throughout Texas ranging from prior approriate doctrine, absolute ownership doctrine to correlative rights and adjudication pumping rights. These doctrines also vary depending on the type of water resources being addressed, either surface or groundwater. Across Texas, there are two regions that are known for their well-established water market: the Edwards Aquifer and the Texas Rio Grande River. There are characteristics that might help with the establishment and enforcement of a water market. This paper will analyze the characteristics of the water market in these two regions and water marketing method can be applied beyond that. Indeed, increasing population together with economic growth in different sectors in the Edwards Aquifer and Texas Rio Grande has considerably shaped water demand and supply. Climate change has also led to more variations in the water supply for the region, which further emphasizes the needs of water redistribution. The water market established and developed here play a very crucial role in redistributing water between increasing and competing uses of water.

The water markets are established in the Edwards Aquifer and the Rio Grande region of Texas not only due to increasing uncertainties in water supply conditions but also the increasing demand for water. Our paper aims at empirically characterizing the Texas Rio Grande Water market and the Edwards Aquifer market and further analyze how the characteristics of each market adapt to their different regional conditions. The paper would look at the institutional characteristics that might make certain markets more likely to reallocate water efficiently than others. Rio Grande water market system is based on a correlative right system where all rights are from the same water storage areas and are reduced proportionally if there is a shortage, rather than allocated based on priority.[1] On the other hand, the Edwards Aquifer water market have a priority system for water rights. Since the Edwards Aquifer market transaction is affected by different uses of water while the Rio Grande is not, we will look at the market transactions regarding different uses of water specifically for Edwards Aquifer. The paper aims at provide a systematic analysis of water market in Texas through the consideration of two markets: one groundwater markets in the Edwards Aquifer and one surface water market in Texas Rio Grande region.

Necessary conditions for the existence of water markets might include: (1) decoupling of the use of water from land rights; (2) regulatory support for water trading; (3) large water storage facilities and conveyance systems that provide ability to trade both upstream and downstream and over time. [2] Moreover, in characterizing the different water markets, state specific rules might not be enough since there also county-specific or regional specific that might impact each water market within Texas.

The paper would focus on how the water market can act as a water distributive tool in Texas Rio Grande and Edwards Aquifer. The paper also aims at determining what institutions might promote the effectiveness of water market and what institutions might impede on water market's operation. There are many different factors to consider when analyzing water market, including the water right prices, factors affecting the demand, factors affecting the supply. The paper especially tries to look at the water right prices in the region and evaluating how the price reflect the supply and demand factors. Indeed, the prices would be looked at across the variations of drought conditions, precipitation, reservoir level, population growth... Through looking at the water market, I also want to analyze the price variations among different water uses.

There are criterias to evaluate the water markets: active, efficiency of the allocation of water resources, how good is the price as the indicator of the market. Moreover, this paper aims at looking at the price variations across the two markets of interest. The different in prices may imply the different markets' characteristics. While we try to analyze the water markets as a tool to reallocate water and resolve

1. TWDB Water Marketing Guide
2. Libecap et al. 2011

potential conflicts between competing water uses, we come across different limitations in terms of water market transparency in the two regions regarding transaction prices and quantities. However, prices being provided may not be as detailed, and as a result may not be the perfect indicator of the market. In other words, there might be some constraints with the water markets in these two regions.

2 Literature Review

Olmstead (2010) analyzes the economic instruments in tackling the water scarcity problems, especially the water markets. Even though problems regarding whether prices truly reflecting what happen in the market have been pointed out, economic instruments in water management still prove to be crucial in redistributing water through different uses. Moreover, Olmstead (2010) proposes that more comprehensive research on water market structures, externalities, and distributional impacts would help improve the current operation of water market.

Hurd and Coonrod (2012) specifically analyze how alternative climate scenarios together with projected population growth over the upcoming 70 years can have an impact on on stream flows, water supplies and water use. They found that even though water delivery costs may hike due to the increasing water scarcity in the future, the use of groundwater together with surface water help tackle the increasing cost.

De Mouche et al. 2011 further emphasize on the importance of water right transfers as a tool in meeting the growth in urban water demand in the Rio Grande Basin. Indeed, Mouche et al. 2011 investigating the potential determinants of the water right prices as under the circumstances of gradual redistribution of water from farms to cities. They found that the priority year of the water right, total urban water consumption, regional farm cash receipts, quantity of the water right transacted, and regional storage reservoir levels have significant impact on the price of water right in Rio Grande Basin.

Schoolmaster (1991) focuses on water market transactions in the Texas's most active water market - the lower Rio Grande Valley, specifically conducted by the cities of Brownsville, Harlingen, and McAllen. The paper aims at examining how regional, institutional, and administrative factors have influenced the development of a water market in the lower Rio Grande Valley, especially showing the redistributive nature of water marketing as a water resource management policy.

Leidner et al. (2011) also look at the water market in the Rio Grande Basin, especially focusing on the Middle and Lower portions of Texas Rio Grande Basin. THe paper provides a comprehensive analysis over the organizations, institutions, policies and geographic characteristics of the region's water management system through its water market. Leidner et al. (2011) found that the rising prices align with the water scarcity and the increasing transfer of water from lower to higher-value water use. Leidner et al. (2011) specifically look at the operation of the water market in the region and further analyze ways that the water market can be improved.

Levine (2007) looks at both short-term and long-term water transfer trading in the Falcon-Amistad water market, specifically focusing on Hidalgo county. He proposed how high population growth especially high urban population together with enabling legal environment, can be an efficient water management mechanism and also with low transaction cost.

Characklis et al. (1999) analyze the priority for municipal over agricultural water use under drought conditions. They argue that such priority in the form of prohibiting against leasing municipal water to irrigators might not be justified in addressing drought. Indeed, Bedient and Characklis (1990) show that intersectoral leasing would contribute to better water allocation and drought management at small cost to municipal users.

Chang and Griffin (1992) look at water transactions between agricultural and municipal users over the 20-year period. They estimate both agricultural and municipal benefits from the transactions together with some unique factors of the region that might affect the water market. Chang and Griffin (1992) then argue that water marketing is a way to better reallocate water among different uses in Texas.

Griffin (2011) and Griffin (2016) analyze the Texas water market within the context of the general water market. Moreover, Griffin(2011) looks at the upside and potential downside of the water market and how the potential downsides can be fixed.

Rimsaite et al. (2016) try to explain the sale and leasing water pricing mechanism in the US. They account for two main factors of the trading prices including the value of the current water use and the expectations for the future supply conditions. The paper argue that the asset pricing theory also hold in the water market. Moreover, the paper also investigates the potential variations in trading prices among the states due to their different water management policies. From their studies, Texas is very active in the sale and lease of water rights, especially the leasing market. Rimsaite et al. (2016) also list out characteristics of efficient versus inefficient water markets including the rules that govern the distribute of water, whether the market is mobile, and the number of market participants.

Yoskowitz (2001) also looks at the price differentials in water trading. Even though the water market is very close to perfect competition among different uses of water, especially between agricultural and other uses. Yoskowitz (2001) argues that these price differences can be attributed to the variations in price elasticity of demand.

Hardberger (2016) evaluates the Edwards Aquifer market in the context of groundwater law in Texas. Furthermore, Hardberger (2016) attribute the success of Edwards Aquifer as a groundwater market to the aquifer's confinement characteristic.

Colby et al. (1993) analyze the water markets in Western U.S. and attribute the price dispersion across the water right transactions to the different characteristics of each market. The characteristics they mention include information and search costs, number and size of the potential market participants, and heterogeneity of water commodities traded.

Brown (2006) also analyzes water market transactions in the western U.S., specifically in the period between 1990 and 2003, and sheds light on how the market activities and prices of water rights are being affected by the local-specific characteristics. Moreover, Brown (2006) also investigates the prices for both leases and sales of water rights and see some different patterns. By showing that the trading prices for municipal use are higher than those for agricultural uses, Brown (2006) also argues the role of water market as redistributing water from lower-valued use to higher one.

Debaere et al. (2014) analyze seven water markets, including the Edwards Aquifer market, to highlight the achievements and challenges of water market as a response to water scarcity. As water scarcity problem is getting more serios, setting limit on water usage is necessary to help conserve water and also encourage users to trade water rights and invest in efficient usages of water. They propose three objectives to evaluate the water market: limiting water usage, protecting water-dependent ecosystems and stimulating shifts in water use towards increased economic productivity. Even though there are some positive results in limiting water usage together with protecting endangered species and reallocating water among competing uses, Debaere et al. (2004) still point out some challenges for the water markets. Nevertheless, they point out that the challenges are varying across the markets depending on their local characteristics. In the case of the Edwards Aquifer, the farmers may be hesitant to trade with users from other sectors if the transactions can negatively affect local communities.

Debaere et al. (2014) also highlights the huge volatility of water prices in the water market, even though they also emphasize that these variations may also vary across the different markets.

3 Background on the water market in Edwards Aquifer and Texas Rio Grande

The Texas water market in general includes different forms such as the spot water markets, option markets and environmental leasing and purchase programs. Certain criteria must be met for a water market to exist within a regional water-management system (Leidner et al. 2011). The criteria are, from Saliba and Bush (1987), (1) a portion of a supply system's right to use water is owned by individuals (either people or firms), (2) those rights must be transferable among these market participants, and (3) claims to these rights must be respected and secured property rights. These criteria may be met differently across the two water markets we consider. Moreover, the investigation into water markets would not be complete without evaluating market efficiency, and in this case how water market efficiency varies across the municipalities.

Following Colby et al. (1993), market efficiency is linked to the magnitude of price variation across the different water uses and also depending on water market characteristics. Colby et al. (1993) suggests that a particular market is less competitive if there is greater price variation.

In the paper, we want to look at characteristics that describe allocation status, especially regarding the system type of each market and the monitoring and enforcement of property rights in the market. The type of the system includes prior appropriation, proportional system, or federal project. Depending on these different system type, some markets might be better at minimizing ambiguities and uncertainties than others.

Furthermore, regarding the water market, there are also characteristics that describe transfer processes. These transfer processes are interconnected with the allocation status. Indeed, the effectiveness of the transfer processes depends on how well property rights are defined and enforced. At the same time, the transfer processes may affect the efficiency of the water allocation. The transfer processes can be described through: (i) the degree of mobility, (ii) the number of participants, (iii) the existence of a clearning house, (iv) the level of homogeneity of the traded good, and (v) the third-party effects.

The Texas surface water and ground water markets are analyzed separately since they are governed by different rules. As a result, there are variations between Edwards Aquifer market and the Rio Grande in terms of water pricing and water management mechanism.

Texas mostly follow the prior appropriation doctrine. Currently, surface water rights are both appropriative and transferable. Generally, the surface water rights are clearly specified with details regarding annual water amount, type of use, location and rate of the diversion, and the seniority date (Texas Water Code 11.021).

For groundwater markets, the property rights are less clearly defined. It is instead attached to the landowner's land, therefore, rather being owned privately by the landowner through the "rule of capture". However, the "rule of capture" is specified to land, not water. As a result, the ownership of groundwater is not clearly defined or enforced (Griffin 2011). Recently, Groundwater Conservation Districts have taken over the management of groundwater in the hope of sustainably managing groundwater resources while minimizing negative externalities.

The two markets we consider do not fall under that prior doctrination system, instead both the Rio Grande and Edwards Aquifer markets follow the proportionate system. Indeed, in Edwards Aquifer market, the rule of capture for groundwater does not hold but replaced by private property rights (Griffin 2011). Edwards Aquifer market is rather governed by a permit system, where every permit is affected proportionately by water shortage (Griffin and Characklis 2002). In the Rio Grande water market, surface water trading dominate that of groundwater since surface water rights are more clearly defined.

Agricultural users have held the majority of water rights in Lower Rio Grande Valley. Indeed, for the lower and middle Rio Grande region, the trade of water rights are mostly between irrigation district and municipalities and Falcon-Amistad is the main water market in the region (Leidner et al. 2011). Water rights in the Falcon-Amistad region employ a unique type of correlated shares doctrine that has three tiers of priority, which is employed in times of water shortage, with priority of the right determined by the type of use (Domestic Municipality Industrial or Irrigation) and by the diversion history (Class A or Class B) associated with the water right (Leidner et al. 2011). Restrictions on trades concerning different types of water use exist in the Falcon-Amistad water market. More specifically, there is a priority of municipal water use over agricultural water use, while irrigators can transfer water to municipalities the leasing between municipalities back to irrigators are not allowed. The A and B subdivisions of irrigation water rights also carry different weights when converted to DMI water rights. Conversion rates correspond to the higher monthly allocation rate accorded to Class A rights over Class B rights. When Class A irrigation water rights are converted into DMI water rights, the amount of water associated with the irrigation rights is reduced to 50 percent of the original water value. When a Class B irrigation water right is converted into a DMI water right, the amount of water associated with the irrigation right is reduced to 40 percent of original water amount. (Jensen, 1987; Schoolmaster, 1991; Stubbs et al., 2003). Class A rights sell for 2,000 to 2,500 US dollars per acre. An acre of water rights is equivalently to 2.5 acre-feet of water annually, or 800 to 1,000 US dollars per acre-foot of Class A water rights. Class B rights bring 1,750 to 2,500 US dollars per acre, which equates to 700 to 1,000 US dollars per acre-foot of water rights.

Falcon-Amistad region permits entitlements to correlated shares of the Rio Grande River. The agents in the Falcon-Amistad water market generally fall into three categories: (1) individuals, (2) irrigation districts (IDs), and (3) municipal suppliers. The Falcon-Amistad water-rights system supports a thriving market for leased water, which is also called "wet water," "contract(s)" water. Unlike permanent sales of water rights, leased water cannot be transferred outside of a sector. Regional water-supply management on the U.S. side of the lower and middle portions of the Texas-Mexico stretch of the River is accomplished through cooperative efforts of several organizations, including: the Rio Grande Regional Water Planning Group (Region M); the Texas Commission on Environmental Quality (TCEQ), specifically TCEQ's Office of the Rio Grande Watermaster (Watermaster); and the International Boundary and Water Commision (IBWC).

In addition, the region has a market for the temporary use and for the permanent entitlement for the temporary use for the permanent entitlement of surface water rights from the River. A variety of transactions are possible ranging from permanent sale of water rights, temporary lease of water-right entitlement, to long term contracts for water-right entitlement. Temporary transfer refers to a contract of up to 1-year while permanent transfers refer to a contract of 1 year and above. For a temporary transfer, the contracting parties need to notify the Texas Water Commission - the region Water Master with the contract indicating the amount of water to be transferred and the length of the contract (Schoolmaster 1991). On the other hand, for a permanent right from an irrigator, a municipality must petition the Texas Water Commission for an appropriate conversion of water transfer (Levine 2007). Another important step after the appropriate agency reviewing and approving the trade application is to inform the public about the transaction (Rimsaite et al. 2016). Such public information may help account for potential externalities. Others being affected by this transaction may have a chance to protest the trade (Griffin 2006).

Price is determined by negotiations between the buyer and seller of the water and not by the RGW. This is important since it allows for price to fluctuate depending on demand and supply. The sale price represents the capitalized value of the water right over time.

A permanent transfer from one user to another user class does require the approval of the TNRCC. On the other hand, the temporary transfer (or lease) may be on a term, or fixed period, basis. This type of contract promises to deliver a certain quantity of water for a specified period of time, up to one year. The contract price reflects the guaranteed delivery of water per year at a fixed price for the specified period of years. Transfers may be spot market transfers, a one-time exchange of a quantity of water from seller to buyer. Short-term lease represents a purchase of water stock, whereas, a purchase of water right is associated with higher uncertainty since it involves the purchase of a right to water flow, and water availability might vary due the changes in climatic conditions. Transfer price should reflect prevailing conditions (drought or abundance) at the time of transfer.

Option contracts in water markets are emerging. These are contingency contracts with water deliveries based upon the occurrence of a set of particular circumstances. This may involve general drought contingencies and water reallocations, or excess demand sub-markets or users, linked to excess supply sub-markets or users. The transfer price usually includes a fee to activate the option contract. Since there are not much data on option contract transaction, for this paper, we would not go into detail on this option contract.

One of the important characteristics of the Rio Grande Water office is that it monitors and enforces water rights effectively. Deputies continually patrol along the river and canals making sure that right holders are in compliance with regulations and no illegal pumping is taking place. The protection of the water rights by monitoring allows for the value of the right not be eroded. It is because the water holds value along the Rio Grande that an effective market has developed.

Since the transfers are on a one time only basis, the water right holder has continued ownership of that right. This might be a comforting aspect to right holders, especially in a region where rainfall and water flows can change dramatically from year to year and the majority of water rights holders are agricultural interests. Additionally, the ease at which water can transfer hands in the spot market is advantageous.

Also in evaluating the water market in Lower Rio Grande Valley, it is essential to look at some institutional, hydrological and climatic characteristics of the region that might facilitate or impeded the development of water trading.

The traditional surface and ground water markets in Texas are not closely monitored and enforced with the exceptions of Rio Grande and Edwards Aquifer market (Griffin and Characklis 2002). In Rio Grande Water market, the trades are closely enforced according to the priority rules by the Rio Grande Watermaster. The Edwards Aquifer market, on the other hand, is closely managed by the Edwards Aquifer Authority. All groundwater usage must be reported to the Authority and the Authority will also help monitor and establish the platform for water trade. Indeed, the establishment of Edwards Aquifer Authority in 1996 has further set the ground for the operation of Edwards Aquifer water market.

Regarding mobility, in order to trade water rights in the Rio Grande market must submit an application to the Rio Grande Watermaster Office. The trade can either be sale or lease of water rights.

For groundwater rights in Edwards Aquifer market, individuals can either lease or sell the access to the groundwater or to gain a title to the water by pumping it to the surface and then sell it. The groundwater rights can be leased and sold through a permit transfer processes within the boundary of the aquifer. All the transfer or change in the use of groundwater must be informed to the Edwards Aquifer Authority.

The traditional surface and groundwater in Texas do not have many participants. For the surface water market, market participants are limited due to the river authorities. On the contrary, for the groundwater market, there are not many market participants because there are limited ways to transfer groundwater with high transaction costs (Griffin and Characklis 2002).

Nevertheless, market transactions in the Edwards Aquifer market are very active since water rights are better defined and enforced. However, market participants are still limited since San Antonio city is the largest buyer and account for more than 50 percent of water usage in the Aquifer.

Surface water transfers in the Rio Grande Valley are also more active than the traditional surface water market in Texas. The market participants are also numerous, vary from individuals, irrigation districts and muncipalities (Griffin 2011). There are no river authorities in the Valley so the market is more competitive (Chang and Griffin 1992).

The Texas Water Bank acts as a clearinghouse for bilateral trades through an online bulletin board for the general water surface and groundwater markets. It plays the role as a negotiator but the price is still determined by the buyers and sellers. For the Rio Grande market specifically, the Watermaster also acts as a clearinghouse for potential buyers and sellers with a low fixed fee (Yoskowitz 1999). For the Edwards Aquifer Authority Groundwater Trust, established in 2001, acts as a clearing house that facilitates temporary and permanent bilateral trades.

Traditional water markets are considered to trade a heterogeneous good due to its seniority principle of water ownership. Moreover, water rights are traded in a variation of markets depending on regions, types of water source, and types of buyers and sellers.

This heterogeneity does not apply in the case of Rio Grande water market since the seniority principle does not hold. The change in water conditions would affect all the shareholders proportionately within the same type of use. Under the proportionate system, all the water rights owners within the same type of use would be equally affected by changes in water availability. There is no heterogeneity in the sense of water per se, but in the purpose of use. In times of drought, all water use regardless of purpose needs to cut down.

Another potential problems with the water market is externality. Most of the water markets in Texas including the Edwards Aquifer market have this problems but not the Rio Grande market. The negative externalities are associated with most water markets due to their rules regarding the water rights allocation. In the case of Edwards Aquifer market, since the property rights are not perfectly defined, overuse of water might happen. The uncertainties regarding water allocation rules and also recharge rate in the aquifer further worsen the negative externality problem. Nonetheless, thanks to its geographic characteristics, the Texas Rio Grande water market does not have to deal with return flow externalities.

In general, the Texas Water Laws are adequate to protect Texas third parties from detrimental return flows that might unexpectedly be associated with water market transactions.

Besides the return flows externalities and the secondary economic effects associated with surface water market, groundwater market might also need to address the problem of inter-temporal externalities regarding the depletion of water stock and the effects of well drawdown on neighboring wells (Griffins and Boadu, 1992). Indeed, many groundwater right transfers would likely change the geographic distribution of groundwater withdrawals, thus altering local patterns of drawdown even when total aquifer extraction is unchanged in the whole aquifer(Griffins and Boadu, 1992).

When addressing the externalities associated with water right transfers in Edwards Aquifer, we also need to consider the fact that Edwards's groundwater discharge into two springs, Comal and San Marcos, that are also important in providing water for the Guadalupe River basin (Griffin and Boadu, 1992).

In the Edwards Aquifer market, there are several competing uses of water, (1) water for sustaining agricultural profits, (2) water for municipal and industrial uses, (3) water for environmental use, and (4) spring discharges for sustaining the surface water supply.

We would also want to evaluate the Edwards Aquifer market based on the details of the Texas Senate Bill [3] including:

1) Establishing the Edwards Aquifer Authority (EAA) to manage the aquifer;

2) Requiring the EAA to reduce pumping to 450,000 af in the near future and to 400,000 af by 2008;

3) Mandating establishment of water rights;

4) Providing for water sales and leases;

5) Guaranteeing that the agricultural share will be a proportional share of historic use and a minimum of two af per acre;

6) Limiting off farm water leasing so that one af per acre must be related for use in irrigation;

7) Charging the EAA to "protect terrestrial and aquatic life, domestic and municipal water supplies, the operation of existing industries and the economic development of the state".

Before the establishment of the Edwards Aquifer Authority and the water mar-

3. Texas Legislature, 1993

ket, the recharge rate has declined significantly relative to discharge – from 1934 to 1999, especially between 1990 and 1999. In the 1990s when there was a major drought, the legislature answered with Senate Bill 1, which significantly changed the procedure for water resource planning in the State.

The Edwards Aquifer water market is established in 1993. All the municipalities that belong to the Edwards Aquifer water market has water transactions right record starting in 1993, which show that all those municipalities joined since the establishment of the market in 1993. These municipalities include Hondo, Kyle, Medina, New Braunfels, San Antonio, Sabinal, San Marcos, Schertz, Universal City, and Uvalde.

Because San Antonio is heavily dependent on the aquifer for tis water supply, pumping restrictions as a component of drought or several aquifer management could have significant impacts on municipal and industrial water prices.

In the Edwards Aquifer, there is a cap of 550 millions m^3 (450,000 acre-feet) per year by 2004, and would be reduced to 493 million m^3 (400,000 acre-feet) by 2008. Moreover, since the late 1990s, the San Antonio Water Service has been implementing an aggressive water restriction program that is tailored to specified water levels in the aquifer. If the aquifer level drops, increasing regulatory controls will be implemented on municipal water use (SAWS, 2013).

If cities could help farmers consume less water, this could free up a new source of water supply for the city while potentially improving the price and reliability of agricultural products (Ward and King, 1998; Gober, 2010).

San Antonio's ability to negotiate water transfers with agricultural users was facilitated by a federal court decision mandating that the state of Texas regulate use of the Edwards Aquifer through the issuance of groundwater permits, which then became a tradable commodity that enabled San Antonio to purchase water permits from farmers. Since 1999, SAWS has purchased or leased 255 different agricultural water rights, amounting to more than 84.4 million m3 per year at a cost ranging from 0.36 U.S. dollars to 2.20 U.S. dollars per m3 (San Antonio Water System, 2012b).

The municipalities that involve in trading water in the Edwards Aquifer are entitled to certain amount of water permits. Those municipalities then can allocate parts of the permits to their own uses and trade the rest of the permits with other municipalities.

Regulations regarding the water trade in Edwards Aquifer: a) agriculture needs to retain 1 acre foot of the original permit allocation; b) trading from west to east of Cibilo Creek needs justification in terms of no harm to spring flows; c) for trades from Uvalde County to Comal, Hays, Guadalupe, or Caldwell County, a 5:1 transfer ratio - 5 acre feet of water must be purchased in Uvalde for each acre foot used, the other 4 held by the groundwater trust and d) for trades from Medina, Atascosa, or

Bexar County to Comal, Hays, Guadalupe, or Caldwell County, a 3:1 transfer ratio - 3 acre feet of water must be purchased for each acre foot used and the other 2 go into the groundwater trust (Edwards Aquifer Authority 2017). Economically, these rules will cause water to have different values in different places and industries.

4 Modeling

The water rights pricing mechanisms as well as availability of prices for public vary across markets. For the two markets we consider, the prices are based on market transactions and vary depending on the types of use. Municipalities without an official water market often obtain large blocks of water time to time rather than making regular water transactions. [4]

We use the logit model to check whether the factors of interest might determine whether a municipality join the water market or not

$$Pr(Transaction) = f(wlevel, lnpop, precipitation, agmajor) \tag{1}$$

Additionally, we would also want to include variables indicating the major economic sector in each municipality. We derive these variables by assigning dummy variable to each municipality depending on the data regarding groundwater usage. We would assign agriculture as a major sector dummy equal to 1 if the usage data showing that the agriculture purpose using water more than industrial uses and 0 otherwise.

Moreover, it is also important to account for each market's activeness of water rights transactions in the pricing model. Indeed, based on the dataset on water rights transaction, we can get an idea of which municipalities might not be part of the two water markets, respectively. The municipalities that are not parts of the Edwards water market include Blanco, Boerne, Brackettville, Bulverde, Kerrville, Rocksprings, Seguin and Wimberley. The municipalities that are not parts of the Rio Grande water market include Indian Lake, Roma, Santa Rosa, and Weslaco. This information is then incorporated into the model as dummy variable, 0 for non-market and 1 for market participants. We would run the model separately for these two groups of municipalities for each market to see if indeed there are differences in the patterns of price movements, while also considering the impacts of the explanatory variables. The variations in price movements may vary not only between the municipalities within one market but also between the two markets. We need to further characterize the municipalities participating in the water market versus the municipalities who do not. The municipalities participate in the water market may be due to their size, their easy access to water and their characteristics

4. Issues and Trends in Water Marketing. Griffin and Characklis, 2001.

of agricultural vs industrial production. Moreover, the location of each municipality within the aquifer or the river may also determine their engagement in the market.

Number of market participants are different across the two water markets of interests. Indeed, in the Edwards Aquifer market, San Antonio metropolitan area is the main market participants. The city of San Antonio, therefore, may have a great influence on the water price. We would show that the percentage of water used here make up most of the water use in the Edwards Aquifer market. On the other hand, Rio Grande water markets have multiple smaller market participants.

Once we have analyzed the factors that might shape the municipality's decision to enter a water market, is is worth analyzing how water pricing and consumption vary depending on not only market participation decision but also other factors. Indeed, it is also crucial to model how water pricing and water consumption vary across different municipalities depending on their socio-economics, climatic and geographical characteristics. We model these variations utilizing a multivariate analysis of variance model (MANOVA) on the municipalities that have been classified into different geographical groups. The group classification will be explained in more detail in the later section of the paper.

More specifically, I want to look at whether the variation of water trade prices match with the variation of water supply. There might be problems for the alignment if there are potential speculations or market manipulation problems.

5 Data

The data on population and water level of each municipality in both Edwards Aquifer and Rio Grande regions from 1990 to 2021 is obtained to look at whether these factors might affect the decision to join the water market. This duration of the data is to ensure that we leave a few years before the establishment of the water market to clearly see the potential impact of those factors.

We also obtain data on water rights trading in the Edwards Aquifer and Rio Grande market to further investigate the variations in water pricing and consumption.

Table 1: Number of water rights active in Edwards Aquifer region by purpose

Variable	**Total**	**In acre-feet**
Agriculture/irrigation	1096	181,405.7
Municipal/domestic	560	348,375.8
Industrial	379	41,818
Water rights active	2035	571,599.5

We can see that even though the number of irrigation water rights active are much larger than that of municipal, municipalities still use more water (in terms of acre-feet of water rights). We collect the data concerning the prices of residential and commercial uses of water from the Texas Municipal League dataset for the years 2014 to 2021. Other variables like income, Palmer drought index, and the dummy variable for implementation of Watermaster program are also considered to compare the water pricing mechanism and water consumption between municipalities in more details.

Table 2: Variables explanation

Variable	**Definition**
Population	annual population municipality level
Popgrowth	annual population growth (in percent)
Precipitation	annual precipitation county level (inches)
FBR	first block residential water price (in dollars)
SBR	second block residential water price (in dollars)
FBC	first block commercial water price (in dollars)
SBC	second block commercial water price (in dollars)
Income	median household income (in dollars)
wlevel	water level (ft)
Pdindex	Palmer drought index
quantityr	quantity traded for residential use (in acre-ft)
quantityc	quantity traded for commercial use (in acre-ft)
quantityag	quantity traded for agricultural use (in acre-ft)
Watermaster	Dummy variable for the implementation of Watermaster program

The water trade price and the prices provided by the city utility manager are both obtained to compare how closely the municipality might adapt water pricing to the actual water sale and lease prices.

Table 3: Major counties' water level in Edwards Aquifer

Year	**Variables**	**Bexar**	**Uvalde**	**Hays**
2014	water level	636.34	829.56	201.8
2015	water level	652.88	840.83	183.14
2016	water level	672.3	866.89	170.73
2017	water level	670.42	875.02	179.84
2018	water level	664.31	871.79	201.96
2019	water level	677.17	879.5	187.74
2020	water level	664.53	873.78	201.09
2021	water level	662.8	865.79	239.59

We would want to evaluate how the presence of water market affect water consumption behavior. More specifically, we look at the water usage by different categories before and after the 1990. After 1990, there was a downward trend in irrigation water use. On the other hand, we see upward trends in municipal, industrial and

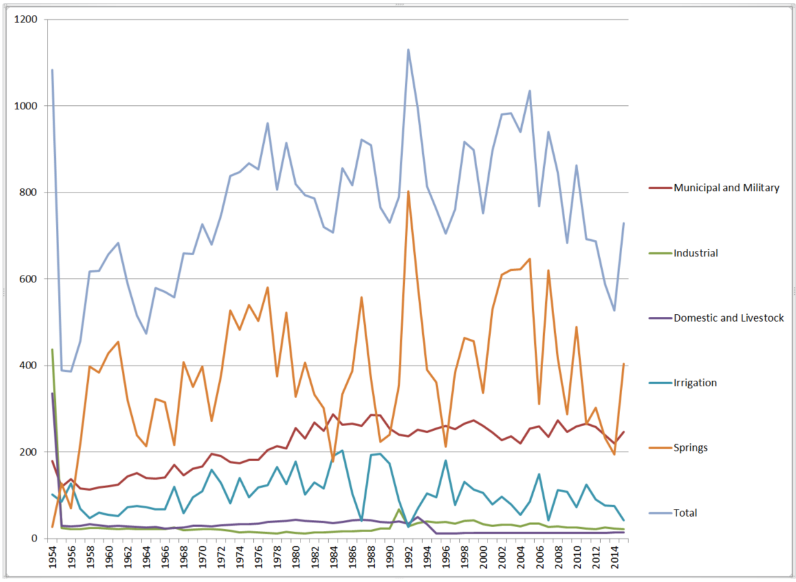

Figure 1: Edwards Aquifer water usage by different categories

spring water usages. We see a peak in total water use around 1992-1994 followed by a downward trend.

The paper looks into the dataset on active water right from 1970 to 2014 in Texas Rio Grande.

Table 4: Number of water rights active by purpose

Variable	Total
Agriculture/irrigation	1173
Municipal/domestic	129
Industrial	37
Recreation	10
Hydroelectricity	3
Domestic/livestock	27
Mining	61
Mariculture	1
Flood control	1
Other	1
Water rights active	1,443

We also want to look at the water rights transaction in Edwards Aquifer. Edwards Aquifer transfers would most likely happen between lower valued agricultural uses and higher valued urban and industrial uses, similar to Rio Grande water market. However, this type of transactions might not always be the case. However, the Rio Grande market sees a higher proportion of agricultural participants than Edwards Aquifer market. As a result, the mechanism of market transactions would be different.

Moreover, while analyzing the data on water rights transaction, it is important

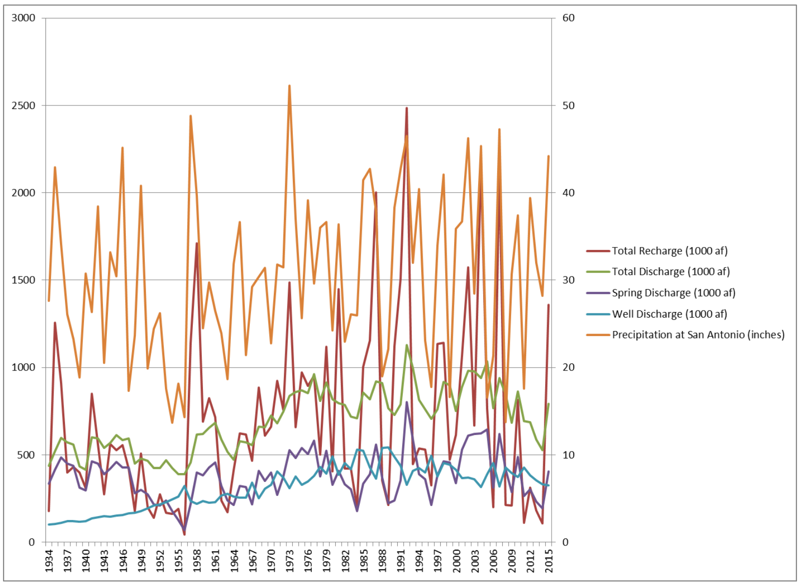

Figure 2: Edwards Aquifer condition

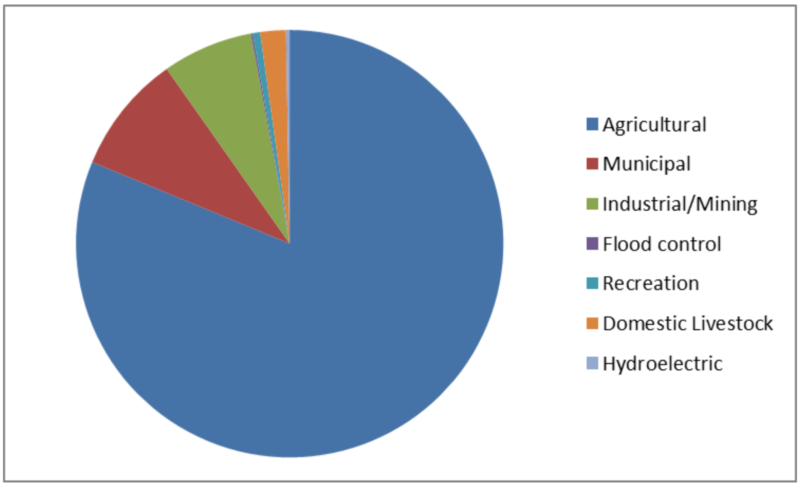

Figure 3: Water right composition 1945-2020

to look at the location of the water right besides the expected use of water right. We analyze the location of water right by looking at the location of each municipality with respect to the Edwards Aquifer or the Rio Grande river.

Table 5: Summary statistics For the Edwards Aquifer market

Variable	Mean	Std. Dev.	Min	Max	N
Population	67509.38	252610.1	1182	1511946	128
FBR	36.75	16.51	10	70	128
SBR	53.37	21.84	18.46	100	128
FBC	263.32	130.49	10	563.1	128
SBC	992.99	411.32	404	1887.79	128

We also want to compare the municipality-specific water price with the average lease and sale price of water rights in the Edwards Aquifer market. As we can see

Table 6: Summary statistics For the Rio Grande market

Variable	Mean	Std. Dev.	Min	Max	N
Population	62102.68	62319.1	804	186738	70
FBR	24.85	8.87	11.15	61.05	70
SBR	39.89	19.22	17.65	123.55	70
FBC	177.87	95.41	0	440.2	70
SBC	630.32	346	0	1550.2	70

Table 7: Weighted average leasing price and contract amount in Edwards Aquifer water market

		Transferor Pool			
		San Antonio Pool		Uvalde Pool	
Transferor Permit Use	Transferee permit use	Average transfer price ($/Acft)	Total transferred quantity (Acft)	Weighted transferred price ($/Acft)	Transferred Quantity (Acft)
Agricultural	Agricultural	$65	9,665	$52	13,095
	Industrial	$140	2,436	$130	40
	Municipal	$121	23,062	$119	7,039
Industrial	Agricultural	-	-	-	-
	Industrial	$228	797	-	-
	Municipal	$172	116	-	-
Municipal	Agricultural	$120	263	-	-
	Industrial	$129	1,105	-	-
	Municipal	$173	3,944	-	-

Figure 4: Weighted avg leasing price and quantity in Edwards Aquifer market

Table 8: Weighted average sale price and contract amount in Edwards Aquifer water market

		Transferor Pool			
		San Antonio Pool		Uvalde Pool	
Transferor Permit Use	Transferee permit use	Average transfer price ($/Acft)	Total transferred quantity (Acft)	Weighted transferred price ($/Acft)	Transferred Quantity (Acft)
Agricultural	Agricultural	$363	543	$652	393
	Industrial	$1,467	133	$10	31
	Municipal	$4,915	4,376	$5,116	3,827
Industrial	Agricultural	-	-	10	75
	Industrial	$3,000	1	-	-
	Municipal	$6,017	3260	-	-
Municipal	Agricultural	$13,000	17	-	-
	Industrial	-	-	-	-
	Municipal	$5,207	318	-	-

Figure 5: Weighted avg sale price and quantity in Edwards Aquifer market

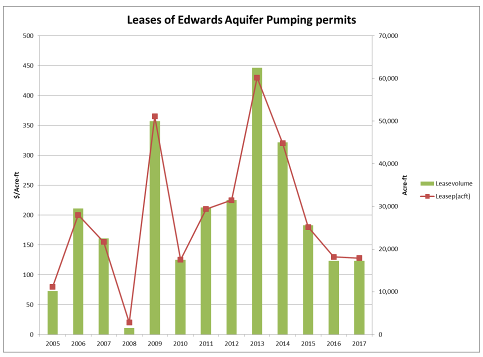

Figure 6: Edwards Aquifer lease permits

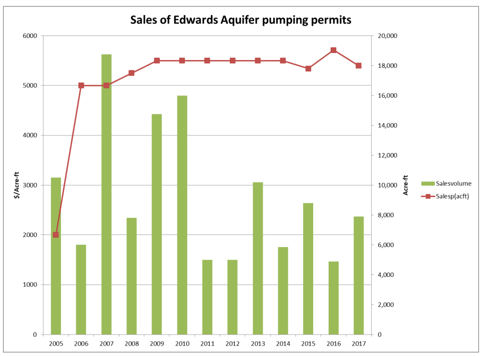

Figure 7: Edwards Aquifer water sale permits

from Figure 8, Blanco, Boerne, Bulverde, Kyle, and Wimberley are the municipalities with relatively high municipal water price as compared to the lease and sale prices of water rights. Among these counties, Kyle participates in the market while the others municipalities do not. On the other hand, Brackettville, Rocksprings, Sabinal, and Uvalde are the municipalities with residential water price being close to the lease prices of water rights. Hondo, Kerrville, Medina, New Braunfels, San Antonio, San Marcos, Schertz, Seguin, and Universal City are the ones with price ranging between lease and sale prices of water rights. Different muncipalities may also have different water prices due to the different pumping and transaction costs.

We want to talk more about the water trading mechanism. The participants can either buy permanent water rights, opt in for annual leases, contingent transfers or spot market leases. The Edwards Aquifer Authority also have the taxing and enforcement authority to collect fees, as well as define and monitor individual pumping rights. By monitoring the water transaction, the EAA can enforce a pumping limits of around 400,000 acre-feet annually. Individual permits specify an annual volume of pumping and may be bought, sold or leased, all or in part, with minimal transaction costs.

In order to make the water trading decisions, the participants need to know information regarding the water level. Depending the term of the rights, whether it is annual lease or multi-year rights, the role of the water level information may be different. We may need to look at the role of other information on water trading as well.

The Edwards Aquifer Authority also implements a drought management plan where it requires the municipality to be reduced under certain aquifer level conditions. If in a given month, the water level in the well drops below 650 ft (above mean sea level), all water users in the San Antonio region must reduce their water usage by 5 percent for that month. If the well water level drops below 640 ft, all water users in the San Antonio region must reduce their usage by 10 percent for that month. If the well falls below 630 ft, water users must reduce their usage by 15 percent for that month.

From Figure 9, we can see in more details the different area of the aquifer and where each of municipalities belongs. The municipality on the recharge zone include Bulverde, the municipalities in the contributing zone are Kerrville, Kyle, Medina, Rocksprings, Wimberley and the municipalities in the artesian zone are New Braunfels, San Antonio, Sabinal, San Marcos, Schertz, Seguin, Universal City, Uvalde . The municipalities that are not belonging to those regions of the aquifer are Blanco, Boerne, Brackettville, and Hondo.

Based on the location along the Edwards Aquifer and the demographics condition, we can group Bulverde together with Boerne. On the other hand, we compare Kerrville with Medina in one group and Kyle, Rocksprings, and Wimberley in an-

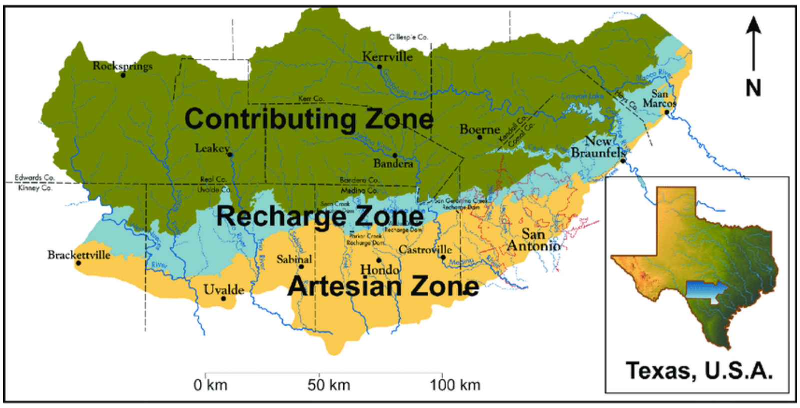

Figure 8: Edwards Aquifer map

other group. Moreover, we can compare Sabinal with Uvalde in one group and we compare Seguin, Schertz, and New Braunfels in another group. San Marcos, San Antonio and Universal City can be grouped together. Combining the location along the aquifer with the population characteristics, we can group Blanco, Boerne, Brackettville and Hondo together.

Once we have the group classification, we can compare within each group the muncipality-specific characteristics and how their water prices reflect their market (in)activities.

Among the municipalities that do not participate in water market, Blanco, Boerne, and Brackettville are not directly on the Edwards Aquifer, Bulverde is in the recharge zone, Kerrville, Rocksprings,and Wimberley are in the contributing zone and Seguin is in the artesian zone.

On the other hand, among the municipalities that actively trade water, Hondo is in the neighboring groundwater conservation district of the Edwards Aquifer, Kyle, Medina are in the contributing zone while New Braunfels, San Antonio, Sabinal, San Marcos, Schertz, Universal City, and Uvalde are in the artesian zone.

These different zones are characterized by the different amounts of water availability. The artesian zone is the area where groundwater being under sufficient pressure to rise above the level at which it is encountered in a well; it does not necessarily rise to or above the surface of the ground. The contributing zone occurs on the Edwards Plateau (or the Texas Hill Country), can also be referred to as the drainage area. In this zone, the water from rainfall is absorbed in the land surface and then runoffs through streams until they reach the recharge zone. The recharge zone is the area where highly water can flow into the Aquifer through the highly faulted and fractured Edwards limestones.

Moreover, the different zones may also determine the different uses of water resources in each municipality.

Most of the counties that are not participating in the water trading have subhumid or semiarid climate, with the exception of Wimberley, together with hilly landscape. Through out those municipalities, the evaporation rate exceeds the preciptiation rate. However, these municipalities' economic activies vary from one to another. The economy of Blanco is based mainly on cattle and livestock. The land surface of Blanco is predominantly hilly, with minimum altitude about 730 feet above mean sea level. Blanco is well drained by streams within the Colorado and Guadalupe River Basins (Texas Water Development Board, 1973). Water level variation in Blanco is usually depends more on the variation in precipitation and evaporation rate than groundwater extraction. Boerne's major economic activity is raising livestock and tourism. Water level variation in the municipality is mainly due to the changing precipitation and natural discharge from the aquifer. Water use in Boerne is mostly for rural domestic, livestock and municipal supply (Texas Water Development Board, 1976). Brackettville's main economic activity is livestock raising. The water resources are used for municipal and industrial purposes in Bulverde. Water utility services are provided to the residents of the city by Canyon Lake Water Service Company (CLWSC) and by Water Services, Inc. While the city receives some compensation for the placement of water lines within the city's right-of-way, rates for these services are set by negotiated rate settlement agreements between the city and the utilities. Kerrville's main economic activity is livestock raising and recreation due to its rough and hilly terrain. Water level in Kerrville here varies majorly due to the relative recharge and discharge rate. Rocksprings's terrain is high, at 2410 feet above mean sea level (Texas Water Development Board, 1969). Groundwater resource in Rocksprings is used for domestic, livestock and public supplies uses. Wimberley's major economic activity is farming and recreation. Wimberley's precipitation is relatively high in the region.

The large amount of domestic water uses in the San Antonio Metropolitan Area further encourages active water trading, especially in times where they see higher future population growth. Among the ones that participate in water market, most municipalities are in the San Antonio metropolitan area except for Hondo, Kyle, Medina and Uvalde. T Hondo also has evaporation rate exceeding the precipitation rate. Hondo's terrain is hilly with the elevation of about 890 feet. Hondo's main uses of water include farming, livestock raising, municipal and industrial (Medina County Regional Water Management Plan, 1999). Kyle's major ground water resources uses include domestic and industrial, with small proportion of agriculture uses. Medina's major economic activity is mining, quarrying and oil and gas extraction. Uvalde's major economic activity is farming and livestock raising, followed by manufacturing.

Moreover, in terms of population, the municipalities actively participate in the water markets have higher population than those who do not.

These differences in geographical, topographical and economic characteristics may in turn explains the differences in water prices across these municipalities.

Across the two water markets, we can see the the water prices are higher in the

Edwards Aquifer market for both residential and commercial uses. Moreover, the price variations are also higher in the Edwards Aquifer, both across the municipalities and across the different uses.

The differences in price variability across the two markets might be attributed to the number of market participants in each market.

Currently, the leasing of water rights regarding groundwater is considered a private contract transaction without any recorded data of price (Hardberger, 2016).

Moreover, I want to look at the sale and lease water markets but there is limited dataset regarding the water lease and sale price in Lower Rio Grande

In order to evaluate the efficiency of the water market, it is also necessary to look at price differentials between different water uses. Indeed, in order for the water market to be efficient, water should be traded from the lower-valued uses to the higher value ones. Moreover, together with the development and changing of the market, it is also crucial to look at how the potential price differentials change over time. Therefore, Imay need to look at the lease and sale price for each sector separately. Nevertheless, there is only data on residential and industrial price, limited data on agricultural price. Instead, I may need to look at the agricultural value of water through farmers' income.

We also need the data set on climatic conditions including precipitation. Besides, reservoir capacity and water level are important factors as well.

The majority of land in the Rio Grande Valley belongs to an irrigation district where water rights are controlled by the district and therefore not separable from the land. The land must be purchased to obtain water rights (Gilliland et al. 2004)

Together with the current population growth trends, I would like look into how the current water market reflect the different uses of water in the region and also extend the analysis to include how the market in Texas affect water use in the Mexico side of Rio Grande basin.

Potential limit to the Edwards market is the prohibition on exporting water for outside uses. [5]

Once we look at the different characteristics determining the participation in the water markets, it is also important to analyze the municipalities after joining the market. More specifically, we want to look whether joining the market can help conserve water better by comparing the water use per capita among the municipalities.

We need to document trading activity, identify the sectors involved, describe the contractual forms used, and illustrate the trends in water transactions over time.

Simultaneous and sequential users of water make exclusion difficult and create numerous interdependencies.

We also need to classify different transactions: whether there are multiple trans-

5. Hardberger 2016

actions for multiple sectors or a single transaction involving multiple sectors

6 Hypothesis

We want to compare municipalities with similar geographical, water supply conditions and socio-economic conditions and hypothesize how municipalities are different in terms of water prices and water uses across different purposes.

We want propose how the factors we look at might increase or decrease the probability of municipality joining the water market.

Log population may positively affect the participation in the market. Water level may negatively affect the participation in the market. In other words, lower water level may create more incentives for municipality to participate in the market and actively trade water rights to meet the demand for water. Precipitation would have a negative impact on the decision since with higher precipitation rate, the municipality might have enough water to sustain themselves without trading.

The municipality economic indicator may also have an impact on whether the municipality would join the water market. If the municipality has agricultural as the major industry, it may only participate in the market only if the benefits of trading exceed the benefits of consuming water on their own. As a result, the relationship might be negative.

The market with prior appropriation has lower efficiency than market with proportional system or managed by federal agency.

Moreover, markets with closely monitored and enforced would be more efficient. As a result, we would also need to hypothesize how the institutional factors in managing water across the two markets might impact the price of different water uses.

In the absence of a water market, irrigation use of water is not significantly different from the status quo, while with the introduction of water market institutions, irrigation use declines while municipal use increases above the scenario with no market institutions. An active water market can reduce the water use value differences. [6]

Once we can get an idea of the determinants of water market participation decision, it is also important to look at the differences between joining vs. not joining the market. In order to evaluate these differences, we would look at the changes in the water usage across the different water uses. We assume that total water usage per capita is on the declining trend for municipalities actively trade water rights but not for those who do not. However, the changes in water usage may vary across different water uses. We may expect that agricultural water use per capita would

6. McCarl et al. 1999

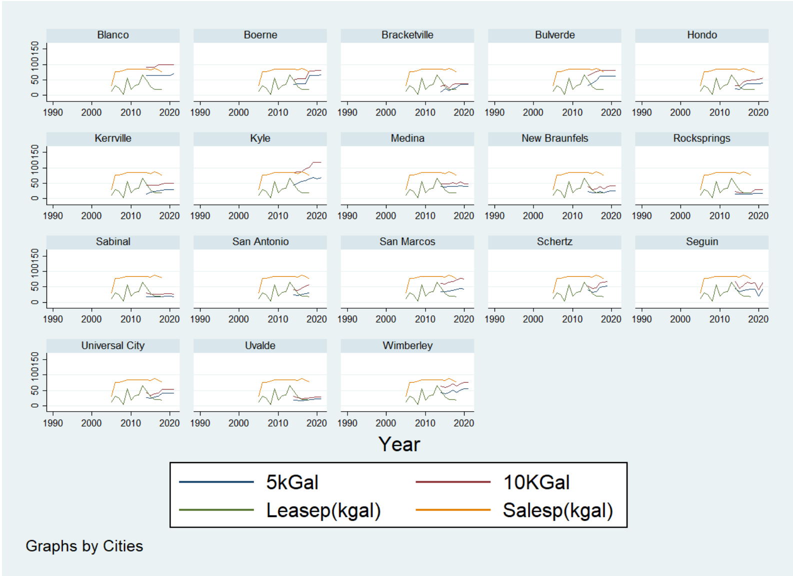

Figure 9

decrease more significantly than municipal and industrial water use per capita.

7 Results

In terms of economic condition, we analyze whether the municipalities use more water for agricultural or municipal/industrial purpose. Among the municipality, there are some municipalities with major agricultural production such as Brackettville, Hondo, Sabinal and Uvalde. On the contrary, municipalities with major industrial production include Bulverde, New Braunfels and Schertz. In addition, depending on the economic conditions, the water pricing and water use behaviors may be different since some municipalities may have more flexibility regarding water pricing and water conservation than others. We may expect to see some variations between municipalities within each group because we allow for some flexibility in terms of size and the geographical background in the group classification.

Along the aquifer, Bulverde and Boerne is on the recharge zone. Bulverde has a population between 3,000 and 5,000, while Boerne has population over 10,000. Both municipalities do not participate in the Edwards Aquifer market. Bulverde has relatively high water prices in the municipal as compared to Boerne. Indeed, the prices are closer to the general water sale prices while Boerne having prices between the sale and lease prices. In terms of water usages, both Bulverde and Boerne see periods of both increase and decreasing water use for both municipal and industrial purposes even though Bulverde experience larger fluctuations.

Kerrville, Kyle, Medina, Rocksprings, Wimberley are in the contributing zone. Among these municipalities, Kerrville, Kyle and Medina are the ones with population between 10,000 and 50,000. On the other hand, Rocksprings and Wimberley have population between 1,000 and 5,000. Kyle and Medina participate in the Edwards Aquifer market while Kerrville, Rocksprings and Wimberley do not. With respect to water prices, the second block price is significantly larger than the first block price for Kerrville and Kyle while the two block prices are closer to each other in the case of Wimberley, Medina, and Rocksprings. Moreover, Wimberley, Kyle and Kerrville are having relatively higher prices than Medina and Rocksprings. Indeed, Kerrville, Wimberley and Kyle are having prices aligning closer with general sale prices while Medina and Rocksprings having prices between sale and lease prices. Regarding water usage, Medina sees low water use during the beginning of water market but then followed by some ups and downs. Kyle and Wimberley sees decreasing water use over time overall since the early 1990s. On the other hand, Kerrville and Rocksprings see some fluctuations over time even though the fluctuations are larger for Rocksprings.

New Braunfels, San Antonio, Sabinal, San Marcos, Schertz, Seguin, Universal City, Uvalde are in the artesian zone. Among these municipalities, New Braunfels and San Marcos have population between 30,000 and 100,000. Universal City, Uvalde, Schertz, and Seguin have population between 10,000 and 50,000. San Antonio is the most populous one with population over 1 million while Sabinal is the lease populous with population between 1,000 and 2,000. Most of these municipalities participate in the water market except for Seguin. Regarding water prices, San Antonio and San Marcos have the two block prices significantly different from each other while the two block prices are closer to each other in the case of New Braunfels, Sabinal, Schertz, Seguin, Universal City and Uvalde. Among the municipalities, San Marcos is the municipality with the highest water prices. More specifically, San Marcos, San Antonio and Seguin have prices between sale and lease prices. On the other hand, Sabinal, Universal City and Uvalde having prices closer to lease prices. New Braunfels have relatively lower prices, with water prices being close to the general lease prices. Regarding water uses, Uvalde and Sabinal are the municipalities with the most fluctuations and also the highest amount of water use per capita across the three different purposes. Moreover, Sabinal and Uvalde - both with major agricultural production, see significant decrease in agricultural water use, as compared to the other types of water use, over time even though the amount is still higher than other municipalities. Schertz and Universal City see initial reduction in water use since the establishment of the water market even though the reduction is more considerable in the case of Schertz. Seguin only see small ups and downs in water use over time. San Marcos see larger reduction in water use than New Braunfels and San Antonio, especially in terms of municipal water use. Although all three municipalities seeing water reduction in the early years of the water market, New Braunfels has some periods where water use is increasing and decreasing again.

On the other hand, Blanco, Brackettville, and Hondo are just outside those zones. While Blanco, Brackettville and Hondo have population between 1,000 and 10,000. Among these municipalities, Hondo participates in the water market while the other three municipalities do not. In terms of water prices, Blanco is having higher price than those of all other municipalities. Moreover, the first and second block prices are further away for Blanco, while those block prices are quite close for Boerne, Brackettville and Hondo. Among these municipalities, Blanco has the highest prices followed by Boerne while Brackettville and Hondo have prices closer to each other's. Additionally, when comparing to the lease prices and sale prices, the two block prices of Hondo and Brackettville are aligning more with water lease prices or closer to the sale prices as in the case of Blanco. Regarding water uses, Blanco sees some small fluctuations for different uses of water over time, Brackettville is seeing periods of significantly increasing and decreasing water use, while Hondo sees some reduction in water use overall especially after the establishment of the market. Regarding agricultural water use, Brackettville and Hondo - the municipalities with major agricultural production, all see some reduction in agricultural water use but the trend varies. More specifically, Hondo sees decrease in agricultural water use few years after the establishment of the water market and the usage stays lower over time, Brackettville does not see any significant fluctuation over time even though there are some periods with decreasing usage.

Overall, we can see that there is a correlation between water pricing and water use. Indeed, we can see that the periods where water pricing is increase align with the periods where water use is decreasing. However, not all counties are seeing prices and water usage moving similarly. In fact, we can see different water use behaviors between those who participate in the market and those who do not. Most of the municipalities that participates in the water trading market see clearer water use reduction in the years following the establishment of the market and also seeing water use on the declining trend over the time period of interest. The two exceptions are Sabinal and Uvalde, which see more fluctuations in both municipal and agricultural water usage. The municipalities that do not participate in the water trading market do not see much changes in municipal and total water use per capita over time. In other words, there is not much evidence of conservation impact among municipalities that do not participate in the water trading market.

We also want to look at the different municipality based on their major production, either industrial or agricultural. The role of the energy industry in the region in terms of water usage.

Once we have classified the municipalities into different groups, we also want to do run the ANOVA to test the differences between the groups. More specifically, we would use the two-way factorial model to explaining the differences in the two block prices across the different group of counties and also whether they participate

```
manova kGal KGal  musepcap iusepcap agusepcap = group##Transactiond
```

Number of obs = 98

W = Wilks' lambda   L = Lawley-Hotelling trace
P = Pillai's trace   R = Roy's largest root

Source		Statistic	df	F(df1,	df2) =	F	Prob>F	
Model	W	0.1668	5	25.0	328.4	8.14	0.0000	a
	P	1.3716		25.0	460.0	6.96	0.0000	a
	L	2.4217		25.0	432.0	8.37	0.0000	a
	R	1.0215		5.0	92.0	18.80	0.0000	u
Residual			92					
group	W	0.3379	3	15.0	243.3	7.81	0.0000	a
	P	0.8506		15.0	270.0	7.12	0.0000	a
	L	1.4239		15.0	260.0	8.23	0.0000	a
	R	0.8513		5.0	90.0	15.32	0.0000	u
Transacti~d	W	0.8741	1	5.0	88.0	2.54	0.0342	e
	P	0.1259		5.0	88.0	2.54	0.0342	e
	L	0.1441		5.0	88.0	2.54	0.0342	e
	R	0.1441		5.0	88.0	2.54	0.0342	e
group#Transacti~d	W	0.7883	1	5.0	88.0	4.73	0.0007	e
	P	0.2117		5.0	88.0	4.73	0.0007	e
	L	0.2686		5.0	88.0	4.73	0.0007	e
	R	0.2686		5.0	88.0	4.73	0.0007	e
Residual			92					
Total			97					

e = exact, a = approximate, u = upper bound on F

Figure 10: Multivariate ANOVA analysis for prices and water use based on group classification and transaction dummy

in the water market. This two-way factorial model would allow us to look at the combined influence of the various combinations of geographical location along the aquifer and the market participation dummy. In order to run the ANOVA analysis, we introduce a factorial variable for the group classification, with group (1) including Boerne and Bulverde denoted as "1", group (2) including Kerrville, Kyle, Medina, Rocksprings, Wimberley denoted as "2", group (3) including New Braunfels, San Antonio, Sabinal, San Marcos, Schertz, Seguin, Universal City, Uvalde denoted as "3", and group (4) including Blanco, Brackettville, and Hondo denoted as "4". This group variable is then used as one of the two factorial variable in the multivariate ANOVA model considering water prices and water usages.

From Figure 10 showing the MANOVA results, we can see that there is a statistically significant difference in terms of water prices and usages across the different groups and also across the market participation decision. Moreover, effect of group classification on water prices and usages also depends on whether those counties participate in the market or not. In other words, within certain group of similar geographical location, the decision to participate in the market or not can explain the differences in water prices and usages across the municipalities. Once we have tested whether there are statistically significant differences in terms of water pricing and using behaviors, it is also important to look at how these differences also reflect other municipality-specific characteristics like population size and climate conditions. Moreover, it is important to explain the meaning of these differences and why they matter.

There are municipalities with huge population growth that may require more attention in terms of water usage.

We would also want to graphically show how the groundwater usage might be different between those who engage in market transactions and those who do not. Moreover, we look at the changes in not just total use but also breaking it down to municipal, industrial and agricultural use.

Figure 11: Municipal water use Edwards Aquifer

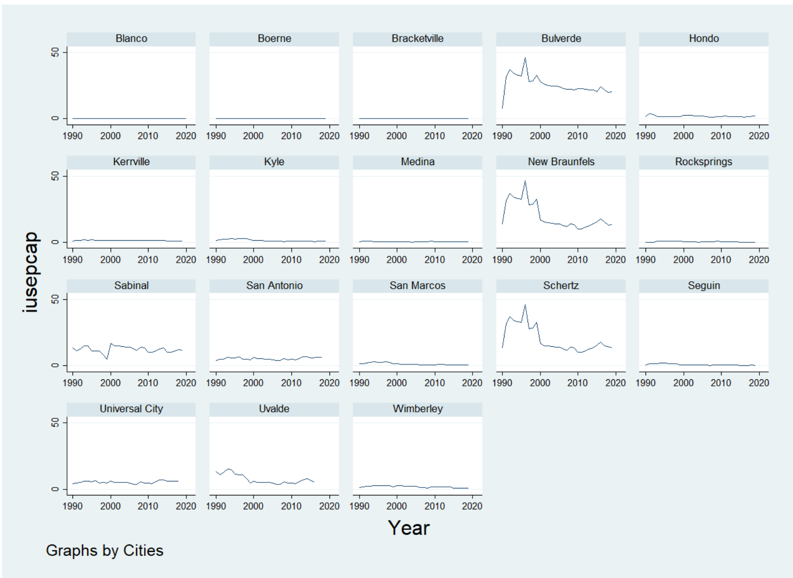

Figure 12: Industrial water use Edwards Aquifer

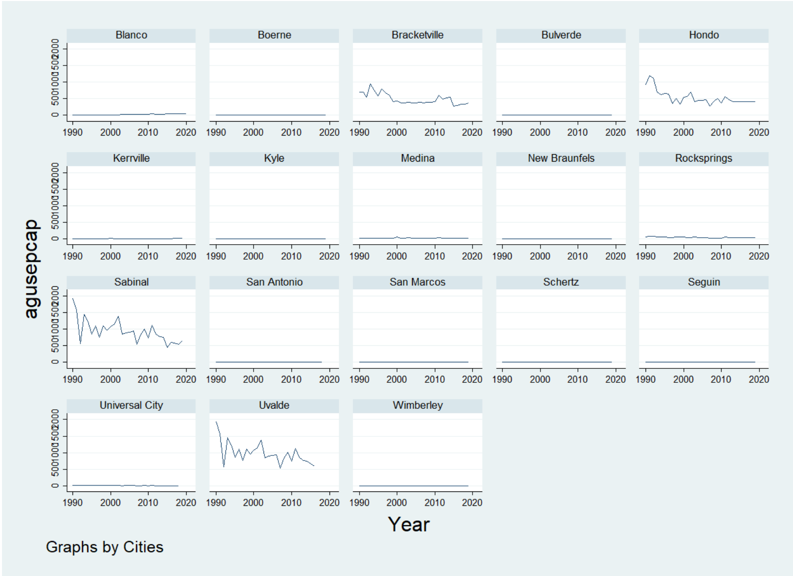

Figure 13: Agricultural water use Edwards Aquifer

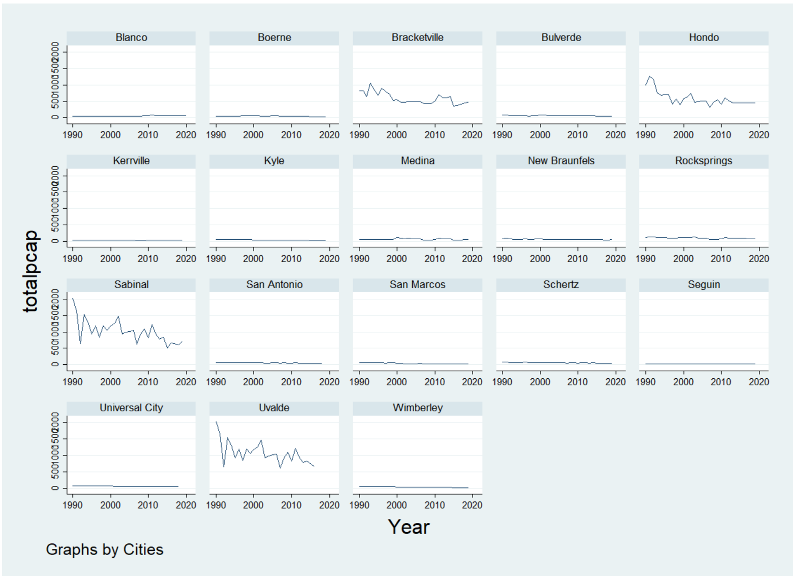

Figure 14: Total water use Edwards Aquifer

Transactiond = 0

Variable	Obs	Mean	Std. Dev.	Min	Max
musepcap	80	36.85755	15.49497	13.65656	74.51955
iusepcap	80	3.940394	7.940342	0	36.92805
agusepcap	80	114.8109	390.6239	.2285838	1932.879
totalpcap	80	155.6089	402.2569	17.40557	2019.064

Figure 15: Water use Edwards market nonparticipant

Transactiond = 1

Variable	Obs	Mean	Std. Dev.	Min	Max
musepcap	450	48.74541	22.65412	7.747891	125.8899
iusepcap	450	6.171117	8.855626	0	46.25601
agusepcap	450	174.1686	330.2823	.068669	1444.895
totalpcap	450	229.0851	345.7492	15.30789	1536.926

Figure 16: Water use Edwards market participant

Referring to Figure 10 to 13, we can have a clearer look into the changes in groundwater usage by each purpose since 1990 to 2020 for all municipalities surrounding Edwards Aquifer. Overall, we can see that the groundwater usage, either total use or usage by each purpose, is on a declining trend for most of the municipalities regardless of market participation. Due to their close proximity, there may be spillover effects of the water market operation. However, for each type of water use, we can see some municipalities with higher volatility. More specifically, in Figure 9 regarding municipal use, Brackettville, Sabinal and Uvalde are the ones with larger changes in water use over time. On the other hand, in Figure 10 regarding industrial use, Bulverde, New Braunfels and Schertz are the ones seeing larger changes in water use. In Figure 11, regarding agricultural use, Brackettville, Hondo, Sabinal and Uvalde are the ones with larger changes. Among those who having more volatility, Brackettville does not participate in market transactions while the others do. Among the different water usage, municipal use is the one changing more often over time.

In addition, we can also have a more general comparison between municipalities participating in market and those who do not from Figure 14 and 15. More specifically, those who participate in market transactions use more groundwater per capita across the different uses. This may be due to the larger industrial and agricultural operations in these counties.

The Edwards Aquifer is not a transparent market, while it provides a portal for parties to apply for either selling or leasing groundwater, it does not provide comprehensive transaction and price data as noted by Collins (2018).

Table 7 and 8 show the dynamic panel data results for potential explanatory variables with respect to the different residential and commercial block prices in Edwards Aquifer for both market participant and non-participant municipalities. From the results, we can observe that water level, median household income, evaporation difference and Palmer Drought Index seem to have significant impact on both residential and commercial block prices, especially the residential block prices across the municipalities with different market decisions. However, the magnitude and sign of coefficients vary across the counties of two transaction groups. For the municipalities not actively trade water rights, we can see that there are some mixture of positive and negative impacts on the explanatory variables across the different

Table 7: Main results from dynamic panel model for water block prices of market non-participating municipalities in Edwards Aquifer

	(1) FBR	(2) SBR	(3) FBC	(4) SBC
wlevel	-0.0012***	-0.0010***	-0.0008***	0.0004***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
popgrowth	0.9497	1.2058**	1.0054	1.6822***
	(0.2119)	(0.0263)	(0.1490)	(0.0015)
lnmedinc	-0.0907*	0.0081	-0.1700***	0.0367
	(0.0652)	(0.8169)	(0.0002)	(0.2846)
PSDI	-0.0577***	-0.0149	-0.0361**	0.0280**
	(0.0011)	(0.2362)	(0.0257)	(0.0227)
evapordiff	-0.0049**	-0.0046***	-0.0051**	-0.0033*
	(0.0406)	(0.0074)	(0.0213)	(0.0508)
Observations	14	14	14	14
chi2	22316.2045	53088.5116	59418.2328	159907.9183

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

Table 8: Main results from dynamic panel model for water block prices of market-participating municipalities in Edwards Aquifer

	(1) FBR	(2) SBR	(3) FBC	(4) SBC
lnple	0.1784**	0.2362***	0.3600**	0.1421**
	(0.0184)	(0.0000)	(0.0173)	(0.0117)
lnpsa	-5.3154***	-4.0686***	-6.9142***	-3.0327***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
wlevel	-0.0007***	-0.0010***	-0.0014***	-0.0007***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
popgrowth	0.5246	0.4918	0.0259	0.8932**
	(0.3199)	(0.1603)	(0.9804)	(0.0231)
lnmedinc	0.2248***	0.2486***	0.3297***	0.0431
	(0.0001)	(0.0000)	(0.0039)	(0.3121)
PSDI	-0.1247***	-0.0960***	-0.1486***	-0.0709***
	(0.0000)	(0.0000)	(0.0003)	(0.0000)
evapordiff	-0.0110***	-0.0063***	-0.0155***	-0.0052***
	(0.0000)	(0.0000)	(0.0003)	(0.0012)
Observations	76	76	76	76
chi2	38019.3717	108781.9576	23046.9097	264649.5445

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

block prices. This is not the case for the municipalities that are actively trading water rights. Population growth seems to have more statistically significant impact for non-market participants municipalities. The possible reason for this difference is that water pricing needs to vary more for those municipalities since they do not secure their supply as often through trading water rights. Those municipalities that participate in water rights trading market also take into consideration of the water right leasing and sale prices, which seem to significantly impact both residential and commercial block prices. Nevertheless, the puzzling observation here is that the sale prices having negative instead of positive impacts on the municipal-specific water block prices.

We should look into the characteristics of different municipalities across the Rio Grande River as well. Texas Rio Grande is in the downstream part of the Rio Grande river.

Figure 17: Texas Rio Grande map

We can divide the municipalities along the Rio Grande river into 4 groups based on their counties as shown in the maps, group (1) being Starr county including Rio Grande City and Roma; group (2) being Hidalgo county including McAllen, Edinburg, Mission, Hidalgo, and Weslaco; group (3) being Cameron county including Brownsville, Harlingen, Santa Rosa, Indian Lake, and San Benito; group (4) being Willacy county including Lyford and Raymondville. This group classification variable is then used in the Multivariate ANOVA model with the transaction dummy in order to explain the differences in water prices and usage across municipalities. We do not just look at these two factorial variables separately but also analyze whether there is an interaction between the two in explaining the dependent variables.

From Figure 18 showing the multivariate ANOVA results, we can see that there are statistically significant differences in water prices and usages across different groups, we do not see the same significant differences regarding whether the municipality participates in the Rio Grande water market or not. Moreover, there is not

```
manova Avguse kGal KGal = group##Transactiond

                         Number of obs =          52

                         W = Wilks' lambda        L = Lawley-Hotelling trace
                         P = Pillai's trace       R = Roy's largest root
```

Source		Statistic	df	F(df1,	df2) =	F	Prob>F	
Model	W	0.4091	6	18.0	122.1	2.52	0.0015	a
	P	0.6919		18.0	135.0	2.25	0.0046	a
	L	1.2076		18.0	125.0	2.80	0.0004	a
	R	0.9899		6.0	45.0	7.42	0.0000	u
Residual			45					
group	W	0.6775	3	9.0	104.8	2.02	0.0440	a
	P	0.3488		9.0	135.0	1.97	0.0470	a
	L	0.4379		9.0	125.0	2.03	0.0415	a
	R	0.3269		3.0	45.0	4.90	0.0049	u
Transacti~d	W	0.9068	1	3.0	43.0	1.47	0.2354	e
	P	0.0932		3.0	43.0	1.47	0.2354	e
	L	0.1027		3.0	43.0	1.47	0.2354	e
	R	0.1027		3.0	43.0	1.47	0.2354	e
group#Transacti~d	W	0.8228	2	6.0	86.0	1.47	0.1987	e
	P	0.1834		6.0	88.0	1.48	0.1939	a
	L	0.2078		6.0	84.0	1.45	0.2039	a
	R	0.1605		3.0	44.0	2.35	0.0849	u
Residual			45					
Total			51					

e = exact, a = approximate, u = upper bound on F

Figure 18: Manova analysis for prices and water use across different groups and transaction behaviors for Texas Rio Grande

a clear statistically significant interaction between the two factorial variables. The insignificance of the transaction behavior show that just participate in the water market might not significantly make the water pricing and water usage behaviors different from those who do not. There are other factors that need to be considered.

Once we have characterize how water pricing and water consumption varies across municipalities depending on their geographical and the market decision, it is time to improve the model by also account for other socio-economic factors.

Table 9 and 10 show the dynamic panel data results for potential explanatory variables with respect to the different residential and commercial block prices in Edwards Aquifer for both market participant and non-participant municipalities. From the results, we can observe that water level, median household income, evaporation difference and Palmer Drought Index seem to have some significant impacts on water prices across the municipalities with different market decisions. However, the magnitude and sign of coefficients vary across the counties of two transaction groups. For both groups of municipalities, we can see that there are some mixture of positive and negative impacts on the explanatory variables across the different block prices. Population growth seems to have more statistically significant impact for non-market participants municipalities in terms of both magnitude and statistical significance. The possible reason for this difference is that water pricing needs to vary more for those municipalities since they do not secure their supply as often

Table 9: Main results from dynamic panel model for water block prices of market non-participating municipalities in Rio Grande

	(1) FBR	(2) SBR	(3) FBC	(4) SBC
wlevel	-0.0010	-0.0101***	-0.0425***	-0.0510***
	(0.2940)	(0.0000)	(0.0002)	(0.0001)
popgrowth	0.4476*	2.3556***	8.4982***	10.8493***
	(0.0612)	(0.0002)	(0.0052)	(0.0016)
lnmedinc	0.0882***	-0.0444	-0.4037	-0.5175
	(0.0064)	(0.6002)	(0.3259)	(0.2668)
PSDI	-0.0032	0.0237*	0.1291**	0.1479**
	(0.5024)	(0.0615)	(0.0360)	(0.0341)
evapordiff	-0.0007	0.0109***	0.0536***	0.0629***
	(0.6455)	(0.0043)	(0.0037)	(0.0027)
Observations	12	12	12	12
chi2	453180.9700	83836.2087	7399.3740	8732.8078

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

Table 10: Main results from dynamic panel model for water block prices of market-participating municipalities in Rio Grande

	(1) FBR	(2) SBR	(3) FBC	(4) SBC
wlevel	-0.0032	-0.0041	-0.0114***	-0.0110***
	(0.2555)	(0.1679)	(0.0001)	(0.0001)
popgrowth	0.0647	0.0050	0.4894***	0.4776***
	(0.7057)	(0.9781)	(0.0055)	(0.0062)
lnmedinc	-0.8665***	-0.9639***	-1.1246***	-1.0690***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
PSDI	-0.0277***	-0.0265***	0.0205**	0.0175*
	(0.0015)	(0.0041)	(0.0238)	(0.0516)
evapordiff	0.0062***	0.0075***	0.0101***	0.0096***
	(0.0060)	(0.0016)	(0.0000)	(0.0000)
Observations	37	37	35	35
chi2	21968.2636	25804.6674	53143.3905	84665.5595

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

through trading water rights.

Regarding water consumption, while the water consumption across the different uses are investigated in the case of Edwards Aquifer, for Texas Rio Grande, we do not specifically look at movements of water consumed across different uses. We take different approaches for these two regions since Texas Rio Grande follows a correlative right system where every use of water are treated the same in times of water supply uncertainties, unlike the Edwards Aquifer market that following priority system.

8 Concluding remarks

There are some different demand and supply characteristics between the two water markets. Indeed, the scarcity of water resources, the water pricing and water consumption behaviors vary not only between the two markets but also across different municipalities.

Some legal regulation might be essential for the groundwater market if the goal is to protect the aquifer. Regulation might be in the form of a pumping cap for current permit value to increase.

Moreover, market conditions should be aligned with the water supply conditions.

Regulation might also be necessary to address the potential third-party effects

Both the Rio Grande and the Edwards Aquifer water markets still have some constraints regarding the incomplete dataset of specific municipality water transaction prices and quantities.

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