Price Efficiency in U.S. Water Rights Markets

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Abstract
With this study we seek to understand the relationship between the sale and one-year lease prices in the U.S. water rights market. Given that the majority of current water rights markets in the U.S. are informal, high in transaction costs, and heterogeneous within and across states, we do not expect for the asset pricing theory to completely explain high variation in prices. Our goal is to understand which part of the pricing can be explained by the arbitrage theory and which part should be attributed to the expectations about the future conditions. Using a unique water rights trading dataset, which consists of water rights sales and one-year leases in six U.S. western states between 1994 and 2007, we follow the Newell et al. (2007) approach applied to New Zealand fisheries, and econometrically analyze the applicability of a present-value asset pricing model to the water rights markets. Our preliminary results show that the asset pricing theory holds in water rights markets, and support our hypothesis that the U.S. water rights market is less efficient than the fishing quota market in New Zealand. We further analyze what policies lead to different water rights pricing mechanisms across and within the studied states.

Key words: water rights markets, arbitrage-free pricing, water institutions, climate change.

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1. Introduction

The global popularity of market-based instruments has been increasing over time with successes in programs such as the U.S. EPA's sulfur dioxide allowance trading program (Stavins 2005) and individual transferable quota systems for fisheries in New Zealand (Newell et al. 2005, 2007, Grainger and Costello 2011). However, some pollution markets, such as greenhouse gas emissions or water pollution permit markets are more complex and less developed (Woodward and Kaiser 2002, Cramton and Kerr 2002). Aside from a few exceptions (e.g., the Colorado-Big Thompson project, the Texas Lower Rio Grande water rights market), the majority of water rights markets in the western U.S. are also underdeveloped (Carey et al. 2002).

In well-functioning markets, asset prices reflect all available information. Newell et al. (2007) test the applicability of the arbitrage-free pricing model in New Zealand fishing quota markets. In a competitive market where lease prices remain relatively constant, the sale price should equal the lease price divided by a relevant interest rate. In water rights-like markets where lease prices are less stable and more heterogeneous, the relationship between the sale and lease price should also depend on expectations of the future environment. Asset pricing models have been applied in cases such as agricultural land (Alston 1986), dairy quota (Willson and Sumner 2004) and other market settings. However, there is lack of scholarly literature quantitatively analyzing pricing mechanisms in water rights markets.

In this study, we seek to understand the relationship between the sale and one-year lease prices in U.S. water rights trading markets. Given that the majority of current water rights markets in the U.S. are informal, exhibit high transaction costs, and are heterogeneous within and across states, we do not expect asset pricing theory to completely explain price variation. In fact, previous literature (Yoskowitz, 1999; Edwards and Libecap, 2015) argues that the law-of-one price does not hold in water rights markets. Our goal is to decompose how much of the difference in price between lease and sale can be explained by arbitrage theory and how much can be explained by expectations about future conditions. We seek to further identify what types of regulations lead to different water rights pricing mechanisms across and within states.

To estimate the relationship between the sale and lease prices in water rights markets, we modify models used in determining price efficiency in created fishing markets by Newell et al. (2005 and 2007) to apply them to the water rights market case. We firstly analyze the water rights market activity, as is recorded in our unique water rights trading dataset, which consists of water rights sales and one-year leases in twelve U.S. western states between 1991 and 2010. We analyze transaction frequency, volumes traded, and price dispersion trends over time. This step of analysis allows us to notice significantly active market activity in some areas, an increase in lease transactions and a decrease in price dispersion over time. Then we econometrically estimate separate but identical equations for water rights sale and one-year lease prices. The preliminary results suggest that the price equations are generally well-behaved, suggesting that the water markets overall tend to operate consistent with theory specific to competitive markets. More specifically, the estimation results show that the sale and lease prices tend to increase from an increase in agricultural profitability and economic growth in urban areas. Overall coefficients tend to yield the same signs for both sale and lease price equations.

Since the sale and lease price estimations yield acceptable results, we proceed the water rights price efficiency assessment with the application of the present-value asset pricing model while assuming that current conditions in water rights markets represent future expectations. We econometrically estimate a sale price equation for six U.S. western states. Despite the limits imposed by a challenging dataset that consists of 31 observations representing six western states and 9 years between 1994 and 2007, we obtain results suggesting that water rights sale prices are positively related to an increase in lease prices and a decrease in interest rates, which confirms that the asset pricing theory holds in water rights markets. The coefficient associated with lease price is smaller than the one estimated in the Newell et al. (2007) study, which, as expected, indicates that U.S. water rights markets are less efficient than fishing quota markets in New Zealand. To our knowledge, this is the first paper that analyzes the applicability of the present-value asset pricing model to water rights trading markets.

The preliminary results, as expected, yield a few inconsistencies from perfect competition theory, which in our opinion can generally be attributed to the institutional differences across different markets. Therefore, the quantitative estimation in this paper is supported by a qualitative analysis of the causes of price variation across U.S. water rights markets. Water rights sale prices are influenced by future expectations that are subjected by uncertainties surrounding future changes in climate and legal institutions.

The rest of the paper is organized as follows. In section 2 some background of the U.S. water rights institutions is provided. The water market characteristics including trends in frequency, volume and price, and all the data used in this study are discussed in section 3. Section 4 describes the models used in this study and provides information about the estimation techniques and preliminary results. Conclusions are provided in section 5.

2. Background of the U.S. water rights institutions

The water rights markets in the U.S. are very heterogeneous not only across different regions and states, but also locally. In the U.S. west, most water transactions are limited by the federal and state regulations, which have been influenced by historical events and the geography of the area, as well as socioeconomic, political, and other factors. For example, the main difference between the water rights systems in the western and eastern U.S. is the doctrine which defines these rights. In the east, water rights are defined by the riparian doctrine[1], which came to the U.S. by way of the English common law, and is defined by the principle of reasonable use; while in the west, water law has emerged primarily from the prior appropriation doctrine[2], which is defined by the principles of seniority ("first in time, first in right"), historical use, and beneficial use (Hutchins et al. 1972, Scott and Coustalin 1995, Miller et al. 1997, Huffaker 2005). Some states have been influenced by both doctrines and currently, combine certain principles from each (Scott and Coustalin 1995, Johnson 2009).

Much of the scholarly literature suggests that water rights markets in the semi-arid U.S. west started to emerge as a solution to water shortages caused by the rapid population growth and economic development (Hartman and Seastone 1970, Vaux and Howitt 1984, Saliba and Bush 1987, Easter et al. 1999, Brookshire et al. 2004). In addition, climate change has started to

[1] In the riparian doctrine a water use right belongs to a person whose land adjoins that body of water. The modified doctrine applies to all bodies of water including lakes, ponds, streams, and marshes and grants the owner to reasonably use the water without interfering with the reasonable use of other riparian owners of the same watercourse (Miller et al. 1997, U.S. Fish and Wildlife Service).

[2] Under the prior appropriation doctrine, a person who was first to claim a water right, has the oldest right and the first priority (seniority) to use the water for beneficial use (domestic, municipal, industrial, agricultural, environmental, recreational, etc.). Junior water right holders are not allowed to execute their rights until senior holders have executed theirs (Hutchins et al. 1972, Scott and Coustalin 1995, Miller et al. 1997).

have an impact on water resources by bringing higher seasonal, inter-annual, and decadal variability in precipitation, streamflow and water in storage (Miller et al. 1997, Colby et al. 2014). Water scarcity has been addressed via formal and informal water rights transfers by reallocating water from lower-valued (agricultural) to higher-valued (municipal and instream) uses (Easter et al. 1999, Brookshire et al. 2004, Brown 2006, Brewer et al. 2008). However, the ability of water markets to act as adaptive institutions, reducing economic losses due to projected increases in water scarcity and variability from climate change by reallocating water, is weakly understood (Olmstead 2014). Water scarcity might cause markets to form and function more efficiently; however, less water could mean fewer gains from trade, reducing the motivation to develop well-functioning markets.

There are many obstacles to efficient water marketing. According to the scholarly research, many of these barriers result from specific legal institutions. For example, Huffaker (2005) states that, generally, issues related to water scarcity in the western states arise from the set of laws and institutions governing western water use, and the manner in which these regulations have been implemented. One of the main barriers to effective and efficient water markets, as identified by many scholars, is high transaction costs. Easter et al. (1999) suggest that appropriate institutional and organizational arrangements must be in place in order to reduce these costs. Therefore, understanding water rights institutions, such as systems of water rights law, systems of administration and enforcement, as well as social-norms regarding acceptable water-use practices (Miller et al. 1997) is a necessary step in understanding why water markets in certain states may provide a better opportunity to improve efficiency than in other states.

The general steps in the water rights transfer process are similar in every prior appropriative state. The procedure starts with the prospective traders submitting an application to the appropriative state agency. Then the state agency reviews the application for technical accuracy. The next step is informing the public about the potential transaction. This step is very important, because theoretically, it accounts for the third-party effects. Normally, the state agency decides which third parties to inform. Also, it is accepted practice to publish information about a potential transaction in a local newspaper for several consecutive weeks, in order for interested parties to be informed and have an opportunity to protest. If interested third-parties protest, the process may take considerably longer and become significantly more complicated. In the next stage, the agency conducts a hearing and rules on the proposed trade. A party affected by the ruling has a chance to appeal (Griffin 2006).

The water markets within each state must be interpreted very carefully, because a state represents many different markets that do not only differ by length of a contract (sale or lease) or type (surface or groundwater), but also by applying many different exceptions to the general state rules, or fall under completely different jurisdictions. Water rights institutions are known to be very decentralized. For example, in some states, the majority of water transfers happen within the areas implemented by the Bureau of Reclamation, which are called projects: Central Arizona Project (CAP), Central Valley Project (CVP), Colorado-Big Thompson project (C-BT), etc. These projects normally operate by different than state-defined norms, they do not follow the seniority principle imposed by the prior appropriation doctrine, and usually are associated with lower transaction costs and higher efficiency. In addition, within projects the water transfer rules are normally a little bit different from the general steps described above—the processes are shorter, less expensive, and more efficient. In addition, the smaller and well-operating markets are not necessarily operated by the federal or state government institutions. For example, the rules in Lower Rio Grande water market in Texas, which is known as one of most efficient markets in the U.S., are highly different from the rest of the markets in Texas. It is important to note that most of these well-defined markets provide access to information needed for the buyers and sellers. The potential trading parties can obtain necessary information for low or no cost, which suggest that prices should be set more efficiently. This is supported by the Australian experience suggesting that a well-functioning clearinghouse institution may lead to increased efficiency in water markets (Brooks and Harris 2008).

Clifford et al. (2004)'s report on water banks in western states provides information on whether or not the bank is a clearinghouse, allowing to separate states based upon the existence of a brokerage institution. A clearinghouse is the simplest type of water bank organization, where trading parties can post their intention to buy or sell. The bids for water rights are posted on bulletin boards, which may be either literal or electronic boards[3]. Not all states have clearinghouses. For example, Montana and Utah have never had an active water bank institution. Idaho has had an active water bank in a clearinghouse form continuously since it was

[3] Colorado has an electronic board for the Arkansas Basin River Bank at: www.coloradowaterbank.org. The Texas Water Bank also has an electronic board at: www.twdb.state.tx.us (Clifford et al. 2004)

implemented, whereas California has had active brokerages only during the presence of droughts.

Another observed difference across the states regards the surface and groundwater rules. In some states, the prior appropriation regime applies only to surface water, while in others both surface water and groundwater can be appropriated. As discussed above, the prior appropriation doctrine generally imposes some difficulties for effective trading, which may suggest that when both surface and groundwater are ruled by this doctrine, as is the case in New Mexico, the prospects for efficient markets may worsen. However, it is also possible that different rules for surface and groundwater could impose higher transaction costs due to extra time being spent in becoming better informed. Some states have management programs specific to groundwater. For example, in Arizona, due to the groundwater overdraft, five Active Management Areas (AMAs) have been implemented. In Texas the groundwater is generally attached to land, thus, is owned privately by the landowner and is subject to ‘the rule of capture’, which is known to allow withdrawing as much as needed, as long as it is not intentionally wasted and is put to beneficial use. The rule has been highly criticized for ignoring future demands as water tables get lowered and impacts external to individual needs of the two exchanging parties are being overlooked (Griffin 2012).

The popularity of short-term transfers (i.e., leases) has been increasing only in recent years. It is easy to think of leases as institutions creating spot markets; that is, allowing buyers to get water when it is most needed at a simpler administrative process than is required for permanent transfers (Yoskowitz, 1999). In general, the administrative processes involving leasing are much simpler and less involving. For example, in Texas Rio Grande a lessor only needs to call the watermaster’s office and inform about a temporary change in ownership. However, the change in purpose of water usage cannot be done through leases (leasing from one sector to another is forbidden) in the Texas Rio Grande market, which explains the simplicity in the process. Another reason why leasing activity has been growing is an increase in tendency for the bigger players like River authorities in Texas, or public utilities in Colorado to purchase high quantities of water rights, and then lease them back to agricultural or urban users. This provides water users an easy access; however, it also suggests an increase in monopolistic power.

3. Data

3.1. Water rights market characteristics: trends in frequency, volume, and prices

The water rights market dataset used in this study is constructed directly[4] from the monthly[5] *Water Strategist* journal issues published during the period of 1990-2010.[6] The full dataset combines twelve different states[7] and consists of 5,467 observations. The buyers and sellers are grouped into three main categories: agricultural, urban, and environmental sectors. Water rights transactions generally happen in one of three forms: sales, 1-year leases and multi-year leases. The long–term leases vary greatly in length across observations (2 to 100 years) and make a group with the smallest amount of transfers in this dataset. In this study we focus on market activity that represents water rights permanent sales and 1-year leases; thus, we have omitted observations associated with recycled effluent water, storage rights, and multi-year leases[8]. In order to provide a better understanding of quantities and prices in the market, we have further omitted observations with missing[9] or lower than $1/acre-foot prices[10] and unidentified[11] buyer.

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[4] We built the dataset used in this study from scratch, directly from the monthly issues of Water Strategist purchased from Stratecon, Inc. Most of the published transactions contained complicated and sometimes ambiguous narratives regarding prices, volumes, forms of transactions, old and new purposes of water usage, and other. Each transaction was studied on individual basis in order to categorize the data using consistent interpretations. We did not use the dataset that was put together by the Bren School of Environmental Science & Management and made available on their website.

[5] Until 1995 water transactions were reported in a separate addition to the journal called "Water Intelligence Monthly". 1995-1998 water transactions were reported quarterly.

[6] The last issue to combine the dataset is December of 2010. Normally, transactions that take place in one month are being reported in the next month's issue, so the transactions that occurred in December of 2010 would have been reported in January of 2011. Therefore, transactions for the year of 2010 are not complete in our dataset.

[7] Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington, and Wyoming.

[8] 155 (out of 5,467) observations were associated with reclaimed effluent water; 49 (out of 5,467) trades involved storage rights; 500 (out of 5,467) observations included leasing contracts for longer than 1-year period. (All the groups of omitted observations are not mutually exclusive from one another.)

[9] The actual price for the transaction was missing mostly for the following reasons: 1) price was not provided, 2) the price was provided for the purchase that was made for the land and water; 3) water rights were dedicated or exchanged for other services. 1,488 (out of 5,467) observations had missing price information.

[10] 36 (out of 5,467) transactions had a lower than $1/af price. We have also dropped three outliers that represented a price for permanent water right being lower than $7.50/af, which is very unusual since the average price for the permanent transfers is more than $9,000/af

[11] In some transactions reported in *Water Strategist* it was not possible to determine which category the buyer belonged to: agricultural, urban or environmental. Generally, prices differ a lot in water markets depending on who is buying; thus, in order to analyze market conditions, it is crucial to know the old and new purposes of water rights usage. 433 (out of 5,467) transactions were associated with unidentified buyer.

We believe that water market issues related to the environmental needs are unique, complex, and beyond the scope of this paper. Since we do not have enough information to properly assess transfers involving the environmental sector[12], we eliminate that sector and a great degree of heterogeneity associated with the prices (water purchases for the environmental sector are highly subsidized) and quantities sold across the studied states. Agricultural sector is the largest water supplier in the western states; thus, we have chosen to keep only those transactions that were associated with the water coming from the agricultural irrigators. As a result, we eliminated all water transactions where urban sector was the seller or lessor[13]. Furthermore, having only one supplying sector guarantees some level of homogeneity in the traded good – all the water in our sample is transferred only from the agricultural sector. Our final sample used in this study consists of 2,249 observations representing transactions that occurred during the period of 21 years (1990-2010), in twelve states, one supplying sector: agricultural, and two buying sectors: agricultural and urban.

The pooled annual average over the period of 21 years is 80 permanent transactions (median is 76) and 34 one-year leases (median is 29). Figure 1 below illustrates the trend of water rights market activity. The average annual transactions have been mostly increasing for both sales and one-year leases until early 2000s. On average there has always been more permanent trades than leases, although the difference after the year of 2000, as illustrated in Figure 1, is significantly smaller due to an increase in the number of leases and decrease in the frequency of permanent transfers. Permanent transfers are generally associated with higher transaction costs than leases; thus, it is not surprising that leasing has started to become a popular alternative allowing to access the water for short-term needs. Also, leasing sometimes is a preferable alternative for the risk-averse water suppliers, who are uncertain about transferring their water permanently, but enjoy profiting from temporary leasing their excess water.

Figure 2 shows which states have the lowest and the highest annual average market activity for both sales and leases. On average most of the states have well below 10 sales or leases per year. The big exception is Colorado, which on average has over 60 sales annually during 1990-2010. California is the leader in number of short-term leases, followed by Texas.

[12] 726 (out of 5,467) transactions included environmental sector.

[13] In 782 (out of 5,467) transactions water supplier was the urban sector. We tried using the observations containing water supplied coming from the urban sector in econometric estimations, but the produced results were not significant

Oregon and Wyoming do not have any sales. Arizona, Nevada, Utah and Washington have lowest leasing activity. Figure 2 provides a general view of the very diverse market situation in the U.S. west—it seems that few states have a better developed permanent water markets, other states might have well-functioning leasing markets, maybe a combination of the two, or neither. It is important to emphasize that although in this study markets are defined by every state's borders, in real world they are spatially smaller than a state, and can vary from large federal projects like Colorado-Big Thompson (C-BT) in Colorado, or Central Valley project (CVP) in California involving large irrigation districts, to thin and/or informal transactions between two neighboring farmers. Market activity by state, transaction type, and buying sector is reported in Table B1, appendix B.

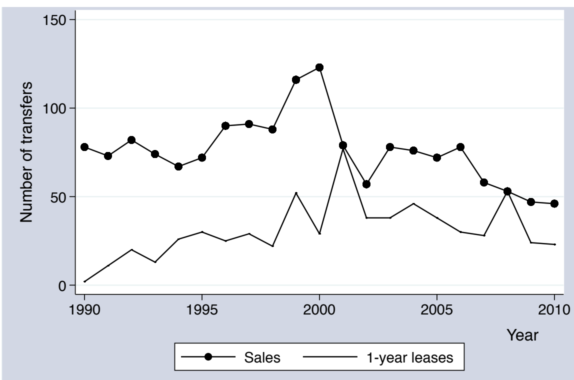

Figure 1: Average number of sales and leases over time

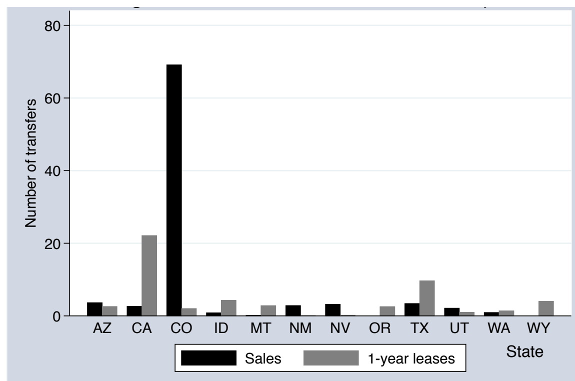

Figure 2: Average annual number of sales and leases by state

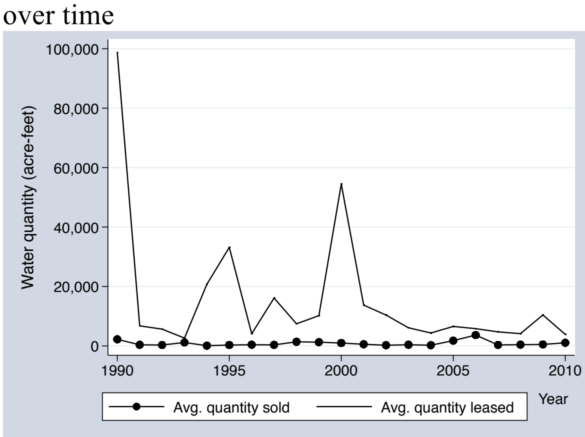

Figure 3: Average water sold and leased over time

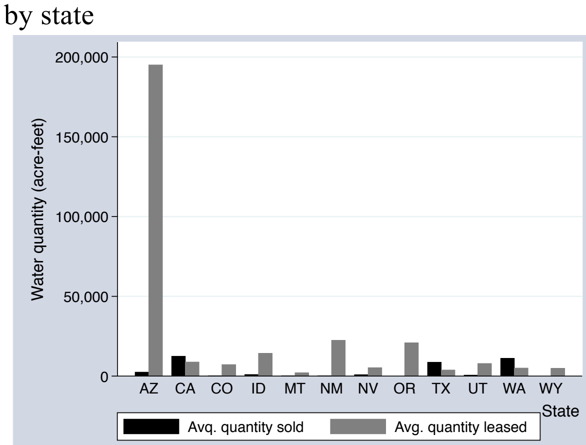

Figure 4: Average water sold and leased by state

Figures 3 and 4 provide some insight about the average volumes (in acre-feet) of water transferred. Figure 3 shows average volume trend for sales and leases, and illustrates that on average, in a given year there is more water leased than sold. No clear trend in terms of an increase or a decrease in volume can be observed. The average quantity sold was highest for the 2005-2007 period. The average volumes of leased water have a few high peaks: 1990, 1995, 1997, 2000, 2009. All these periods correspond to the years when U.S. west was hit with droughts (see historical U.S. drought in Figure B1, appendix B), and suggest that weather and climate conditions matter more in making decisions about leasing than selling.

From Figure 4 we can see that on average most of the water through leases is transferred in Arizona, however, the Figure 2 does not suggest that there is an active leasing market in the state, which indicates that a very large quantities of water are being transferred in single leasing transactions. The lessor in most of Arizona's cases is the Central Arizona Water Conservancy District (CAWCD), which leases water to multiple users in a single transaction[14]. This explains why single observations in Arizona contain large quantities transferred. Arizona is also a big driver of the peaks shown in Figure 3. If we compare Figure 2 with Figure 4, we can see that Colorado also strikes as an interesting case, which is completely opposite from the Arizona's case. The state is the leader in market activity for annual average of permanent water sales, however, the average quantity of water sold is very minimal (Figure 4), which might suggest that Colorado has an active and a well-functioning water rights market. Most of the Colorado transactions reported in our dataset happen within the Colorado-Big Thompson project (C-BT), which is known as one of a few efficient water markets in the U.S. (Griffin 2006). California, Texas and Washington on average transferred the largest volumes via permanent sales. (Figures B2 & B3 showing total volumes transferred per year and by state are available in appendix B.)

The nature of water transferred via lease is different from water that is transferred via sale. The sale represents an annual flow of water. Whereas, water transferred through a 1-year lease represents water stock—it is an agreed amount of water that needs to be transferred from a water right holder to a lessee within one year. Thus, if we do not discount the sale transactions, they represent only the first year of the entire sale, and look exactly like 1-year leases, which based on Brewer et al. (2008) biases downward the permanent sales effect on the volume of water traded. They emphasize this difference, and introduce a 'committed' variable by projecting the annual flow forward in perpetuity for a sale; then discounting the flow by 5% per year, which

[14] Sometimes transactions involving multiple buyers or multiple sectors in Water Strategist are reported as single transactions (not only in Arizona). We tried disaggregating such transactions whenever it was possible to do so without losing any information.

is supposed to represent a present value of annual payments. However, in this study we use the annual, not “committed” quantities and prices in our study, because we explicitly seek to check the applicability of a present value model in water rights market. (Graphs showing average and total volume of ‘committed’ water traded are available in Figures B4-B7, in appendix B.)

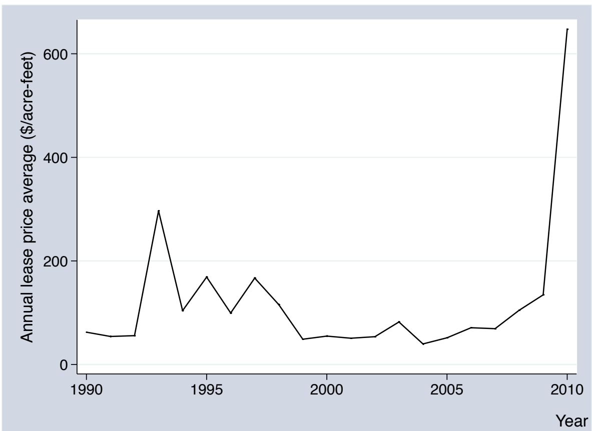

Figure 5: Annual lease price average trend

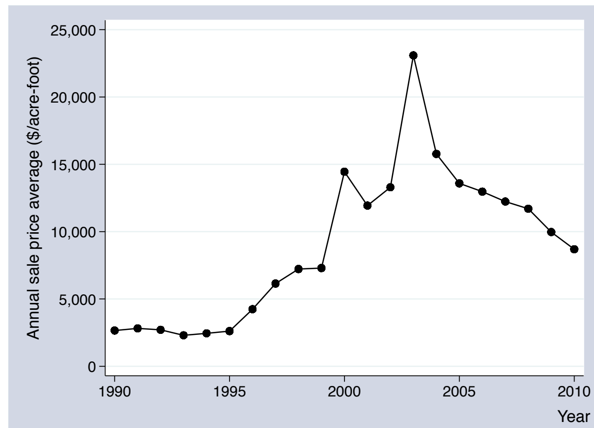

Figure 6: Annual sale price average trend

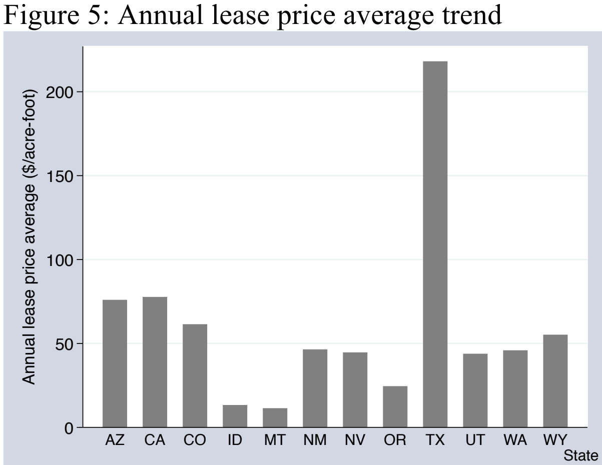

Figure 7: Annual lease price average by state

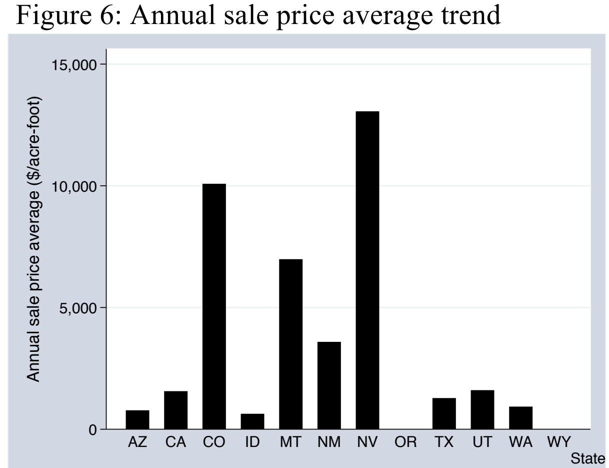

Figure 8: Annual sale price average by state

Figures 5-8 provide information about the price for water right sales and leases. The price is converted into 2009 dollars using the consumer price index (CPI), and is expressed as $/acre-foot. Figures 5 and 6 show that annual average water lease price is much lower than the sale price, which is expected. But can the difference between the two be explained by the discount rate? We try to answer that question in section 4 below. Across all the states the sale price has been increasing until 2005, and the leasing price looks to be steadily increasing since 2005, with a huge jump from 2009 to 2010. Figure 7 displays that highest prices for leased water is paid in Texas. Arizona, California and Colorado have much lower prices for leased water than Texas, but are still noticeably higher than other states. From Figure 8 we can see that average annual sale prices are highest in Nevada, Colorado, and Montana.

By looking at Figures 7-8 we can see that the price dispersion across states in water rights markets is large, especially in permanent transfers (Figure 8). Newell et al. (2005) measure price dispersion in New Zealand's fishing quota market as the mean absolute percentage price difference between the individual trade prices within each month and the monthly mean for its fishing quota market. They find that the price dispersion has decreased over the period of 1987-2000 for both sales (from ~25% to ~5%) and leases (from ~35% to ~25%) and suggest that this is a sign of the market learning how to operate more efficiently over time, which should be affected by the operational and transaction costs that are becoming lower over time.

In calculating price dispersion, we followed Newell et al. (2005) method described above. The mean absolute percentage price deviation has been calculated as a difference between a singular transaction and a quarterly[15] mean. Figure 9 shows sale and lease price dispersion calculated using state specific weights, because a state represents a market in our dataset. Surprisingly, as shown in Figure 9, the price dispersion is lower in water rights markets than in fishing quota markets: with a few exceptions leases are generally close to 5% deviation, and sale prices are close to 2-3% deviation. Interestingly, it is hard to see a trend in Figure 9—the price dispersion seems to increase and decrease over time, especially in leases. Although, if we look at the 1994-2009 period, we can see that the price dispersion for both sales and leases was highest in 1994: 14% and 8% respectively and decreased a lot by 2009: <1% and 2-3% respectively. The weather conditions and water supply availability might play an important role in price dispersion, especially in leases, because 1-year lease markets operate similarly to the spot markets – water is purchased when it is mostly needed, which is the case in the presence of a drought. Another reason might be the fact that generally, operational and transaction costs in water markets do not become lower over time, like it is in fishing markets. There are a few examples across the states, like C-BT project in Colorado, where initial investments on infrastructure had paid off and helped lower both operational and transaction costs associated with transfers, however, markets like that are a minority.

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[15] Price deviation from a monthly mean could not be calculated, because not all trades have been reported by month in Water Strategist. How we divided data into quarters is explained in Section 4, and the appendix.

Figure 9: Sale and lease price dispersion over time specific to state

The dataset is limited due to its high diversity across and within states and years in terms of numbers of transactions, the selling and buying sectors (trading agents), types of transfers (sales or leases), prices paid, quantities transferred, and institutional context. Such variation makes it hard to compare sales and leases occurring in the same market, which in our study is defined by one state (transfers occur within one state, not across states), certain time (quarter, year), and buying or selling sector (transfers occur within and across sectors). Most of the states do not report either any sales or any 1-year leases for certain years (or quarters), which makes this panel dataset highly unbalanced and does not allow to perform as deep of an analysis of water rights sale and lease prices as we would like to. On the other hand, we have been able to notice high market activity for water rights sales in Colorado, and for leases in California and Texas; the price dispersion in leases and sales has decreased since 1994, which suggest that markets have a tendency to behave rationally and competitively.

We have discussed the data that is used for the water rights *sale* and *lease price*, *quantity*, and *frequency* variables. The following section describes data used for other variables applied in our model. Some of the variable construction is specific to our model used and it will be described in greater detail in methods sections below.

3.2. Other data

The *crop price* variable has been constructed depending on which crop is largest based on value and area planted in each state over the period of 1990-2009 (see Table B2 in appendix B). *Wheat*, *alfalfa, and rice crop prices* have been collected from the U.S. Department of Agriculture (USDA) website, and converted to 2009 dollars using CPI. The crop price varies by state and year. *Wheat production costs* have been obtained from the USDA. They have been converted into 2009 dollars per ton using a producer price index (PPI) and an employment cost index (ECI), and then used to construct a *wheat cost index* specific to labor and material cost shares. The cost index varies only by time (the same across states). More detail on how the index is derived is provided in the appendix B.

Population change variable has been obtained from the U.S. Bureau of Economic Analysis website. Two types of population annual growth variables are used in this study: one is state level growth, another is specific to a population growth in metropolitan statistical areas (MSA) within a state. The *per capita income* variable has been also collected from the U.S. Bureau of Economic Analysis website. The variable differs by state.

The *precipitation* variable is represented by the Standardized Precipitation Index (SPI), which is obtained from the Western Regional Climate Center website. The chosen SPI is a previous 24-month average, which varies by state and year. The index has a range from -3 to +3, where negative numbers indicate a low cumulative probability of rainfall event. Positive numbers suggest higher cumulative probability of rainfall. When index is equal to zero, the cumulative probability of rainfall event is 50 %. Thus, an increase in the index value suggests and increase in precipitation which as a result, should indicate a decrease in sale and especially lease price.

We also use the Palmer Drought Severity Index (PDSI), which is obtained from the National Oceanic and Atmospheric Administration (NOAA) website. The PDSI is a measurement that usually ranges from -6 to +6, where all negative values indicate dry weather conditions (-4 and below suggests extreme drought), and positive values imply wet conditions (+4 and above mean extreme moist). In order for the PDSI to measure *risk premium* it has been converted into a fraction providing information for how many months in a year the index was between -2 and +2 (which is a mid-range suggesting that on average weather conditions were normal).

The real market interest rate is a 3-month U.S. Treasury bill rate. The nominal U.S. Treasury bill rates have been collected from the Federal Reserve website. The interest rates then have been converted by adjusting for inflation using CPI.

Total water withdrawals have been obtained from the U.S. Geological Survey (USGS) website. The withdrawal data is published every five years. The annual state level total water withdrawals have been constructed by interpolating the data (1990, 1995, 2005, 2010) in order to have the annual variation in this variable.

All the data sources are provided in Table B3, appendix B.

4. Methodology

To examine the relationship between the sale and lease prices in water rights markets we econometrically estimate the determinants of the identical water rights lease and sale price equations, which allows us to assess whether the prices are generally well-behaved and whether they tend to follow the essential theory. Our model is described in section 4.1., which provides information about the sale and lease price determinants (section 4.1.1.) and estimation results (section 4.1.2.). Then, in section 4.2., we apply the capital asset pricing model framework to the water rights market which allows us to further assess the efficiency in water rights markets. The empirical model as well as estimation results are discussed in sections 4.2.1. and 4.2.2. respectively.

Both models are estimated using the instrumental variable methods in order to avoid endogeneity problems. The method is applied using the two-stage least squares (2SLS) approach, which simultaneously estimates multiple endogenous variables.

4.1. Sale and lease price model

Water is a factor in a production process. For the agricultural side, it is an input in crop production maximization. For the urban side, it is generally an input in public utilities' function of delivering the resource to the end users in a cost minimizing way, sometimes it represents an input in industrial development process[16]. In our set up we have two water buying agents:

[16] In some of the transactions the new purpose was described as the 'municipal and industrial' use. These transactions were included in the dataset under the urban sector.

agricultural and urban sectors, and one water supplying agent: agricultural sector. Both types of buying agents can obtain water in two ways: through a lease or through a permanent sale.

We model the sale and lease price equations as inverse input demand functions consisting of the general factors as expressed in equation (1):

$$p_w = f(q_w, P_y, w_f, cond) \tag{1}$$

Where:

p_w - represents the price paid for a transferred water via a permanent or lease transaction;

q_w - is a demand for the water;

P_y - is an output price;

w_f - is the price of other inputs;

$cond$ - represents conditions influencing input productivity, which in our case is an external influence coming from climate context.

4.1.1. Sale and lease price determinants

Empirical specification of the price function is shown in the following equation (2).

$$lnp_{ijt} = \beta_1 ln\hat{q}_{ijt} + \beta_2 buyer_{ijt} + \beta_3 lncropp_{jt} + \beta_4 wci_t + \beta_5 lnincome_{jt} + \beta_6 SPI_{jt-2} + \alpha_t \\ + \alpha_j + \varepsilon_{ijt} \tag{2}$$

Where:

i - indicates a water rights transaction: transfer from ag-to-urb or ag-to-ag,

j - indicates a region—state,

t - indicates time period—year,

p_{ijt} - is a water right sale price,

$\hat{q}_{ijt}$ - represents a predicted water demand (variable estimated in the first stage),

$buyer_{ijt}$ - dummy variable indicating whether a buyer is an agricultural sector or an urban sector,

$cropp_{jt}$- crop price,

wci_t - wheat cost index,

$income_{jt}$ - is a per capita personal income,

SPI_{jt-2} standard precipitation index,

α_t year fixed effects,

α_j state fixed effects,

ε_{ijt} error term.

Equation (2) is expressed for sale price, but we separately estimate identical equation for the lease price as well. The same variables used in estimating both prices should allow us to determine the relationship between the two prices, and whether their behavior follows the fundamental theory of market prices.

Demand side is represented by the *quantity* variable indicating how many acre-feet are traded in a single transaction. Based on economic theory, an increase in demand might create an excess demand at the initially set price, which as a result, should increase the price and lead to the suppliers providing more of the good. However, due to the economies of scale we expect an increase in the amount of water purchased to have a negative impact on both sale and lease prices. Most of the transaction costs are independent of the amount of acre-feet transferred per trade. The complexity of a transaction, and thus, transaction costs associated with it are unique to every transfer, but the costs generally increase with the number of transfers, not the volume of water transferred. Since some of the costs are presumably inherent in the prices paid, the economies of scale come into play: the price per acre-foot in one transaction decreases as the number of acre-feet in that transaction increases. This would suggest a negative relationship between the price per acre-foot and the amount of water transferred. Permanent transfers (sales) are associated with much larger transaction costs than temporary transfers (leases), because generally a sale represents a transfer of a water right, and such process includes many legal and administrative steps; whereas 1-year lease usually represents a transfer of an agreed upon amount of water only, leaving the actual water right to the original owner, and requiring less legal and administrative involvement.

The water rights price should also depend on who is demanding the water. That is, anecdotal evidence and scholarly findings, as noted in sections 2, suggest that water to urban sector is sold for much greater prices than agricultural sector. Therefore, we expect that an urban purchaser should have a positive influence on prices relative to an agricultural buyer's influence.

The output price in our estimation is represented by the *crop price* variable, which is constructed from alfalfa, wheat and rice prices, as explained in the data section. Since we model the price function, as an inverse intermediate demand for water, the variable represents the agricultural side of demand. However, the agricultural sector is also the only supplier in our model, thus, we must look at the supply side as well when we formulate our hypothesis. From the demand side, the higher output prices should suggest that the more of the input is acquired. An increase in demand, as discussed above, should have a negative impact on price due to economies of scale, or positive effect due to the excess demand at the initial price. From the supply side, the variable represents the supplier's profit from a crop production, where water is used as an input. An increase in crop prices should have a positive impact on sale and lease prices due to the option value – as long as the agricultural water users are getting more profit from using water in production than from selling or leasing it, they will keep using it in the production raising their "willingness to accept" values.

The other inputs' prices are represented by the wheat cost index, which was calculated specific to labor and material cost shares. The costs for water were not included in index calculation. This variable represents the agricultural side (which is a supplier and a demander in our model). Water generally is a compliment among other inputs used in the crop production, which suggests that an increase in other input prices should decrease the demand for the water input, which as a result should lower the price for water, but only if supply stays stable. However, if the supply simultaneously decreases more than the demand, the price might increase. On the other hand, water is hardly a substitutable good in a crop production process, so the buyer would either have to continue purchasing the same amount and acquire losses or invest in new irrigation or crop technology allowing to use lower volumes of water. An increase in crop production costs might suggest a decrease in profits from producing wheat. From the supply side, if the profits are lower than what the agricultural water users can get from trading their water rights, they will be more inclined to sell or lease their water rights, and, as a result, will be willing to accept lower prices. Thus, we hypothesize that an increase in crop production costs will have a negative impact on water right sale and lease prices.

We also include a state level *per capita income* variable, which is associated with the average economic development in the area. State's GDP is mostly driven by the growth in the municipal and industrial sectors; thus, the per capita income variable mostly represents the economic status and the demand of the urban region. Urban growth and development can be successful only with effective water delivery, which is necessary for both industrial and domestic water usages. Therefore, the variable in the way proxies for the output, and not only the demand in the urban side. An increase in income indicates an increase in demand, which results in higher asking prices from the supply side. Thus, we expect for the per capita income to have a positive relationship with the water rights prices.[17]

We believe that climate conditions may have an impact on water input productivity, and thus, on its prices. The variation in climate is represented by the *precipitation* variable. Both water supply and demand are highly dependent on the precipitation. More precipitation suggests a simultaneous increase in water supply and decrease in input water demand, which results in lower prices. Therefore, we expect that higher levels in precipitation will have a negative effect on water rights sale and lease prices. The variable is expected to have a stronger effect on lease prices, since leasing market in a way resembles spot market, where purchasing decisions can be made quicker due to lower transactions costs associated with that process. Permanent water right transfers involve longer decision making processes and higher transaction costs.

The quantity variable creates endogeneity problem in this model, which arises because the quantity variable is simultaneously affected by the price determinants, and is correlated with the error term. Therefore, the quantity variable is instrumented as is shown in equation (3). The excluded instruments consist of the population change rate, last year's total water withdrawals, and the annual number of transactions (sales in sale price equation, and leases in lease price equation). We apply a two-stage least squares (2SLS) approach, which allows us to estimate for quantity and price (equations (2) and (3)) simultaneously. Colby et al. (2011) use the same method in estimating lease prices in water rights markets for California and New Mexico.

$$ln\hat{q}_{ijt} = \beta_1 \boldsymbol{pop_{jt}} + \beta_2 \boldsymbol{lntww_{jt-1}} + \beta_3 lnincome_{jt} + \beta_4 lncropp_{jt} + \beta_5 wci_t + \beta_6 SPI_{jt-2} + \beta_7 buyer_{ijt} + \alpha_t + \alpha_j + \varepsilon_{ijt} \tag{3}$$

Where:

[17] In order to more accurately represent the output on the urban side, we initially included the urban land value variable, which characterized urban growth and development in a more precise way than per capita income. However, the urban land value is directly linked to the housing value, and since our data (1990-2010) covers the period of a housing crisis, the urban land value variable in our model created more fluctuation in prices than we were able to control for, and the model was not robust when the state fixed effects were included.

pop_{jt} annual population change in a state,

tww_{jt-1} total water withdrawals lagged by one year[18].

All the variables used, except for the dummies, fixed effects, and variables, which are expressed in indexes or rates have been converted in logs. Summary statistics of variables specific to transactions used in lease and sale price estimations are available in Tables C1 and C2, in appendix C.

4.1.2. Sale and lease price preliminary estimation results

Table 2 shows the second stage estimation results for the sale and lease prices. The first stage results for the sale and lease quantity estimations are available in the appendix D. Two sets of results for the identical sale and 1-year lease price estimations are presented. The first set does not include any state fixed effects; in the second set the state fixed effects are included.

The sale and lease price models are identified in the case where state fixed effects are not included. The over-identification test (Hansen J test) results are satisfying suggesting that the used instruments are exogenous to the quantity variable. First stage F-tests are satisfying for both sale and lease price models. The set of results that include state fixed effects are not so satisfactory. The sale and price estimations do not pass the first stage F-test, and the lease price model fails the over-identification test, suggesting a need of a better instruments for the quantity variable. In all regressions the standard errors have been corrected for heteroscedasticity.

In general, both sets of preliminary results allow us to show that water rights sale and lease prices are largely well-behaved, suggesting that the water markets overall tend to operate consistent with theory. More specifically, coefficients tend to yield the same signs for both sale and lease price equations. Also, the coefficient for the crop prices and income tend to be significant and positive, which implies that the sale and lease prices incline to increase from an increase in profitability and economic development. In addition, higher probability of precipitation has a negative and significant impact on lease prices, implying that lease prices

[18] Since total water withdrawals are published every 5 years (1990, 1995, 2000, 2005, and 2010), we did not have observations for the 1989, and as a result all the 1990 observations were dropped, because the variable we use is lagged by one year.

increase when there is a shortage in a resource. These results indicate that water rights market prices are generally well-behaved.

Table 2: Preliminary results for sale and lease price estimation without and with state fixed effects.

2SLS 2nd stage results	*(1) Log(sale price)*	*(1) Log(lease price)*	*(2) Log(sale price) with state FE*	*(2) Log(lease price) with state FE*
Log(quantity hat)	-0.500*** (0.060)	-0.214 (0.139)	-0.427* (0.226)	-0.656*** (0.125)
Urban buyer (dummy)	0.466*** (0.072)	0.924*** (0.186)	0.399*** (0.068)	0.396* (0.178)
Log(crop price)	**0.809*** **(0.373)**	**1.581***** **(0.172)**	**0.257** **(0.699)**	**2.705***** **(0.461)**
Wheat cost index	-0.464 (0.383)	0.347 (0.385)	-2.066* (1.243)	-2.148 (1.357)
Log (income)	**1.986*** **(0.822)**	**0.946*** **(0.476)**	**5.561*** **(2.591)**	**4.733*** **(3.003)**
SPI (24 month)	**0.031** **(0.137)**	**-0.395**** **(0.126)**	**-0.125** **(0.105)**	**-0.613***** **(0.133)**
Constant	-14.102* (7.039)	-13.576** (4.423)	-45.712* (24.054)	-46.723* (23.699)
Year) FE	yes	yes	yes	yes
State FE	no	no	yes	yes
N (obs)	1518	650	1517	650
First stage F-test	18.42****	14.64****	**3.21***	**6.50****
Underid.Test:X^2(1) *P-val*	26.215 0.0000	15.597 0.0004	5.075 0.0791	3.009 **0.2221**
Hansen J test:X^2(1) *P-val*	1.562 0.2114	0.093 0.7602	2.640 0.1042	1.724 0.1891

Note: *** Significance at 1%, ** Significance at 5%, *Significance at 10%; values in parentheses are standard errors.

Both prices are significantly and negatively impacted by an increase in demand due to the economies of scale that arise because of the high transaction costs, which normally increase together with the number of transfers, not with an increase in volume transferred. Urban buyers, as expected, have a significant and positive affect on water right sale and lease prices (the base case included agricultural buyers).

Interestingly, an increase in precipitation has a negative and significant impact on lease prices, but does not have the same effect on sale prices. The negative influence on lease prices, as expected, suggests that an increase in precipitation probability lowers the lease price for water rights, because of the plentiful supply. However, the probability of precipitation does not influence the price of permanent water rights transfer[19]. Since leasing transactions involve less transaction costs and can be processed quicker than permanent sales, it makes sense that the leases are more sensitive to weather than sales. However, it is hard to intuitively explain the positive sign (when state FE are not included), which suggests an increase in water rights sale price after an increase in precipitation. Although, the practice in C-BT market suggests that this might be a possibility. The Northern Water Conservancy District (NWCD) is a regulatory body for water rights transfers in C-BT, and it is responsible to annually set quotas for the water shares that are distributed among the owners. The quotas tend to be lower when the water supply is expected to be higher, because the District seeks to fill their reservoirs and save water for the "bad times", which results in there being less water available to trade when whether condition are wet; and that would raise the price for that water.

The coefficient for the wheat cost index is negative and significant only for the sale price when state fixed effects are included. We hypothesized earlier that the variable should be associated with a decline in profits, which should create an incentive for the suppliers to profit from water by selling it, and as a result lower the selling price. From the input demand side, an increase in other input costs should decrease the demand for that input, and consequently lower its price.

4.2. Asset pricing model

Since we have been able to show that water right sale and lease prices tend to behave well; that is, they show that the sale and lease prices tend to increase from an increase in profitability and economic growth, we continue by assuming perfect competition in the water rights markets,

[19] The past 72-month average for the SPI was tried in the sale price equation, but the resulted coefficient was not significantly different from the one reported in Table 2.

which allows us to apply the rational pricing theory that suggests that the present value of the permanent water rights should be equal to the discounted value of all future expected earnings represented by the water rights lease prices. Assuming constant lease prices and constant growth rate, the price of a permanent water right should be the following:

$p^{sale} = p^{lease} / _{interest\ rate}.$ Thus, the interest rate would equal to the expected rate of return from holding a water right.

Following Newell et al. (2007), who apply the present value model to the relationship between the fishing quota asset and lease prices, we use the Gordon growth model (Campbell, Lo, and MacKinley 1997), as shown in equation (4), and modify it to fit the water rights market context.

$$p_t = \frac{\pi_t}{r_t - g} \tag{4}$$

Where:

t - indicates time period,

p_t - is an asset price: water rights sale price,

π_t - is a future profit from the asset: water rights lease price,

r_t - is an interest rate,

g - is a constant growth rate.

We mentioned in earlier sections that water markets are highly impacted by the future expectations, which are mostly influenced by the climate conditions and institutional settings. We expect that the anticipations about the future affect the variation in prices. Therefore, as suggested by Alston (1986), Cochrane (1992), and Newell et al (2007), we decompose the interest rate (r_t) into a real market interest rate ($\tilde{r}_t$) and risk premium (θ_i). Ideally, the risk premium specific to a water right, should address both an institutional context and the uncertainties in climate. Another way to address the divergence in market prices would be to add a multiplicative function including factors related to uncertainties about the future to the growth model, as is done by Newell et al (2007). However, due to a very limited data used for the estimation of this model, we have not been able to add any additional variables testing the variation in prices without negatively impacting the significance of the entire model.

4.2.1. Empirical asset pricing model analysis

Empirical specification of the equation (4) for the water rights market is the equation (5) below.

$$lnp_{ijqt} = \beta_1 ln\pi_{ijqt} + \beta_2 \ln \tilde{r}_t + \beta_3 ln\theta_{jt} + \beta_4 lng_{jt} + \alpha_j + \alpha_t + +\varepsilon_{ijqt} \qquad (5)$$

Where:

i - is a transaction involving a permanent or temporary water rights transfer from ag-to-urb or ag-to-ag,

j – indicates a region—state,

qt – is a quarter (q) of a certain year (t),

p_{ijqy} – is a water rights sale price calculated as a quarterly average for the state specific transfers from agricultural sector to urban and agricultural sectors,

π_{ijqt} - is a water rights lease price calculated as a quarterly average for the state specific transfers from agricultural sector to urban and agricultural sectors,

$\tilde{r}_t$ - an annual real market interest rate for the U.S.,

θ_{jt} – risk premium is proxied by the drought variable,

g_{jt} - growth rate is proxied by the annual MSA specific population growth rate,

α_j – state fixed effects,

α_y - year fixed effects,

ε_{ijqt} – an error term.

All the variables used, except for the fixed effects, have been converted in logs.

The water rights sale and 1-year lease prices are quarterly averages for each state-specific water rights market. Water rights transactions are water rights transferred from agricultural sector to both agricultural and urban sectors. The data covers six states from the Western U.S. (AZ, CA, CO, NM, TX, and UT) for the 1994-2007 period. Due to the chosen model for this study we have decided to use quarterly averages for the sale and lease prices. The quarterly averaged lease prices need to match with quarterly averaged sale prices across years, quarters and states, in order for us to be able to apply the financial asset model. Creating such observations extremely shrunk our dataset, because, as we discussed earlier in the data section, many states did not have any lease or sale transactions for certain years. We were left with 70 quarterly observations. In addition, we eliminated all the observations that were linked to the negative real interest rates[20], and a few that were positive, but much lower than 1 %. That ultimately left us with 31 observations. The method used to create quarterly averages, as well as transaction frequencies specific to states and years are described in appendix E.

Following the asset pricing model, we expect the future profits that are represented by the quarterly lease price to have a positive impact to the water rights sale price. However, the real market interest rate, which in our model is represented by the CPI adjusted 3-month U.S. Treasury Bill rate should have a negative effect on sale prices.

A proxy for the *risk premium* in our model is constructed using the Palmer drought severity index (PDSI). In order for the PDSI to measure risk premium it has been converted into a fraction providing information for how many months in a year the index was between -2 and +2, which is a mid-range suggesting that on average weather conditions were normal. A risk premium variable should be partially responsible for higher variation and uncertainty in returns on assets. An increase in number of months with normal and expected weather conditions should lower the uncertainty related to water availability among the risk averse buyers; thus, an increase in such variable should have a negative impact on the asset price

The growth rate in our study is proxied by the population growth rate in metropolitan statistical areas (MSA). Most of the transactions in our dataset are water trades from agricultural to urban sector, thus, a growth urban growth represents demand for water, and is associated with an increase in sale prices.

Summary statistics of variables used in asset pricing model estimation are reported in Table E1, in appendix E.

The lease price variable creates an endogeneity problem in this model, which arises because the *price* variable is correlated with an error term. This means that other independent variables from the same equation have an impact not only on the dependent *sale price* variable, but also on the independent lease *price* variable. We address this problem by using the instrumental variable method, which we execute by solving the equations via 2SLS approach. An

[20] During the time period of our study, the real interest rate was negative in the U.S. Ideally, we would not have dropped the negative observations, because they resemble the reality. However, given a very low number of observations in our dataset, the negative interest rates would have not been consistent with the asset pricing model.

ideal instrument for an endogenous variable is a variable that is correlated with that endogenous variable (1-year lease price), but is not correlated to the dependent variable (sale price of water rights) of the main equation; that is, it is uncorrelated with the error term in the explanatory equation. In the application of the asset pricing model, the instrumental variable has been constructed from the same dataset, because it was not possible to find a suitable instrumental variable from other sources. The price instrument is the average price specific to year, sector, and state, excluding local state observations ($\overline{P_{t,d,J-l}}$; where d is a sector and l is a local state).

4.2.2. Preliminary asset pricing model results

Table 3 shows the results received estimating asset pricing model applied to the water rights markets. The results were obtained using the 2SLS with robust standard errors (corrected for heteroscedasticity). The F-statistics for the excluded variable in the first stage does not pass the "thumb-rule test"; it is lower than 10, which is not surprising given a low number of observations. However, the statistic is very close to 10, which suggests that the instrumental variable used might have some validity. The under-identification test is passed because it is rejected at 10%. Since the equation is exactly identified (one endogenous regressor is instrumented with one variable), the over-identification test (Hansen J statistics) is not reported.

Table 3: Asset pricing model results

2SLS *2nd stage results*	*Log (sale price)*
Log(lease price)	0.110 *(0.147)*
Log (growth rate= MSA pop growth rate)	1.877* *(0.862)*
Log(risk premium = drought expectations)	-0.038 *(0.121)*
Log (real interest rate = T-Bill rate)	-47.008*** *(8.056)*
State FE	Included+
Year FE	Included+
N (obs)	31

R^2 : centered: *uncentered:*	0.9127 0.9972
First stage F-test	**9.49****
Underid.Test: $X^2(1)$ *P-val*	3.948 0.0469

Note: *** Significance at 1%, ** Significance at 5%, *Significance at 10%; values in parentheses are standard errors.

+ The state and year specific fixed effects were included in the 2SLS regression, but had to be partialled out due to singleton dummies. The partialling out did not have an impact on the coefficients of the independent variables, but resulted in not providing any coefficients for the fixed effects.

All the coefficient signs are as expected. Consistent with asset pricing theory we find a positive relationship between the water rights sale price and contemporaneous lease price. Water rights associated with lower variation in weather conditions, as expected, have a negative impact on prices. The insignificance of the lease price and risk premium coefficients can be attributed to the very low number of observations (31) used in this study. Asset prices are positively and significantly impacted by an increase in growth rate and a decrease in the real interest rate.

5. Conclusions and discussion

In this study we sought to assess the price efficiency in U.S. water rights markets. As a first step, we have analyzed the water rights market activity. More specifically, we looked into volumes traded, and prices paid across twelve western states over the period of 21 years (1990-2010) The market activity is not consistent or systematic overall, but we noticed that the market for sales and leases is significantly active in some markets (sales in Colorado, leases in California and Texas), and that the annual lease activity has been increasing over time. In addition, the price dispersion for both sales and leases is relatively low.

As a next step in our assessment we econometrically estimated identical equations for water rights sale and one-year lease prices employing a unique water rights trading dataset, which consists of water rights sales and 1-year leases in twelve U.S. western states between 1991 and 2010. The estimated coefficients are generally identical in terms of signs for both equations. In addition, the results support rational economic behavior, since prices tend to significantly increase with an increase in profits.

The last step in our quantitative analysis of water market prices was the examination of the applicability of the asset pricing model to the water rights markets. We had a very limited dataset consisting of 31 observations for six western states and 9 years between 1994 and 2007 to perform this investigation; however, the obtained coefficients had the expected signs, although not all of them were significant. There is a positive relationship between the sale price and expected increase in future profits, the growth rate, and a rise in weather variability. An increase in interest rate negatively impacts the asset price. However, the magnitude of the received lease price coefficient is low (compared to ~0.85 estimated for fishing markets by Newell et al (2007)), which as expected suggest that the difference between the water rights sale and lease prices cannot be explained alone by the discount rate. As discussed in section 2, water rights markets differ greatly not only by state, but also within state. The institutional settings in all these markets have a high impact on how the market price is being determined.

Based on the analysis of the background in water rights institutions, the water rights markets can be organized in three general forms:1) markets following state regulation and the prior appropriation principles, 2) markets that are "autonomous" to general regulations and create their own rules, and 3) informal markets. Markets in all three forms exist in most of the western states, and all of them differ by the magnitude of transaction costs associated with them. The only easily identifiable markets exist in the second group (e.g., Central Arizona Project, Central Valley Project, Colorado-Big Thompson project, Lower Rio Grande market, etc.). Markets belonging to other groups are harder to define due to the poor or non-existent monitoring and enforcement. We believe that all three forms of the markets were represented by our challenging dataset (at least the first two); that is, we represented a mixture of efficient and non-efficient transactions, which as a whole had a tendency to behave based on the competitive market theory, the assessment of which was our main goal. The picture, however, is different when we try to perform a more state specific analysis (hence, poor results when we include state fixed effects in the sale and lease price estimation).

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APPENDIX A

[Include brief institutional analysis by state]

APPENDIX B

Table B1: Market activity by state, type of transaction, and buying sector

State	AZ	CA	CO	ID	MT	NM	NV	OR	TX	UT	WA	WY	Total
# sales	23	36	1,343	12	1	39	23	0	73	38	7	0	1,595
Buyer ag/urb	6/17	9/27	222/1,121	7/5	0/1	2/37	0/23	0/0	12/61	6/32	1/6	0/0	265/1,330
# leases	14	241	41	54	5	2	3	32	183	14	11	54	654
Buyer ag/urb	8/6	170/71	20/21	47/7	4/1	2/0	1/2	30/2	66/117	11/3	9/2	24/30	392/262
Total	37	277	1,384	66	6	41	26	32	256	52	18	54	2,249

Figure B1: Historical U.S. drought

Source: Arizona State Climate Office, https://azclimate.asu.edu/drought/

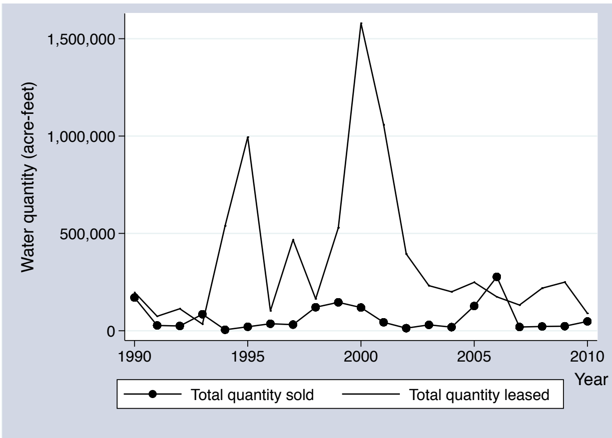

Figure B2: Total water sold and leased over time

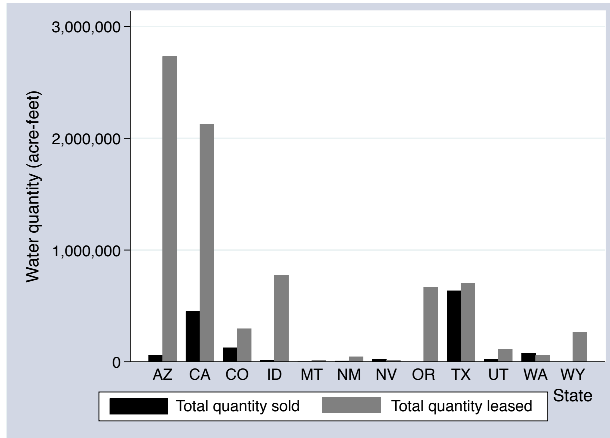

Figure B3: Total water sold and leased by state

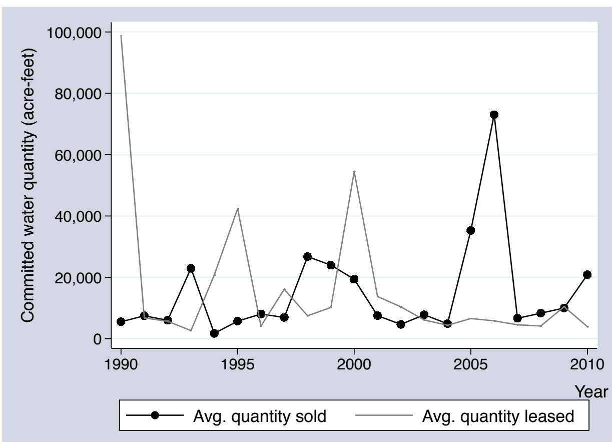

Figure B4: Committed annual average of water sold and leased over time

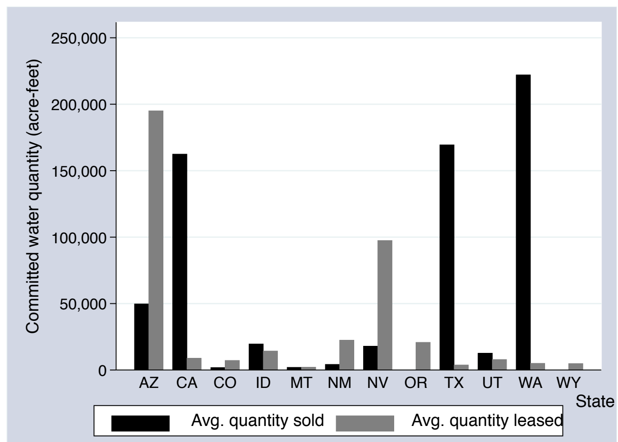

Figure B5: Committed annual average of water sold and leased by state

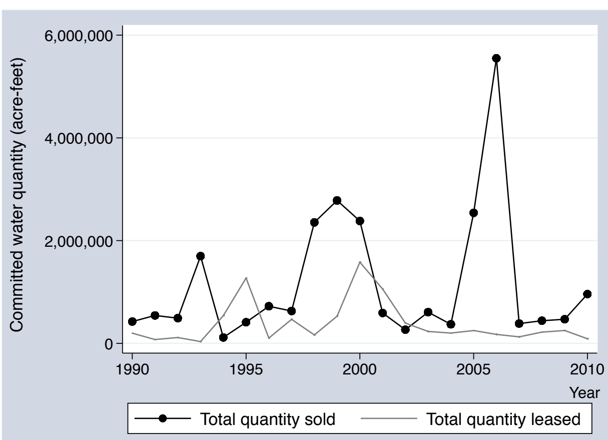

Figure B5: Total committed water sold and leased over time

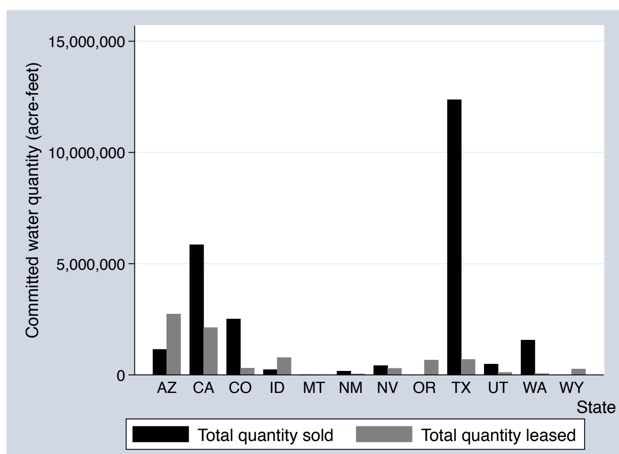

Figure B6: Total committed water sold and leased by state

The *crop price* variable has been constructed depending on which crop is largest based on area planted in each state (see Table 1 below). The information was collected from the U.S. Department of Agriculture (USDA) website. All prices are adjusted to 2009 dollars using CPI, and converted to a $/ton.

Table B2: Major crops by state based on area planted in 2012.

State	AZ	CA	CO	ID	MT	NV	NM	OR	TX	UT	WA	WY
Crops	Alfalfa	Rice	Wheat	Alfalfa	Wheat	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Wheat	Alfalfa

Note: Alfalfa is just a part of the category "all hay and haylage, grass silage, and greenchop". We use only alfalfa from this category, because the crop requires more irrigation than other types of hay; thus, profits from alfalfa are more sensitive to water availability.

Wheat cost index (wci) was constructed to proxy for the crop production costs. It was built by separating the variable costs into labor and material costs (per acre), adjusting them using the employment cost index (EPI) for the labor costs, producer price index (PPI) for the material costs, and multiplying them by shares specific to annual labor and material costs and then summing them as shown in the following formula:

$$Wheat\ Cost\ Index_t = (\Delta Labor\ cost_{base-t} * Labor\ cost\ share_t) + (\Delta Material\ cost_{base-t} * Material\ cost\ share_t)$$

The base year is chosen to be 1989. The wheat cost index for the base is set to equal 1. t indicates the contemporaneous year.

Table B3: Data sources

Variable	Source
Water rights sale and lease price per acre foot (CPI adjusted for 2009$); Quantity of water traded (in acre-feet); Buyers (ag and urb sectors); Federal/state project	*Water Strategist* journal from Stratecon, Inc.
Total water withdrawals	U.S. Geological Survey http://water.usgs.gov/watuse/
Population growth rate	U.S. Department of Commerce / Bureau of Economic Analysis
MSA population growth rate	U.S. Department of Commerce / Bureau of Economic Analysis
Per capita income	U.S. Department of Commerce / Bureau of Economic Analysis
T-Bill interest rate	Federal Reserve: http://www.federalreserve.gov/releases/h15/data.htm
Risk premium: PDSI	National Oceanic and Atmospheric Administration http://www.ncdc.noaa.gov/cag/
SPI	Western regional Climate Center http://www.wrcc.dri.edu/wwdt/time/
Wheat price per ton (CPI adjusted for 2009$)	U.S. Department of Agriculture http://www.nass.usda.gov/Statistics_by_State
Hay (alfalfa) price per ton (CPI adjusted for 2009$)	U.S. Department of Agriculture http://www.nass.usda.gov/Statistics_by_State
Rice price per ton (CPI adjusted for 2009$)	U.S. Department of Agriculture http://www.nass.usda.gov/Statistics_by_State
Wheat cost index (wci) (PPI & EPI adjusted for 2009$)	U.S. Department of Agriculture http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx
Consumer price index (CPI)	Bureau of Labor Statistics http://www.bls.gov/cpi/
Producer price index (PPI)	Bureau of Labor Statistics http://www.bls.gov/ppi/
Employment cost index (EPI)	Bureau of Labor Statistics http://www.bls.gov/news.release/eci.toc.htm

APPENDIX C

Table C1: Summary statistics for the lease price equation variables

Variable (650 obs.)	mean	sd	min	max
Lease price *Log (lease price)*	104.16 *3.51*	372.06 *1.35*	1.17 *0.15*	5409.22 *8.60*
Leased quantity per transaction *Log (quantity)*	11,646.49 *7.13*	49,963.75 *2.43*	1 *0*	738,630 *13.51*
Total last year water withdrawals *Log (total withdrawals)*	26,300,000 *16.89*	13,000,000 *0.75*	13,800 *9.53*	43,000,000 *17.58*
Crop price *Log (crop price)*	144.83 *4.95*	31.77 *0.22*	82.39 *4.41*	219.66 *5.39*
Per capita income *Log (per capita income)*	31,400.17 *10.32*	7,195.011 *0.24*	16,015 *9.68*	49,067 *10.80*
Number of leases in a year *Log (number of leases)*	12.78 2.12	12.63 0.97	1 0	50 3.91
Wheat cost index	1.31	1.36	0.11	5.25
SPI24	0.067	0.775	-1.62	2.24
Pop change	0.017	0.007	0.0007	0.055
Buyer dummy	2 sectors: Urban and agricultural			
Year dummy	20 years: 1991-2010			
State dummy	12 states: AZ, CA, CO, ID, MT, NM, NV, OR, TX, UT, WA, WY			

Table C2: Summary statistics for the sale price equation variables

Variable (1518 obs.)	mean	sd	min	max
Sale price *Log(sale price)*	9,229.34 8.62	7,715.83 1.25	13.25 2.584	53,625 10.89
Sold/leased quantity *Log(quantity)*	815.32 3.16	8181.34 2.09	0.36 -1.01	26,4074 12.48
Pop growth rate	0.022	0.007	0.006	0.062
Total water withdrawals last year *Log(last year's withdrawals)*	12,700,000 15.92	7,011,126 1.63	13,800 9.532	43,000,000 17.58
Crop price *Log (crop price)*	146.71 4.96	35.58 0.24	89.78 4.48	226.96 5.42
Wheat cost index	1.13	1.04	0.11	5.25
Per capita income *Log (income)*	103,594.5 11.40	51,397.49 0.65	6,134.73 8.72	60,067.73 13.31
Number of transfers in a year *Log (number of transfers)*	59.46 3.71	30.30 1.20	1 0	108 4.682
SPI24	0.371	0.76	-1.59	1.58
Buyer dummy	2 sectors: Urban and agricultural			
Year dummy	20 years: 1991-2010			
State dummy	10 states: AZ, CA, CO, ID, MT, NM, NV, TX, UT, WA			

APPENDIX D

Table D1: Preliminary results for sale and lease quantity estimation without and with state fixed effects

2SLS *1st stage results*	*Ln(sale q)*	*Ln(lease q)*	*Ln(sale q)* *with state FE*	*Ln(lease q)* *with state FE*
Pop growth rate	85.130** (25.915)	50.007** (16.389)	23.526 (22.077)	18.426 (27.919)
Ln(lag total withdrawal)	0.751*** (0.133)	-0.691*** (0.148)	0.189* (0.082)	-0.803** (0.232)
Ln(crop price)	3.584*** (0.658)	1.885*** (0.407)	2.072** (0.664)	2.481*** (0.488)
Wheat cost index	6.158*** (0.549)	-2.214** (0.696)	2.569 (2.560)	-5.066** (1.849)
Ln(income)	-13.320*** (0.886)	2.166* (0.977)	-6.516 (5.047)	7.903* (3.597)
SPI24	0.148 (0.294)	-0.535** (0.185)	0.079 (0.222)	-0.381* (0.188)
Urb buyer dummy	-0.022 (0.130)	-1.196*** (0.204)	0.007 (0.111)	0.946*** (0.207)
Constant	96.892*** (7.713)	-10.037 (9.352)	54.452 (47.219)	-61.440* (33.585)
Year (1991-2010) FE	Included	Included	Included	Included
State FE	Not included	Not included	Included	Included
N (obs)	1518	650	1517	650

APPENDIX E

Table E1: Descriptive statistics—trades from AG to AG & URB

Variable (31obs.)	mean	sd	min	max
Dep v. Sale price *Log (Sale price)*	2746.738 7.14	3691.711 1.33	82.21 4.41	13806.49 9.53
Lease price *Log (Lease price)*	100.09 3.92	119.12 1.32	1.47 0.39	559.48 6.33
Avg. lease price excluding local obs.(log) (lease price instrument)	4.24	0.66	3.05	5.37
3 m. T-Bill interest rate *Log (3 m. T-Bill interest rate)*	0.024 -3.73	0.005 0.22	0.017 -4.10	0.033 -3.41
MSA Pop growth rate *Log (MSA Pop growth rate)*	0.023 -3.80	0.007 0.29	0.015 -4.22	0.042 -3.16
Risk premium (PDSI fraction) *Log (Risk premium)*	0.63 -0.68	0.317 0.78	0.08 -2.48	1 0
Quarter dummy	4 quarters			
State dummy	6 states: AZ, CA, CO, NM, TX, UT			
Year dummy	9 years: ’94, ’95, ’96, ’97, ’98, ’99, ’00, ’06, ‘07			

Quarterly averages have been created in the following way, because June/July transfers are reported in one WS issue:

- 1st: Jan, Feb, March, April
- 2nd: May June/July
- 3rd August, September
- 4th: October, November, December.

One month's transactions are reported in next month's issue.

Table E2: Quarterly transactions[21]

Quarter	*Water Strategist* Issue
q1	Feb, March, April, May, Spring
q2	June, Jul/August, Summer, Summer/Fall
q3	September, October, Fall, Fall/Winter
q4	November December, January, Winter

Table E2: Frequency of observations by state

State	YEAR	OBS
AZ	1995, 2000	3
CA	1997, 1998, 1999, 2000	7
CO	1994, 1995, 1997, 1999, 2006, 2007	8
NM	1997	1
TX	1995, 1996, 1997, 1998, 1999, 2000, 2006, 2007	10
UT	1994, 1996	2

Table E3: Frequency of observations by year

Year	Frequency
1994	3
1995	4
1996	2
1997	4
1998	2
1999	6
2000	5
2006	2
2007	3

[21] For the 1995-1998 years WS reports transfers in quarters, but there is also two combined quarters: Fall'97/Winter/98 and Summer/Fall'98, which are assigned to quarters as shown in Table 3. We have tried assigning them to different quarters, but that did not yield significantly different results.