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Efficiency of Water Markets under Prior Appropriation: Evidence from Permanent Water Rights Sales in Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Economics

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Abstract

Throughout much of the semiarid West, water is managed by states under the legal doctrine of prior appropriation, where those with the earliest claim to a beneficial use of water have the first right to use that water in times of scarcity. In Nevada, as in other western states facing water scarcity concerns, there have been efforts to adopt new formal water market institutions to encourage water conservation and achieve a more efficient allocation of the state's water supply. Many such proposals are based on the assumption that voluntary exchanges under the existing prior appropriation system do not result in efficient reallocation of water. In this paper, we study water right-level and basin-level drivers of prices of water right sales to evaluate the efficiency of water rights markets under prior appropriation in Nevada. We use a new dataset of all reported water rights sales in Nevada between 2006 and 2019. Our findings show that characteristics of water rights, buyers and sellers, and basins all significantly affect the transaction price of a given water right. We find a price premium for more reliable rights, with a 4.1% decrease in price for every ten years after the earliest priority date in the basin, and no significant price difference between groundwater rights and surface water rights. Our model shows that M&I buyers purchase at only 12% higher prices than agricultural users when controlling for the types of rights purchased and basin of purchase. This suggests that the conclusions of previous literature that many water markets are inefficient may be a result of agriculture, mining, and M&I buyers being represented differently across geographically distinct markets. Finally, through utilizing an instrumental variable, we show that transaction volume has no significant effect on prices. Based on a Nash bargaining framework, our findings suggest that bargaining power lies more in the hands

of sellers than buyers of water rights. These findings suggest that prior appropriation water markets may be efficient at allocating water between uses. This motivates investments in infrastructure rather than new water market institutions for addressing water scarcity.

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Introduction

With continued rapid urbanization and population growth, as well as more frequent drought and disrupted timing of water flows due to climate change, many western states are seeking creative solutions to meet their rising water demands (Sun et al. 2008; Zeff et al. 2016). The Nevada state legislature recently considered a proposal to create a formal market for buying and selling water under a water banking system, with the motivation that it would incentivize conservation and encourage transfers of water that would not occur without such a system (Metz 2021). At present, the default means of reallocating water in most regions is through the voluntary exchange of water rights between users. These regulated voluntary markets are a means for water to be purchased by users where its value is likely to be highest and moved away from lower-valued uses, resulting in a more efficient allocation of water (Chong and Sunding 2006; Lee, Rollins, and Singletary 2020; Debaere and Li 2020). Little is known, however, about the extent of these voluntary markets, their efficiency at pricing variation in water right characteristics, or who participates and has leverage in purchases within these markets. A better understanding of these dynamics is needed to help policymakers and water managers make decisions about the kinds of institutional changes or infrastructural investments that would be most effective in leading to optimal water allocation.

Much of the water in the western United States is managed by states under the doctrine of prior appropriation. All nineteen westernmost US states use some form of a prior appropriation system (National Agricultural Law Center 2021). This policy means that the state owns water and grants users the right to use a given volume of water for a particular type of use (Donohew 2009). Historically, water rights have been assigned by

the state to users based on the order in which they put water to a beneficial use. Beneficial uses are determined by the state and typically include irrigation, municipal and mining uses, and rules have been updated to include water left in-stream for environmental benefits as a beneficial use (King 2016). Because the supply of water in any given year is uncertain, rights holders may have some of their water right curtailed by the state during low-flow years. Users who were granted water rights the earliest are the least likely to have their use curtailed. Water rights can be for surface water or groundwater, with the latter typically not having been subject to curtailment in Nevada.

The prior appropriation doctrine means that the earliest uses, not necessarily the most valuable uses, were initially allocated the most water. In much of the West, this means that a majority of water rights were initially allocated to agriculture, which has remained the dominant use to this date (Donohew 2009; King 2016). As states' populations have grown and the nature of economic activity has shifted from agriculture and resource extraction to more diverse manufacturing, service and technology industries, there has been a continuing need to reallocate water to its most beneficial use. Additionally, many basins in Nevada have more water rights allocated than the perennial yield of the groundwater basin. Agriculture-dominant areas such as the highly overallocated basin of Diamond Valley in Eureka County, NV have been exploring alternative mechanisms for reallocating water such as local collective management as a common pool resource to avoid state curtailment (Zeff et al. 2016). Other states have proposed creating proportional share systems, or mutual fund arrangements similar to ditch companies (Goemans and Pritchett 2014). The Nevada legislature proposed a bill in

2021 that would establish a state water banking system that would create a new market for conserved water (Metz 2021).

The fact that alternative mechanisms are being proposed implies that the current option for reallocating water—buying and selling in a voluntary market—may be insufficient for reaching preferred water allocation. The lack of existing knowledge on prior appropriation markets motivates further study to better understand what may be inhibiting efficient water reallocation or giving bargaining power to certain participants over others. This research seeks to address whether or not voluntary water rights markets in Nevada are leading to an efficient allocation of water across the state. In this context, efficiency is primarily defined as the law of one price, where two water rights with similar characteristics and potential uses should sell for the same price if purchased at the same time. This also means that if municipal water users are willing to pay more than agriculture producers for the same water, then we should expect trades into municipal use until the value of additional water in municipal or agricultural use is the same within a water market.

Each water right transaction involves many steps. It includes a negotiation between one or more buyers and sellers who often are putting water to different types of uses, and a legal framework for when, how and where the water may be used. On top of this, legal fees, state regulations and infrastructural constraints on where water can physically be moved can all greatly affect the price at which water rights are transacted. Understanding the pricing of water rights allows for an evaluation of the law of one price, which is a useful starting point for understanding the efficiency of these markets.

Previous studies have documented large differences in the price of water rights within U.S. states (Brewer et al. 2007; Pullen and Colby 2008; Rimsaite et al. 2020). Due to data limitations, research to date has not been able to explain many of the factors that drive these price differences. It is crucial to understand these factors to better understand how current western water rights markets, which primarily consist of voluntary exchanges under prior appropriations doctrine, are functioning at reallocating water in areas of high scarcity. This project addresses this gap by collecting a complete dataset of 3,548 transactions of water rights sold as individual assets separate from land and property in Nevada between 2006 to 2019. The data set combines detailed information on each water right transfer obtained from the Nevada Division of Water Resources with information on the price of each transaction obtained from county recorders offices across Nevada and will be used to answer several research questions. Overall, we seek to explain the differences in observed prices across Nevada. First, we ask how characteristics of water rights affect their sale price. Second, we explore the extent to which observed differences in prices in Nevada are driven by geographically segmented markets and limitations on conveyance. Next, we address the endogeneity of price and volume to determine the relationship between prices, transaction costs, and volume of water traded. Finally, we use economic theory to describe the bargaining process for water rights transfers to determine how the relative bargaining power of buyers and sellers drives variation in prices.

The data used in this article allows us to overcome three limitations of previous studies. First, water rights are heterogeneous goods. This data allows us to analyze how the price of water rights differ based on their place of use, their source (e.g., ground or

surface water), buyer and seller characteristics, and their priority date, which determines the reliability of supply under prior appropriation. Previous state-level studies that have relied on water transfers reported in the trade publication *Water Strategist* (Howe and Goemans 2003; Brookshire et al. 2004; Brewer et al. 2007; Pullen and Colby 2008; Rimsaite et al. 2020) have not been able to analyze the extent to which these features of water rights explain observed differences in prices.

Second, limitations on water conveyance mean that there are several geographically distinct water markets within each state. Previous studies have been constrained to analyzing water markets at the state level (Brookshire et al. 2004; Brewer et al. 2007; Pullen and Colby 2008; Ghosh 2019; Rimsaite et al. 2020) or in a single basin (Howe and Goemans 2003; De Mouche, Landfair, and Ward 2011; Ayres, Meng, and Plantinga 2019) and, as such, have not been able to consider the extent to which observed difference in prices are the result of the forces of supply and demand operating differently in distinct water markets. Our data set includes the geographic coordinates of each water right before and after the transfer. This allows us to sub-divide the state into water markets based on conveyance and analyze the determinants of water rights prices within each market.

Third, water rights transactions vary in size from very small (one acre-foot of water sold or less) to extremely large (thousands of acre-feet sold). Previous studies that have analyzed water markets at the state level using *Water Strategist* data have used a potentially non-random sample of water rights transactions. In contrast, our data set contains the universe of water rights transactions in Nevada, including many small

volume transactions. This feature of our data allows us to analyze the relationship between volume transacted and price, as well as explore the role of bargaining power in explaining variation in water rights prices.

Background on Water Rights Markets

Most western states are governed under the prior appropriation doctrine. Generally, the guiding principles of prior appropriation include the requirement of beneficial use, "first in time, first in right", and no third-party injuries when transferring water (Donohew 2009). Although institutions vary greatly by state, there are a number of important similarities across western states. Namely, transfers are typically reviewed by a state agency or board, return flows and consumptive use are considered when approving transfers, and markets are mostly informal (meaning deals are often brokered through an agent or in conjunction with a licensed water rights surveyor). Institutions, such as irrigation ditch companies, water municipalities, conservation districts and other quasi-governmental entities all have a hand in managing water and influencing transfer decisions. Donohew (2009) notes that there are over 1,000 such entities in the western US.

Water rights transfers are subject to a number of regulations that can restrict transactions. Research to date has shown that most water markets violate economic market theory such as the law of one price (Chong and Sunding 2006). Federal laws, as well as some state regulations, prohibit profit-making in water transfers (NRS 533). Additionally, state requirements of not adversely impacting third parties have subjected water transfers to public protest and litigation. There are also cases in which water transfers can have dramatic economic consequences when large volumes of water are

transferred out of agricultural use and moved to urban use. This has led to catastrophic economic impacts for some rural areas, such as in Crowley County, Colorado, where a substantial number of farms shut down after selling water rights, causing ripple effects on local businesses and tax revenues (Lustgarten 2016).

Markets for paper water rights are not equivalent to markets for physical water. Howe and Geomans (2003) show that water markets that allow for identical shares of water are traded facilitate efficient reallocation of water between uses across space and time. Water rights markets comparatively function much less efficiently since rights are not homogenous. Prior appropriation means that each water right has a defined type and location of use, along with different sources and levels of risk that water delivery will be disrupted. The non-homogenous nature of water rights makes the study of the drivers of prices in water rights markets especially important. This is because the assumption of transparency and equal knowledge between buyers and sellers may be more tenuous given the complex legal framework of water rights.

Water Rights Pricing

A large body of literature has studied the drivers of prices in water rights markets. Much of this research has relied on a single, proprietary dataset of transactions published in the trade journal *Water Strategist*. This dataset, while large (over 4,400 sales and leases in 12 states between 1987-2009), has many notable weaknesses that has limited the scope of much existing research on water markets. The dataset misses transactions that were not reported to the journal and provides few details regarding the water right and buyer and seller in each transaction (Brewer et al. 2007). Most transfers—about 66 percent—are from California and Colorado, and only 156 sales (4.5 percent) are published for Nevada

(author's calculations from Donohew and Libecap 2019). This weakens the ability for detailed study on market characteristics within most states. The *Water Strategist* data only identifies the state of the transaction, volume of water and the type of use by the buyer and seller. Details such as the water basin where the right was located or, more precisely, the exact geospatial coordinates where the water was transferred are important determinants of transfer price but are not included in the data. Further, the dataset lacks information about the underlying right itself, such as the priority date, status of the right, and source (groundwater vs. surface water).

Existing literature on pricing and efficiency in water rights markets has looked at either state-level determinants of prices or market characteristics of a single basin. The research at the state level has suggested that water markets are an effective solution to the economic problem of water scarcity, despite institutional constraints and regulations (Colby 1990; Howe and Goemans 2003; Pullen and Colby 2008; Rimsaite et al. 2020). For example, Rimsaite et al. (2020) finds that water rights follow the capital asset pricing theory, meaning the market effectively captures their value. There is evidence of inefficiencies in these markets, however. Brewer et al. (2007) demonstrate that prices vary dramatically across states and across types of buyers for the period of 1987-2005. The average sale price of water in Oregon was only $110 per acre foot (in 1987 dollars) and nearly $2,700 per acre foot in Colorado during the study period. Overall, they find that mean prices are nearly 2.1 times higher for agriculture-urban sales than ag-ag sales, yet these prices vary considerably across states. They analyze 126 transfers in Nevada, 112 of which are permanent sales. The average sale price over the whole timeframe for Nevada was $1,990 per acre foot (in 1987 dollars). Across all states, the prices were

$1,750 per acre foot and $28 per acre foot per year for leases. They note that 84% of transactions in Nevada were agriculture to urban transfers, with the rest being urban to urban transfers. Other states tended to have a much lower proportion of ag-urban transfers. The mechanisms driving these price differences were not identified.

Rimsaite et al. (2020) used *Water Strategist* data and an asset pricing model to determine if water rights prices reflect an efficient market based on asset pricing theory. Their findings suggest that asset pricing theory applies to western water rights markets and that markets are efficient when examined at the state level. Because the volume of water transferred and manner of use for the water before and after the sale were the only identifying factors in each water transaction, it is unclear how asset pricing theory holds when other sources of heterogeneity in water rights are accounted for.

Brookshire et al. (2004) econometrically estimate the drivers of water rights prices in Arizona, New Mexico and Colorado using *Water Strategist* transfers. They show that institutional, geographic, and climatic variables in each state significantly influence the prices of water rights. For example, the proportional shares system (an institutional variable) in Colorado in the CBT encourages transfers and drives prices up, as risks and administrative costs are lower. Compared to Arizona, both New Mexico and Colorado have a much higher percentage of municipal buyers and fewer government buyers (geographic variables). This also explains the higher prices in these two markets. Finally, they show that prices are lower in wetter years and higher when per capita income increases. Looking at volume of transactions, they show that as agriculture value decreases, trade volume goes up. This supports the theory that as the opportunity cost

associated with holding onto water rights for agricultural use increases, the supply of rights increases, and the market price goes up. The authors note that since markets are informal, many traditional assumptions of market theory fail. As markets develop, however, margins for water rights brokers decrease and water is more efficiently allocated. Proportional share systems, they conclude, are the most efficient allocation mechanism.

Due to the limitations of *Water Strategist* data, few conclusions have been made regarding the degree to which regional characteristics or water right characteristics influence prices. A small number of studies have collected data on trades within a particular water basin (Howe and Goemans 2003; De Mouche, Landfair, and Ward 2011; Ayres, Meng, and Plantinga 2019). For example, De Mouche et al. (2011) find that every year increase in priority date for rights in Las Cruces, New Mexico decreases sale prices by $13, or about 6% of the mean sale price in their dataset. They also find that total municipal water consumption and average farm income were both associated with higher sale prices, and higher volume transactions were associated with lower prices. They were not able to control for the exact location or type of use, nor the source of the water (groundwater or surface water).

Factors Influencing the Price of Water Rights

There are a number of factors that influence the price of each water right transaction. Previous literature has identified many of these factors. The following variables have been identified either in the literature, theory, or are an important component of water rights transfers in Nevada.

Water Rights Characteristics

Volume of Water under Water Right

Water rights in Nevada have a specified annual duty, or a volume of water in terms of acre-feet delivered annually or within a specified period (e.g., a growing season). The full annual duty of a water right may be split amongst multiple owners or owned and utilized by a single individual or entity. Volume of water per transaction may influence price through economies of scale, transaction costs or bargaining power differentials between buyers and sellers. DeMouche et al. (2011) find that higher-volume transactions are associated with lower prices in the Rio Grande Basin of New Mexico, while Pullen and Colby (2008) find the opposite relationship in the Gil-San Francisco Basin. In some cases, particularly in active markets, the quantity of water and price may be co-determined if higher prices give rise to higher quantities desired to be sold or fewer desired to be purchased. DeMouche et al. estimate a simultaneous equations model to show that prices did not significantly explain quantities of water traded. Pullen and Colby, however, find evidence of endogeneity and use an instrumental variable for size of transaction to show that higher volume transactions are associated with higher prices. It is hypothesized that the relationship between volume of transfer and price will depend on transaction costs, market participants and bargaining power for differently sized transactions, and economies of scale for buyers and sellers.

Priority Date of Water Right

Water rights with a more senior priority date have a greater reliability that the full quantity of their water right will be delivered in any given year (Colby 1990; Zachary Donohew 2009; De Mouche, Landfair, and Ward 2011). In Nevada, this has applied almost exclusively to surface water rights, where the supply of “wet” water in any given

year is more variable than groundwater aquifers. *Water Strategist* data does not provide the priority date of the water transferred, so most research has not been able to determine the impact of priority date on prices. However, De Mouche et al. (2011) find that every year increase in priority date for rights in Las Cruces, New Mexico decreases sale prices by $13, or about 6% of the mean sale price in their dataset.

Water Source (Groundwater or Surface Water)

Surface water includes water from rivers, creeks, lakes, and other sources where the water is primarily stored above ground. Groundwater includes belowground sources of water stored in aquifers. Surface water and groundwater are both subject to the same legal rules of prior appropriation, but each requires different infrastructure to utilize. For irrigators, for example, surface water is frequently delivered by irrigation ditches, while groundwater requires a well to pump. In Nevada, most early water rights came from surface water, and groundwater rights became the most common source of new rights in the second half of the 20th century. Groundwater use in Nevada has also not been subject to curtailment of use, making groundwater rights more reliable than surface water rights. Different sources of water may also have different third-party effects, creating different expected transaction costs between each type of right. Water Strategist data does not specify the source of the water right, meaning little is empirically known about the relationship between source of water and price. De Mouche et al. (2011) control for reservoir level as a proxy for supply of surface water. Their findings suggest that users in the Rio Grande Basin of New Mexico treat surface water and groundwater as direct substitutes.

Permitting Status of Water Right

Water users go through several steps to apply for and receive a water right in Nevada. First, an application is filed with the state. Once the state makes a decision on whether or not to grant the water right, it enters a protest period, where other users can appeal the decision by the state. If this period is passed, the right is permitted. Once permitted, the water right holder receives a permit document spelling out the terms of use. The user must demonstrate to the state that the water is being put to beneficial use every five years. If beneficial use has not been proven, a permitted right is subject to cancellation. A permitted right holder may apply for a certificate once beneficial use is proven to the state. A certificated right may still be withdrawn by the state but is much more secure and unlikely to be cancelled. A water right may be traded at any step of this process. A right in application status bears considerable risk of not being approved by the state. A permitted right is secure, but comes with stricter beneficial use requirements, while a certificated right is most secure. The status of water rights is likely to influence the price of the right, but no study to date has accounted for this variable when modeling the drivers of water rights prices.

Period of Use and Presence of Supplemental Rights

Each water rights in Nevada have a specified period of use. For most M&I rights, this period includes the entirety of a year (January 1 to December 31). However, certain irrigation rights are designated only for a portion of the year, based on different portions of the growing season (frequently with portions cut off in April, June, and September). For example, in the Humboldt River basin, curtailment policy is designed based on both the priority date of a water right and its period of use (NDWR 2021). Irrigation rights with intended use only through April, for example, may be worth relatively little to

municipal users needing full year water supply. Additionally, surface water rights can be granted supplemental groundwater rights that may be used in years when surface water use is curtailed by the State Engineer. These supplemental rights are expected to make the surface water right more valuable, as its full annual duty is able to be utilized in low-flow years. Most, if not all, supplemental rights are able to be used only for irrigation use, and thus are of little value for municipal and industrial buyers.

Buyer and Seller Characteristics

Type of Buyer and Seller

Market participants frequently include agricultural producers, mining companies, water municipalities, land developers, and conservation organizations. Previous studies have documented large differences in purchase price based on the type of buyer and seller (Howe and Goemans 2003; Brookshire et al. 2004; Brown 2006; Brewer et al. 2007). Brewer et al (2007) find that mean prices are nearly 2.1 times higher for agriculture sales into municipal and industrial use than sales between agricultural users. Leases are priced over four times higher for urban users than agricultural producers. These differences vary considerably across states, and Brewer et al (2007) found that agriculture to urban transfers were actually priced 25% lower than trades within agriculture in California. The overall price premium for municipal and industrial users may be due to a number of reasons. For example, it could be that municipal and industrial users purchase rights with more valuable characteristics such as those with a more senior priority date. They may purchase rights with larger or smaller volumes or be in a position with stronger or weaker bargaining power. Finally, it may be due to the two buyers participating in distinct markets, as each set of buyers will be limited to water that can be conveyed to their

location. Previous work has been unable to parse these potential explanatory factors, as *Water Strategist* data does not provide detailed information on the buyer and seller and the water right being traded.

Marginal Value of Water for Buyer and Seller

In theory, buyers and sellers should determine their reservation price in part from the discounted net present value of the expected value of the water in the use that the buyer and seller are using it for. Buyers and sellers should be willing to pay or accept an amount based on the value of the water to them. A water municipality may be willing to pay a large sum in order to secure rights to meet expected future demand for a growing population or expanded economic production. Agricultural producers may have a lower reservation price to sell their rights if they expect that profitability of their enterprise is likely to decrease in the future, owing either to expected prolonged drought, shifts in commodity prices, or changing regional economies. A number of studies have estimated the effect of the marginal value of water in alternative uses through the use of proxy variables. For example, Pullen and Colby (2008) proxy for the relative value of water in urban, agricultural and mining use through population growth, calf prices, and copper prices, respectively. Such approaches have provided a rough approximation of the influence of external economic forces on sale prices.

Conveyance Infrastructure Accessible to Buyer

Groundwater requires a well to access, and surface water typically relies on irrigation ditches or other water delivery mechanisms to transport water. Whether or not the purchasers have this infrastructure will constrain their ability to buy certain water rights.

Transaction Costs

Buyers and sellers are each subject to transaction costs. Changes in place of use, manner of use or point of diversion must be approved by the Nevada State Engineer (King 2016). Additionally, buyers must be certain that the chain of title is updated prior to purchasing the right to ensure that the seller is the current owner of the water right in question according to the state. Finally, applying to change the place or manner of use may result in legal proceedings fees (Truckee Meadows Water Authority 2016). In general, it is expected that a greater volume of water in each transfer may incur lower transaction costs per acre-foot of water transferred.

Market Characteristics

Number of Buyers and Sellers

Thick markets, or those with a large number of buyers and sellers, should have less price disparity and more efficient matching of water users (Gan and Li 2016). Previous studies have controlled for local or regional population when evaluating the drivers of water rights prices (Brookshire et al. 2004; Pullen and Colby 2008; De Mouche, Landfair, and Ward 2011). Although in many models, population was meant to proxy urban demand (Pullen and Colby 2008; De Mouche, Landfair, and Ward 2011), it likely is highly correlated with the number of buyers and sellers in an area. Pullen and Colby (2008) show that as population increases, the price of water rights increases in the Gila-San Francisco basin in New Mexico.

Relative Scarcity of Water in Basin

While the supply of water in any given year may vary based on climate, the amount of water rights available is typically fixed, as many basins have already been fully appropriated (King 2016). Urbanizing basins have seen a growing concentration of water

in municipal and industrial uses (Legislative Council Bureau 2019). In highly populated and growing areas such as Reno and Sparks, finding additional water to move into an urban water supply may be more constrained by quantity of non-municipal rights than for more rural municipalities such as Winnemucca or Yerrington.

Presence of Institutions

Donohew (2009) notes that water markets may be influenced by the presence of governmental or quasi-governmental organizations that have an outsized market presence. For example, in Reno, Truckee Meadows Water Authority (TMWA) is a major participant in the market and owns nearly 180,000 acre-feet of water rights in the basins it uses to service the city. They have converted 69,000 acre-feet from irrigation to municipal rights (Truckee Meadows Water Authority 2016). Given that TMWA is a not-for-profit entity, they have an incentive to keep prices low rather than to bargain for the highest sale price or lowest purchase price. Basins that lack such a major institutional buyer may be more sensitive to supply and demand forces but may have a greater challenge in matching buyers and sellers.

Water Conveyance Infrastructure in Basin

The state of Nevada grants inter-basin transfers that have allowed water users to transport water from outside the hydrographic area. For example, Vidler Water Company was granted the right to transport water from Honey Lake, on the CA/NV border, to Lemmon Valley just north of Reno via a 28-mile pipeline (DeLong 2015). Although water rights in Honey Lake would typically not be able to be used several basins over in the greater Reno area, the approval of the pipeline project allowed for the water to be transported across basins from where it had predominantly been used for agriculture in a sparsely

populated area into an urbanizing basin with high water demand. Water transfers may be made based on speculation that new infrastructure will be constructed. Typically, however, basins with a greater capacity to transport water via pipelines, irrigation ditches, or pumps are likely to have a greater capacity to facilitate transfers.

Drought and Annual Variations in Physical Water Supply

The supply of water regionally depends on climate—namely levels of precipitation, snowmelt, runoff, and evapotranspiration. Several studies have demonstrated a relationship between weather fluctuations and sale price of water rights. Pullen and Colby (2008) use a drought index to look at the relationship between weather variation and prices. They find that drought periods are associated with a higher price per acre foot of water transacted. Ghosh (2019) uses *Water Strategist* transfers published by Donohew and Libecap (2019) to look at the relationship between drought and water rights prices. The study focuses on drought-affected areas and those with increasing urban water demand with a large enough number of observations—Texas, California, Colorado, and Arizona. Proxying for climate variation through an "extreme drought" variable based on NOAA drought monitor index, the author finds that lease prices are much more sensitive to drought than sale prices. The author also finds that multiyear leases and permanent sales both facilitate a greater volume of water transferred than annual leases, and at a higher price. Since sales, rather than leases, out of agricultural use are permanent, economic theory would suggest that the decision to sell a water right would be made only if the producer expects the drop in water supply to be permanent and thus they are choosing to move out of agriculture production. These findings in the literature, however,

suggest that even in markets for permanent transfers of water rights, climate variables such as drought may be partly driving market activity and prices.

Based on a review of published literature, it appears that no study of water rights pricing has been able to effectively control for all the water right characteristics, buyer and seller characteristics, market characteristics and spatial variables that are likely to vary across transactions and regions and affect prices. The lack of comprehensive information about how these factors together may be driving market prices and efficiency represents a major gap in water markets literature to date.

Data

Data Sources

Nevada is divided into 14 hydrographic regions and 256 hydrographic basins and sub-basins across the state, defined by physical topography. All transfers of water right ownership must be filed with the Nevada Division of Water Resources (NDWR) as a report of conveyance. As with other sales of real property, taxes on water right sales are required to be paid to the county recorder in the county where the water right is located. Many of these transfers can be matched to deeds of sale in the county recorders offices where the water right is located. This project collects data primarily from four sources.

First, all transfers of water right ownership must be filed with the Nevada Division of Water Resources (NDWR) as a report of conveyance. Although a small number of water right transfers may go unreported due to a lack of enforcement, a majority of water right transfers can be found by searching the NDWR water rights

"Titles Search" database. Many of these transfers can be matched to deeds of sale in the county recorder offices where the water right is located.

Records for reports of conveyance were downloaded from the NDWR online transfers database[1] for each of the 256 hydrographic basins and sub-basins in Nevada from 2006 to 2019. These records include the date of the title transfer, the permit number, hydrographic basin, and names of both the previous owner and new owner. Although a small number of water right transfers may go unreported due to a lack of enforcement, rights holders have an incentive to report changes of title for two reasons: 1) to verify that the previous chain of title prior to their ownership had been properly updated, thus securing their ownership status, and 2) so that the right holder is notified of state management decisions affecting their water use. NDWR personnel believe that the vast majority of water right transfers in Nevada are entered into NDWR's online report of conveyance database (personal communication, S. Clayson, Engineer Technician V, NDWR, 2/19/2020).

Second, as with other sales of real property, taxes on water right sales are required to be paid in the county where the water right is located. After obtaining the report of conveyance records from NDWR, a manual search was then conducted in each county recorder's online records repository for each deed of sale using the name of the buyer of the water right and a date range listed on each report of conveyance. For reports of conveyance that were successfully matched to a deed of sale, the assessed value, real property tax value, date of recording and acre-feet of water listed in the deed and its

[1] http://water.nv.gov/titles.aspx

associated declaration of value form were obtained. Of the 25,985 reports of conveyance obtained from the NDWR database, 5,953 were successfully matched to a deed of sale. An additional 1,842 deeds of sale of water rights were found in county recorder's offices that could not be matched to a report of conveyance from the NDWR database. This does not necessarily mean these transfers did not file a report of conveyance, it simply means it could not be matched to a report of conveyance. This may have been due to the name used to file the report of conveyance being different than that listed on the deed of sale (eg, a subsidiary company filing on behalf of their parent company, or a development company purchasing a right and filing a deed of sale then immediately transferring title straight to the local water authority rather than into their name first). In some cases, the deed of sale did not have a sale price listed for water rights. For example, government entities are not required to pay taxes on transfers of real property, and thus do not have to report the sale or appraised value of the water rights on a declaration of value form. In these instances, prices of sales were not able to be identified and these transfers are likely systematically underrepresented in our sample[2].

In total, 27,827 total transfers of water rights were identified from reports of conveyance and county recorders deeds. The process of matching reports of conveyance with deeds of sale revealed that water rights transfers typically fell into one of four

[2] A request was made to Truckee Meadows Water Authority (TMWA) and Las Vegas Valley Water District (LVVWD), two of the largest providers of water service in Nevada, for records on the prices paid for all water rights during the period of this analysis. For LVVWD, nearly all water rights were purchased appurtenant to property and thus were excluded from our sample. TMWA establishes a "Rule 7 Price," on a rolling basis according to market conditions. The Rule 7 price is the maximum price they will buy a water right for, and is meant to provide a buffer for the transaction costs and legal risks associated with a purchase. For all TMWA transactions in the dataset where the purchase price is not observed, we apply the published rule 7 price shared by TMWA for the month and year when the transaction occurred.

categories: (1) those where the water right was the sole asset transferred, (2) those where water was transferred with land or other real property, (3) those where title was transferred as part of moving assets into a trust, and (4) all other types of transfers of title, including title for mining claims (dewatering, for example) or those where the type of asset was not clearly specified in the deed of sale. About 28% of the reports of conveyance identified were for transactions where the water right was the sole asset transferred. Over 54% of reports of conveyance were for transfers of land or other property where water rights were bundled in the trade. About 4% were transferred into trust and 14% were for other types of transactions. Of 7,795 individual water rights transfers that were identified where water was the sole asset transferred, 3,365 transfers had complete price information from deeds of sale. Transactions frequently bundled multiple individual water rights together into a single deed of sale. There were 1,758 unique transactions of bundled water rights in the dataset.

Third, for each of the 27,827 transferred water rights, the NDWR online *permit* database[3] was scraped to collect identifying information about each transferred water right, including its priority date, source, manner of use, status, location of use and any changes in use, status or location filed with the NDWR after the transfer. Additional details about this data scraping procedure and assumptions made to match water rights can be found in Appendix I.

Fourth, several additional geospatial variables were collected, including the distance from the water right's location of use to the nearest municipality, population of

[3] http://water.nv.gov/permitsearch.aspx

the nearest municipality, climate in the location of use, size of the land parcel where the water is used, land cover type on the parcel where the water is used, the depth to groundwater at the point of diversion, the elevation, and potential crop yield in the location of use. Geospatial variables were collected using ArcMap software, merging spatial datasets of the control variables with the location of use information of each water right. Data sources of all geospatial variables and other relevant variables are shown in Table 1.

Data Cleaning

Data were cleaned for outlier values. Observations where the sale price was greater than $50,000 or less than $100 per acre-foot were flagged as outliers and reviewed. Based on discussions with licensed Nevada water rights agents, these prices are anomalous and may reflect either misrecorded data or irregular transactions. Each flagged outlier was reviewed to determine if the data had been misrecorded, such as the bundle of rights including supplemental rights, property sales misrecorded as water rights sales, or incorrect portions of the full water right duty being recorded in the sale. If the volume of water or sale price needed to be adjusted, the data was corrected. All other outliers were dropped from the main analysis of this paper.

Additional data cleaning procedures were developed to identify transactions where water rights had special terms of use, such as the maximum annual duty allowed to be used under a bundle of rights being smaller than the sum of individual rights. This was frequently the case with transfers that included supplemental rights in addition to the base right.

Additionally, decreed rights are those that were granted from a federal or interstate decree and are subject to slightly different terms of use than regularly issued water rights permits. The type of use is typically not specified in the NDWR permits database. The type of use had to be inferred from the business name of the new owner. Companies with “construction”, “homes”, “development” or similar terms in their name were classified as municipal rights. Rights owned by Truckee Meadows Water Authority, Great Basin Water Company or other water utilities were classified as municipal rights. Other decreed rights where the correct manner of use could not be determined were kept as decreed rights.

Finally, a number of assumptions had to be made in cleaning the raw dataset of transfers. The treatment of variables relating each water right is described in more detail in the appendix. After an intensive data cleaning procedure, it is believed the final dataset reflects the true price recorded for each transaction and the characteristics of the underlying water right transferred before and after the transaction.

Data Description

Table 1 shows the list of variables included in the dataset with a brief description of each variable. A more detailed description of the data sources and coding for each variable can be found in the Appendix to this thesis.

Table 1 List of Variables

Variable Name	Description	Source
Price per acre foot	Price paid per acre foot of water right(s).	Calculated- price from county recorder’s office; AF from NDWR.
Acre feet of water right	Volume of water delivered annually or seasonally under water right(s).	Deeds of sale from county recorder’s office. NDWR permit info was used if deed did not

		specify acre feet (if numbers did not match, value on deed of sale was used as default).
Transaction date	Date that deed of sale was recorded with county recorder's office.	Deeds of sale (from county recorder's office).
Hydrographic basin number	Basin number where water right source is located.	NDWR reports of Conveyance.
Status	Status of water right: permit status with the Division of Water Resources.[4]	NDWR permits database.
County	County where the water right source is located.	NDWR permits database.
Source	Physical source of the water for use (groundwater, stream, lake, etc.).	NDWR permits database.
Use	Manner of use for how the water right specifies the water may be used (eg, municipal, irrigation, mining and milling, etc.).	NDWR permits database.
Priority date	Priority date of water right.	NDWR permits database.
New Use	Manner of use for how the water right specifies the water may be used after transfer.	NDWR permits database.
Period of Use	Dates which water can be used under water right (split into April, July and November cut off dates).	NDWR permits database
Supplemental Rights	Existence of supplemental rights (groundwater rights securing use for associated surface water rights) in a bundle of water rights.	NDWR hydrographic abstract
Distance to major metro area	Distance (in miles) from the point of diversion to a city of 50,000 or larger	U.S. Census Bureau; ArcGIS
Market	The hydrographic basin or series of basins in which water is assumed able to transfer freely.	Inter-basin transfers identified from scrape of NDWR permit database.
Total yield of groundwater rights in basin	Total volume of water rights granted in basin. Split by M&I, agricultural, mining and environmental water rights.	NDWR hydrographic basin summary.

[4] Statuses most frequently include: application, permit, certificate, abrogated, withdrawn, cancelled, expired, forfeited, vested right, decreed right, and several other terms referring to the status of decisions made by the state engineer regarding the use of the right. Water rights can be transferred in any status. A right in application status has not yet been approved by the state engineer, while a permitted right has. A certificated right is a permitted right where beneficial use of the water has been demonstrated. Certification makes a right more secure from being moved into a status where it cannot be used. Rights in some form of terminated status that were traded have frequently filed a change application to create a new right with different terms of use.

Overallocation percentage	Ratio of total yield of groundwater rights to perennial yield	NDWR hydrographic basin summary.
Population within hydrographic basin	Population living within the hydrographic basin.	U.S. Census Bureau
Water use parcel size	Size of land parcel of place of use.	Nevada Division of Water Resources
Potential farm output on land	Quality of farmland where water right is designated for use.	Natural Resources Conservation Service

A summary of the continuous variables is found in Table 2. The average price per acre foot of all transfers of water rights as a sole asset in the dataset is $11,180 (unweighted, not adjusted for inflation), with an average total transaction size of 137.6 acre-feet of water. In the dataset, 35% of transacted rights were surface water rights, with the remaining 65% as groundwater or geothermal rights. Municipal and industrial users were the most common buyer, with 49% of transactions, while agricultural users comprised 38% of sellers. Environmental buyers were uncommon, with less than 1% of all transactions being made to keep water for instream flows. The water right moved locations in only 9% of transactions, and the water moved between basins in only 3% of transactions. The actual number of rights where the location of use changed is likely higher than this, but transfers into a municipal system, for example, frequently did not result in an application to change the place of use of the right. In other cases, it is possible that purchasers bought rights with plans to change the place of use when or if new conveyance infrastructure is developed.

A majority of rights were designated for use for the full year, with the remainder split between decreed rights, whose period of use were not specified, and rights with early, middle, or late season shut-off dates. The average sale was for rights 39 miles from

a major metropolitan area, although this average is distorted by the fact that the only cities larger than 50,000 are in northwestern and southern Nevada. The average size of the place of use is similarly distorted by rights that are owned by Truckee Meadows Water Authority and Las Vegas Valley Water District, which cover areas totaling 350,000 and 5 million acres, respectively.

Many basins in Nevada have allocated water beyond the perennial yield of the system. The average basin in the dataset had 256% of the perennial yield allocated for use. On average, 34% of rights in a basin were for municipal and industrial use, 33 % for agricultural use, with the remaining 33% split across environmental, mining, and other uses. The average perennial yield of the basin where transfers occurred is 19,000 acre-feet.

Table 2 Summary Statistics for Selected Variables

Variable	Mean	Standard Deviation
Bundled Acre Feet	137.60	786.70
Price per Acre Foot ($)[5]	$11,180[6]	11,612.76
Certificated Status	24 %	0.43
Surface Water	39 %	0.49
Full Year Use	95 %	0.21
Supplemental	29 %	0.45
Distance to Nearest Metro Area (miles)	39.24	49.77
Acres of Place of Use Parcel	42,414	163,545
Priority Year	1936	49.21
Agricultural Buyer	28 %	0.45
M&I Buyer	49 %	0.50
Mine Buyer	3 %	0.16
Other Buyer[7]	13 %	0.34
Agricultural Seller	38 %	0.49
M&I Seller	32 %	0.47
Other Seller[5]	3 %	0.16
Good Farmland	32 %	0.47
Perennial Yield (Acre-Feet)	19,004	14,997.7
Population	124,498	362425.28
Overallocation	256 %	1.66
% Agricultural Use in Basin	33 %	0.29
% M&I Use in Basin	34 %	0.24
% Environmental Use in Basin	4 %	0.12
% Mining Use in Basin	0 %	0.02
Moved Location of Use	9 %	0.29
Moved Basin of Use	3 %	0.16
Filed Change Application	36 %	0.48

[5] Note, dollar values are not adjusted for inflation

[6] The average price per acre foot is an unweighted average. Previous work on water rights markets has focused either primarily on large transfers, or has reported volume-weighted average prices. The volume-weighted price per acre foot in this sample is $2,640.

[7] Decreed rights whose old and new use could not be determined are classified as “Other.”

Prices fluctuated considerably across the state over the study period. Figure 2 shows the number of transactions and average sale price per transaction for all water rights transferred in Nevada between 2006 and 2019 where the water rights were the sole asset transferred. Figure 3 reports the total volume of water transacted over the study period. Together, Figures 2 and 3 show that both the number of trades and the average transaction price peaked in 2006, and steadily declined during the Great Recession (between 2007 and 2011). Following the Great Recession, the total volume of water transferred and the average price per acre foot increased steadily each year following 2013 and peaked in 2016, when over 100,000 acre-feet of water was transacted, not

including water rights moved into trust or transferred with other property (Figure 3). The spike in 2011 is due to a large mining transfers totaling 25,000 acre-feet.

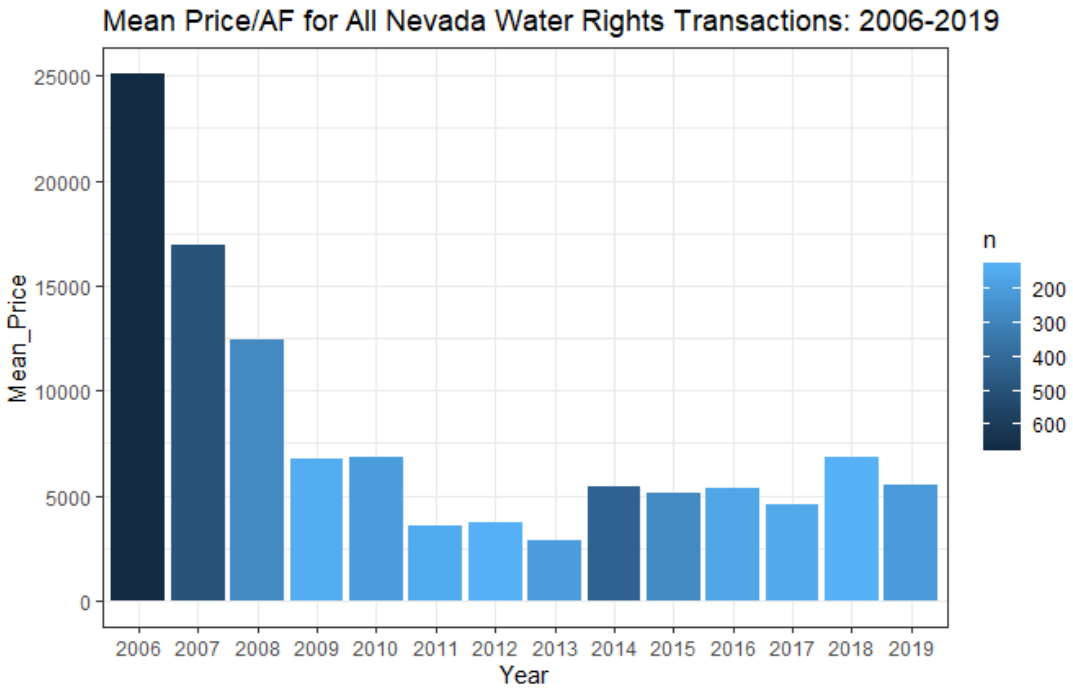


Figure 1 Average Price per Acre Foot by Year: All Water Rights Transfers in NV

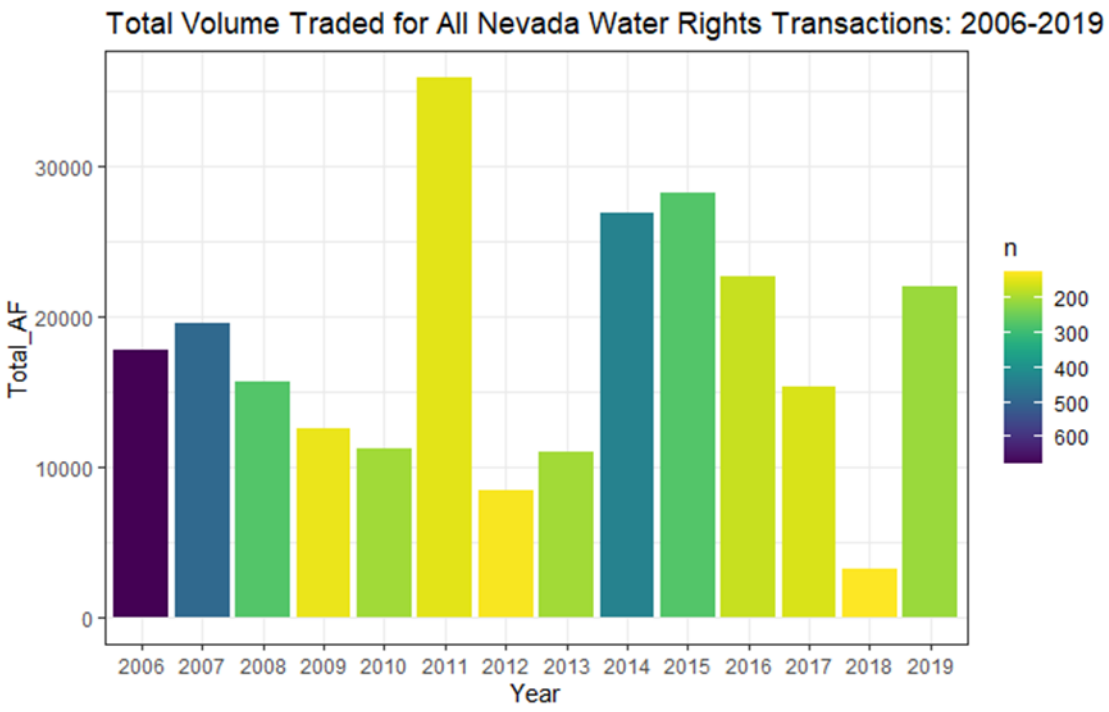


Figure 2 Total Volume of Water Traded by Year: All Water Rights Transfers in NV

Table 3 shows that the number of transfers, average volume of transfer, average price and priority year varied considerably across hydrographic regions. The Truckee River hydrographic region had the greatest number of transfers (676 sales), but also had one of the lowest average volume of water per transaction in any active basin, at 43.8 acre-feet per sale. Transferred rights in the Truckee River region also tended to be of a much earlier priority date than other active basins, which reflect the fact that a higher portion of transfers in the region were surface water rights, which have earlier priority dates than groundwater. Rights transferred in the Truckee, Colorado, and Carson Rivers sold at the highest prices. Of basins with over 25 transactions, Death Valley, Walker River and the Western Region had the lowest prices.

Table 3 Characteristics of Transfers by Hydrographic Region

Hydrographic Region	Total Number of Water Rights Sold	Average Volume of Water Rights Sold (Acre Feet)	Average Price/Acre-Foot	Average Priority Year
Northwest	3	2393.8	$5,279	1898
Black Rock Desert	12	841.1	$1,618	1946
Snake River Basin	2	28.4	$268	1889
Humboldt River	106	344.5	$3,591	1971
West Central	3	501.6	$1,155	1956
Truckee River	676	43.8	$16,285	1907
Western Region	27	545.7	$7,649	1967
Carson River	253	217.0	$7,174	1962
Walker River	117	422.7	$3,394	1969
Central Basin	387	115.8	$7,457	1963
Salt Lake	1	0.1	$2,143	1908
Escalante Desert	1	1.1	$881	1959
Colorado River	68	109.1	$11,189	1956
Death Valley	68	38.7	$1,862	1971

Figure 4 shows similar variations across the most active counties in terms of number of water rights transfers in Nevada. Washoe (in the Truckee River hydrographic area) and Clark (in the Colorado River hydrographic area) Counties commanded the highest sale prices, while Humboldt, Churchill, and Lincoln had relatively low average sale prices.

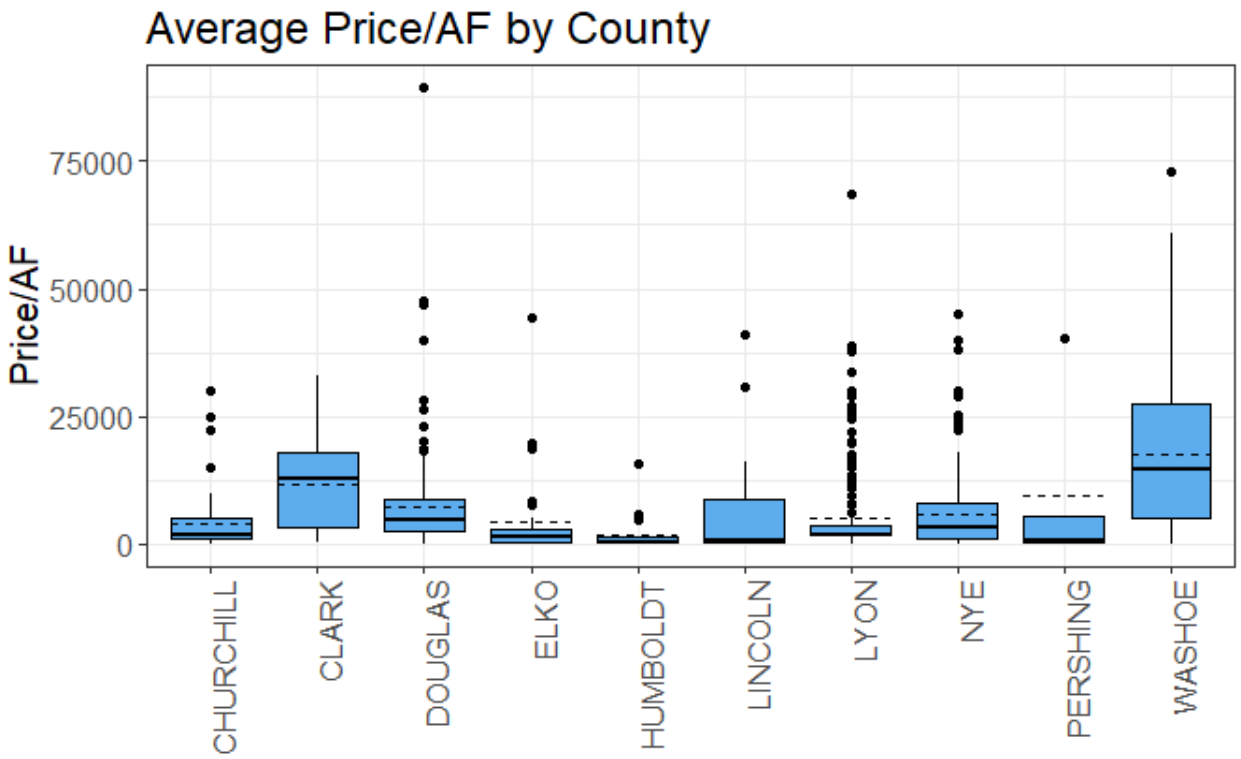


Figure 3 Average Price per Acre Foot for Water Rights Transfers in Most Active NV Counties

The variation in volume of water transferred, average price, and priority date may be due to heterogeneity in buyers, sellers, types of rights, and regional variation in demographics, institutions and other geographic factors. As expected, prices varied considerably by characteristics of each transferred water right. Table 4 shows that surface water rights tended to sell for a substantially higher price than groundwater rights—$17,630 per acre foot for surface rights compared to only $6,786 for groundwater rights. This trend is somewhat surprising, as surface water rights may have less reliable delivery year-to-year and thus should be expected to trade at a lower price than groundwater. However, surface rights are often easier to transfer to different locations and may be

more reliable than groundwater in basins where the total pumping exceeds perennial yield and the aquifer is being depleted over time.

Table 4 Characteristics of Transfers for Groundwater and Surface Water Rights

	n	Average Volume of Bundle (Acre Feet)	Average Price/Acre-Foot	Average Priority Year
Surface Water	780	102.6	$17,630	1884
Ground Water	1145	161.4	$6,786	1970

Figure 4 displays this relationship between transfer price and volume of water. Prices were negatively correlated with volume of water transacted (R = -0.12), with large transfers (ie, those over 1000 acre-feet) having the lowest prices per acre foot. Groundwater and surface water rights were relatively evenly distributed across transfer size, but groundwater rights tended to be sold in higher-volume transactions.

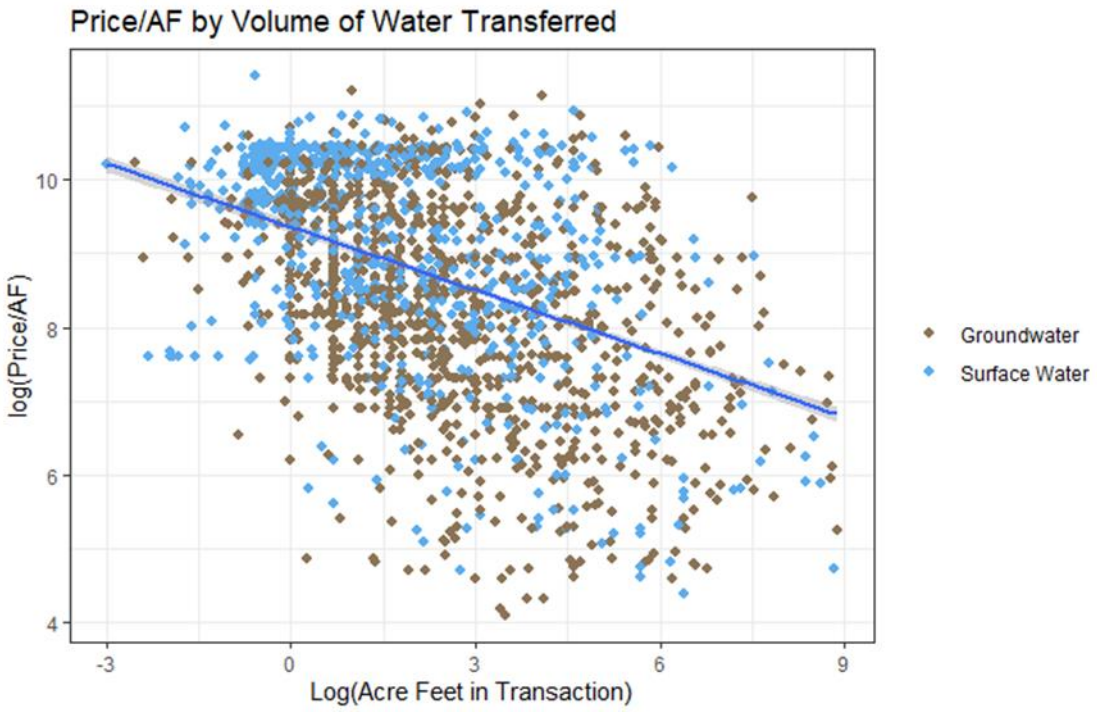


Figure 4 Price per Acre Foot by Volume of Water Transacted (Log-Log scale)

Figure 5 displays the relationship between transfer price and priority date. Priority is negatively correlated with price. This price premium for more senior rights may reflect the increased year-to-year reliability of water delivery of these rights compared to more junior rights subject to greater curtailment risk. However, nearly all pre-1945 rights are surface water, while most newer rights are groundwater. Given this, it is unclear whether the pricing relationship is due to differences in the value of surface water compared to groundwater rights, or due to differences in priority.

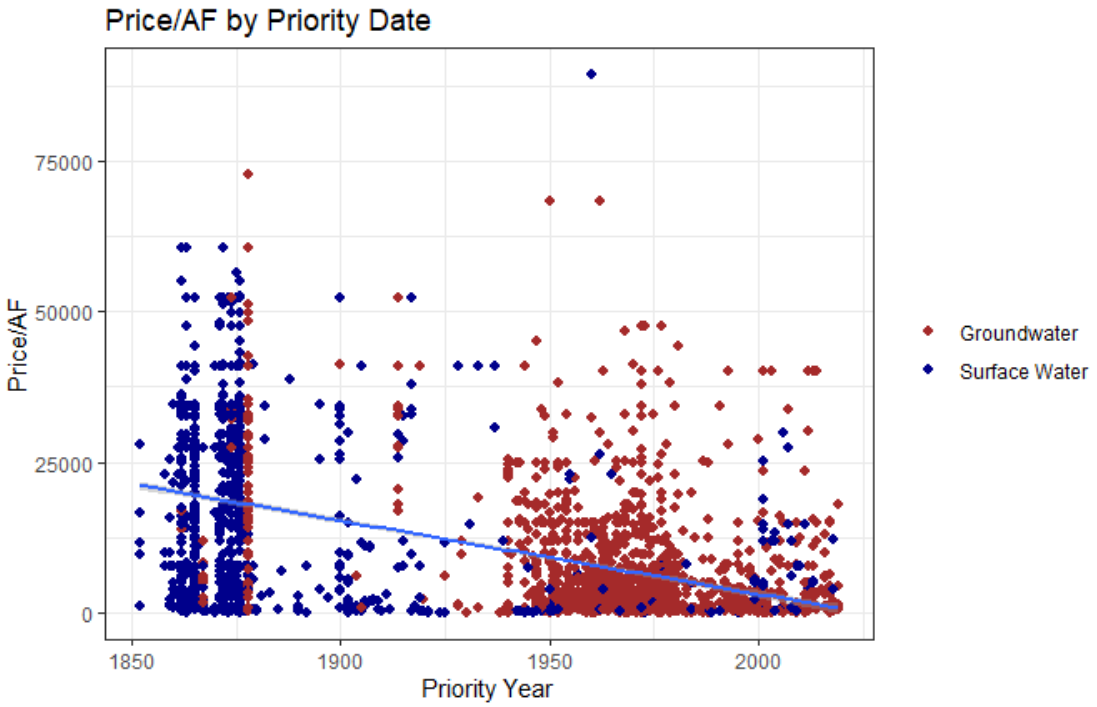


Figure 5 Price per Acre Foot of Transactions by Priority Date of Water Right

Prices paid for water rights vary considerably across different types of buyers. Municipal and industrial buyers purchased the most rights, and at the highest price per acre foot—$12,897. Agricultural users were the next most frequent purchasers, at a price of only $5,406. Agriculture buyers did, however, tend to make higher-volume purchases than buyers intending to use water for municipal and industrial uses. The data had very few environmental water transactions. Mining companies bought the highest volume of water rights in each transaction, at the lowest price. This is likely due to differences in the types of rights purchased by mining companies. Many mining rights are used for dewatering, or removal of water from the ground during mining activities. These dewatering rights have no value for other water users. Partly due to these new dewatering

rights, and partly due to the lower importance placed on priority date for mining companies, the average priority year was significantly earlier compared to other users. The "Other" buyers are those yet undefined in the dataset. A majority of these transfers are for decreed rights, where the manner of use is specified by decree, rather than in the water right permit. These rights must be evaluated manually to determine the type of use which may be industrial, agricultural, mining, environmental or any other type of use.

Table 5 Characteristics of Transfers by Type of Buyer

	n	Average Volume of Bundle (Acre Feet)	Average Price/Acre-Foot	Average Priority Year
Municipal & Industrial	939	99.9	$12,897	1934
Agricultural	530	247.2	$5,406	1957
Environmental	19	51.5	$12,325	1933
Mining	49	481.3	$2,709	1967
Other	229	49.7	$12,159	1927

Finally, water rights tended to sell at different prices based on both the degree of overallocation and relative scarcity of water rights in municipal use. As more water rights are transferred into municipal use, there are fewer rights available for purchase by urban water users. Since M&I water users are the most common buyers in this dataset, it follows that increasing scarcity of new rights to move into municipal and industrial use is associated with higher prices. Further, many overallocated basins tended to be dominated by agriculture, while a smaller fraction are dominated by municipal use.

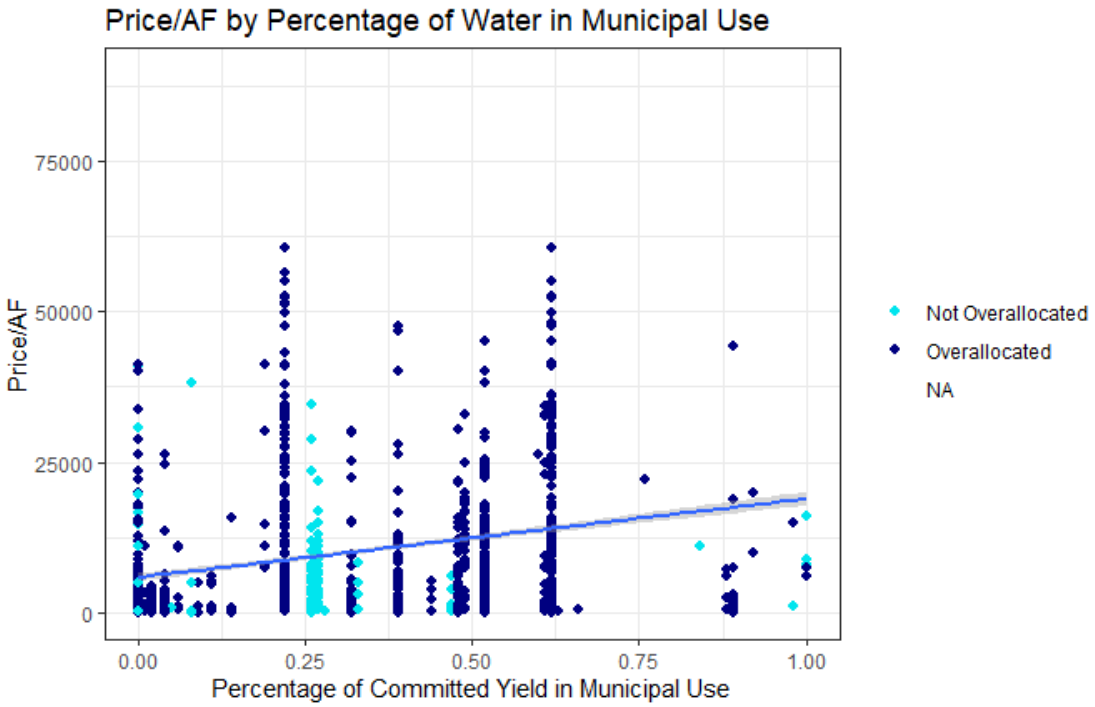


Figure 6: Average Price/AF by Percentage of Water in Municipal Use

Comparison with *Water Strategist* Data

Table 6 shows a comparison between the data collected for this study and the publicly available *Water Strategist* data for Nevada from Donohew and Libecap (2019). Compared to the *Water Strategist* dataset, our data has about 20 times the total number of transfers with price information. As expected, our dataset has a much lower average volume of water per transfer, about 137.6 acre-feet compared to 1329.2 in the *Water Strategist* data. Our data also shows an average price per acre-foot about 38% higher than the *Water Strategist* data.

The types of buyers and sellers involved in the transfers also highlights the uniqueness of our dataset. About 26% of our transfers are transfers between agricultural users, while *Water Strategist* has no within-agriculture transfers in Nevada. We find

relatively fewer agriculture-to-urban transfers and 6% fewer within-urban transfers. We also include mining transfers (part of "Other"), while Water Strategist does not.

We conclude that our dataset represents a much broader range of the types of transfers than Water Strategist. Our dataset includes about 20 times more transfers in total, more smaller-volume transfers, as well as more transfers within agricultural use and transfers for mining use.

Table 6: Comparison with Water Strategist Data for Nevada

Variable	**Water Strategist Data (NV Sales)**	**Study Data**
Years Included	1987-2009	2006-2019
Total Number of Transfers	156	7,938
Number of Transfers with Price Information	97	1,926
Number of Transfers with Price Information per Year	4	148
Acre-Feet of Transfer	1329.2	137.6
Price per Acre-Foot of Transfer[8]	$8,088	$11,180
Ag-to-Ag	0.00	0.26
Ag-to-Urban	0.35	0.20
Ag-to-Enivo	0.25	0.00
Urban-to-Ag	0.00	0.01
Urban-to-Urban	0.35	0.29
Urban-to-Enviro	0.01	0.00
Enviro-to-Ag	0.00	0.00
Enviro-to-Urban	0.00	0.00
Enviro-to-Enviro	0.00	0.00
Other	0.04	0.24

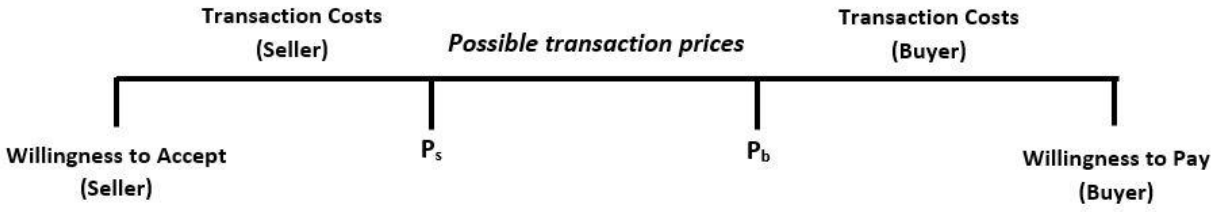
[8] Water Strategist data is adjusted to year 2009 dollars. All dollar values in our dataset are not inflation-adjusted.

Theoretical Model

A bargaining theoretical framework was adopted as a model from which to base the econometric model. Previous studies have assumed a supply and demand framework for analyzing water rights markets (De Mouche, Landfair, and Ward 2011; Pullen and Colby 2008; Brookshire et al. 2004). The supply and demand framework assumes that all market participants have the same information, individual buyers and sellers do not influence equilibrium prices, and that equilibrium prices will adjust to fill excess demand or supply (Pullen and Colby 2008). While a useful conceptual framework, it has notable limitations. First, water rights markets are limited by geographical factors. Excess demand in Las Vegas, for example, cannot be readily met by excess supply in Elko without developing new infrastructure. Thus, state level analyses that have used a supply and demand framework have discounted the significance of spatial factors. Second, water rights are heterogeneous goods. Nearly no two rights are identical in terms of priority date, source, location of use, and volume of water. Each right comes with different levels of risk, transaction costs, and reliability of water delivery, all of which will affect the price an individual is willing to pay. While Pullen and Colby (2008) note this, they are unable to capture all sources of variation in a water right, thus they treat otherwise heterogeneous factors about each right as homogenous. Relatedly, because each water right buyer's needs might be highly specific in terms of desired characteristics of a water right, transactions are frequently brokered through a licensed water rights agent who will match buyers with willing sellers. While these agents have access to market information through viewing deeds of sales, the prices may be negotiated based off factors such as

municipal water supplier budgets rather than market forces (Mark Warren, MAI, personal communication 12/9/20).

We adopt a Nash bargaining framework for analyzing the price determinants in water rights markets in Nevada (Mas-Colell, Whinston, and Green 1995, 1:). The theoretical model assumes that transfer price will be a function of the characteristics of the underlying water right, in addition to both the buyer's and seller's characteristics, desired use of the water, transaction costs, and their relative bargaining power. Each agent's reservation price is based upon the individual water right characteristics such as priority date, source of water, and status along with geographic and biophysical variables where the right is located (like county population, precipitation, and land values). They will also be based on the type of buyer and the type of seller, in this case whether the right is being purchased for agricultural or municipal use, and which uses it is being sold from. Both the buyer and seller have unknown transaction costs associated with the sale. Graphically, this is represented below.



Further, following the Nash bargaining framework, the model assumes that there is no asymmetric information—the buyer and seller's utility functions and transaction costs are known, as well as all variables related to the water right itself. Further, it

assumes that each water right or bundle of rights is offered in a fixed quantity, and that the negotiation does not involve the portioning of water rights.

The seller and buyer have symmetric utility functions, generally defined as:

$$U_s(m_s, Z; X_s) = m_s + WTA_s + \varphi(0; X_s)$$

$$U_b(m_b, Z; X_b) = m_b - WTP_b + \varphi(Z; X_b)$$

Where m represents the initial wealth of seller (s) and buyer (b), respectively, U() represents the buyer and seller's respective utility, Z is a vector of water right characteristics, X is a vector of characteristics of the seller and buyer, and WTA and WTP are willingness to accept and willingness to pay, respectively.

From these utility functions, the buyer and seller's reservation prices are:

$$p_s^* = \frac{WTA_s}{V} + \frac{TC_s}{V}$$

$$p_b^* = \frac{WTP_b}{V} - \frac{TC_b}{V}$$

Where TC represents the transaction costs faced by the seller and buyer, respectively, and V is the volume of water traded in each transfer. Each actor's utility if the sale occurs is defined as:

$$u_s = m_s + pV - TC_s + \varphi_s(0; X_s)$$

$$u_b = m_b - pV - TC_b + \varphi_s(Z; X_b)$$

The generalized Nash bargaining solution to this problem is the unique solution to the following maximization problem:

$$\max_{u_{s+u_b}} (u_s - u_s(p_s^*))^{\tau}(u_b - u_b(p_b^*))^{1-\tau}$$

Where τ represents the bargaining power of the seller, and 1- τ is the buyer's bargaining power. Since utility is monotonous with respect to prices, this maximization can be rewritten in terms of price rather than utility:

$$\max_{p \geq p_s^*; p \leq p_b^*} (p - p_s^*)^{\tau}(p_b^* - p)^{1-\tau} \times V$$

Solving the first order conditions for the sale price yields following equation:

$$p^{sale} = \tau \times p_b^* + (1-\tau)p_s^*$$

This gives the intuition that as bargaining power for the seller increases, the price increases, and as bargaining power for the buyer increases, the price decreases. Substituting the earlier equations for the buyer and seller's reservation prices gives:

$$p^{sale} = \tau \times (wtp - \frac{TC_b}{V}) + (1-\tau)(wta + \frac{TC_s}{V})$$

If we assume that buyers and sellers have the same preferences for water right characteristics, then WTA and WTP can be rewritten as:

$$WTA_s(Z', X_s) = \alpha_0 + \alpha_1 Z' + \alpha_2 X_s$$

$$WTP_b(Z', X_b) = \alpha_0 + \alpha_1 Z' + \beta_2 X_b$$

Then, the optimal p becomes:

$$p^{sale} = \tau \times (\alpha_0 + \alpha_1 Z' + \beta_2 X_b - \frac{TC_b}{V}) + (1-\tau)(\alpha_0 + \alpha_1 Z' + \alpha_2 X_s + \frac{TC_s}{V})$$

Which can be simplified to:

$$p^{sale} = \alpha_0 + \alpha_1 Z' + \lambda_2 X_b + \gamma_2 X_s + ((1-\tau)TC_s - \tau TC_b)\frac{1}{V}$$

This provides a structural form for our econometric model of interest. Note that X, Z and V are observed, but τ and TC are not.

Econometric Model

The theoretical model in this paper assumes the water right price per acre foot is a function of water right characteristics and county and year fixed effects. This serves as a structural model with the econometric specification of:

$$Price_i = \alpha + \beta_z Z'_i + \beta_{Xs} X_{s_i} + \beta_{Xb} X_{b_i} + \rho \frac{1}{V_i} + Y + \varepsilon$$

Where:

- Price is the natural log of price/AF for each transaction *i*.
- Z' is a vector of water right characteristics:
  - Priority date
  - Source of water (surface water vs. groundwater)
  - Certificated status
  - Period of use of water
  - Existence of supplemental rights
  - Distance from point of diversion to nearest metro area
  - Market (basin) in which water right exists
  - Characteristics of the basin where water right is located (degree of overallocation, population, allocation of rights across different uses).
- X_b is the buyer characteristics:
  - A dummy variable for type of buyer (municipal, ag, mining, env).
  - Productivity of land in farm use in location of water use for buyer.
- X_s is the seller characteristics:
  - A dummy variable for the type of seller (municipal, ag, mining, env).
- V is coded as an inverse variable of volume, with ρ representing the relationship between buyer and seller's bargaining power and transaction costs.
- Y is the year that the transaction occurred.

It is expected that priority date will have a negative relationship with price, as more junior rights are worth less given the increased risk of curtailment in drought years. Certificated rights should be more valuable as they are not subject to cancellation, and surface water rights are subject to more risk of curtailment and return flow requirements than groundwater rights and should have a negative sign. Rights used for the entire year and those that have supplemental rights should both be worth more. The market in which each sale occurs is expected to have an effect on prices, with more active markets likely having a positive sign, and rural markets with little activity likely having a negative or neutral sign compared to the baseline market. More populated basins, those with more municipal and industrial rights, and overallocated basins all should have a higher price. Further, in overallocated basins, groundwater rights may be subject to future curtailment policy to avoid unsustainable groundwater pumping. In these basins, priority date and groundwater may have a different relationship with prices than in basins where future curtailment is unlikely. Finally, the inverse volume of transaction is hypothesized is ambiguously signed. Transaction costs are invariant to transaction size, so they may be substantially lower per acre-foot for large transfers. However, bundling large transactions may exhibit economies of scale, where buyers making large purchases get a lower price per acre foot.

Buyer and seller characteristics, based upon the findings of previous literature, are expected to have an effect on prices. Many existing studies have found that municipal and industrial buyers purchase at price premiums up to and over 100% higher than agricultural buyers (Brookshire et al. 2004; Brown 2006; Brewer et al. 2007). Most studies have not separately looked at pricing for mining or environmental rights. Given

these findings, it is expected that the dummy variable for municipal and industrial buyers will be positively signed compared to the omitted group, agricultural buyers. Mining and other buyer types remain ambiguously signed. The type of seller is also expected to be neutral, as much of the variation in prices should be driven by costs expected to be incurred by the buyer instead of the seller.

A potential weakness in our model, which has been discussed in DeMouche et al (2011) and Brookshire et al (2004) and others, is that the volume variable (acre-feet) is endogenous with price per acre foot. This is because buyers and sellers may respond to variations in prices by altering the quantity of water demanded or supplied. As Wooldridge (2016) notes, this endogeneity issue may be addressed through the use an instrumental variable that affects quantity but not price.

To address the endogeneity of price and volume, we follow the approach identified in Wooldridge (2016), using an instrument for the volume of water transacted: the land parcel size of the water right's place of use. The parcel size variable is a relevant instrument for acre feet traded because water rights are able to be split up and sold in pieces, meaning a right on a larger parcel is likely associated with a larger volume of water sold. It is valid because the price will be uncorrelated with the acreage of the land parcel on which the water itself is used.

This approach allows us to test whether the OLS estimator for the effect of volume on prices is biased. The following two-stage least squares regression model is tested:

$$1)\ V_i = \alpha + \beta_z Z'_i + \beta_{Xs} X_{s_i} + \beta_{Xb} X_{b_i} + \rho \boldsymbol{A}_i + \varepsilon$$

Where ***A*** corresponds to the acreage of the land parcel on which the water is used. Then, predicted volume of water transacted from (1) [$\widehat{V_i}$] is used to predict price in equation (2):

$$2)\ Price_i = \alpha + \beta_z Z'_i + \beta_{Xs} X_{s_i} + \beta_{Xb} X_{b_i} + \rho \frac{1}{\widehat{V_i}} + \varepsilon$$

Results

Regression models were run using Stata version 16.1 software. A total of 307 observations had at least one variable imputed using multiple imputation chained equations (MICE). [9] The results provide several insights into the three main research objectives of this paper: 1) what is the effect of the underlying characteristics of water rights and buyers and seller characteristics on their sale prices? 2) what is the effect of market (hydrographic basin) characteristics on prices? 3) how does the size of transaction affect price and bargaining power?

Regarding the first question, Table 7 shows the effect of water right and buyer and seller characteristics on prices. From left to right, the table shows model specifications (1) without any geographic controls; (2) adding a proxy for transaction costs; (3) controlling for the county of transfer; and (4) controlling for the market (basin(s) where water right can be transferred) of transfer. Using the model with market controls as the preferred specification, the results suggest that several key water right characteristics play an important role in price, including priority date, water source, the existence of supplemental rights, and distance from the point of diversion to the nearest metro area. For every year increase in departure from the earliest priority right in the transferred right's basin, prices decrease by between 0.41% and 0.62%, reflecting a

[9] Missing observations for basin characteristics were imputed using MICE. This method allows for observed variables to predict values for missing observations in independent variables. It assumes that the variables are missing at random, meaning there is no systematic reason why variables are unobserved for certain transfers. This may be a strong assumption, as the basin characteristic variables rely on geospatial information about the water right. Digitizing geospatial information on water rights is time consuming, so only just over half of water rights in Nevada have this information. It is believed that newer rights or those that have been recently surveyed are more likely to have geospatial information. This means missing observations may be explained by having an older priority year or having filed a change application. If these are true, they would violate the missing at random assumption of MICE

preference for rights with less probability of curtailment. Put in context, the oldest decreed right in the Truckee River transferred in this dataset has a priority year of 1858. A much more junior right with a priority date 100 years later would sell for 41.2% less than the most senior right.

Table 7: Regression Specification Results Without Basin Characteristics

	Dependent Variable: ln(Price/AF)			
	Base Model	Base Model with Transaction Costs	Base Model with County Controls	Base Model with Basin Controls
Water Right Characteristics				
Years from earliest priority year	**-0.00619*****	**-0.00612*****	**-0.00509*****	**-0.00412*****
Full year use	**0.507*****	**0.481*****	**0.385*****	**0.388*****
Certificated Status	0.0449	0.0370	0.0651	0.0503
Has supplemental right	**-0.127***	**-0.115***	-0.0607	-0.0735
Surface water	-0.0490	0.00620	-0.0713	-0.0634
Distance to nearest metro area (miles)	**-0.00682*****	**-0.00679*****	**-0.00491*****	**-0.00504*****
Buyer and Seller Characteristics				
Good farmland	**-0.123****	**-0.109***	-0.0799	-0.0554
M&I Buyer	**0.295*****	**0.262*****	**0.263*****	**0.120***
Mining Buyer	**-1.153*****	**-1.158*****	**-1.023*****	**-1.132*****
Other Buyer	**0.354*****	**0.344*****	**0.314*****	**0.272*****
M&I Seller	**0.144****	**0.177****	0.0721	0.0308
Mining Seller	0.381	0.434	0.299	0.574
Other Seller	-0.00453	-0.0316	-0.136	-0.141
Volume and Transaction Costs				
1/Acre-Feet	**0.159*****	**0.139*****	**0.149*****	**0.147*****
Filed Change Application		0.0557		
Change Application*Volume		**0.169****		
Controls				
Year	X	X	X	X
County			X	
Market				X

Intercept	7.916***	7.850***	6.769***	8.038***
N	1922	1922	1918	1922
r2	0.375	0.377	0.412	0.468

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Despite frequently selling for higher prices in the observed dataset, surface water rights were not found to sell for a significantly different price than groundwater rights. There are reasons to expect that groundwater rights may be preferred to surface water rights in some cases. Groundwater rights have historically not been subject to curtailment or to return flow requirements. The observed relationship of higher sale prices for surface water rights in the dataset may be due to surface water rights more frequently selling to urban areas and municipalities (particularly in the Truckee River), compared to groundwater rights being sold to mining companies and rural agriculture users.

The existence of supplemental rights lowered the sale price, contrary to the expectation that bundles with supplemental rights would sell for a higher amount given their greater security of full water delivery. Despite efforts to verify the transaction records, this may be due to an incorrect summing of total annual duties under supplemental rights on the deeds of sale. The period of use of the water and the status of the right did not have a significant effect on prices. Finally, as expected, water rights with points of diversion closer to metro areas sold at higher prices, likely due to their access to more buyers. To put in context, a water right diverted 10 miles from a major city was worth 5% less than a right directly in a major city.

Buyer characteristics had a strong effect on prices, while seller characteristics generally did not have a statistically significant effect on prices. The quality of land

where purchasers used the water had a strong effect on prices. Buyers on land designated as the best quality farmland in the state[10] paid 12% less than rights not used on prime farmland. When controlling for the market of transfer, however, this effect disappears. The effect of buyer types followed a similar pattern. In the base model, municipal and industrial (M&I) buyers paid 29.5% higher prices than agricultural buyers and other buyers (largely environmental buyers and those with decreed rights) paid 35.4% more than agricultural buyers. When controlling for the market of transfer, however, the differences in prices for M&I and agricultural buyers diminish significantly. When including the basin control, M&I buyers pay a 12% premium for rights. This implies that the findings of previous literature that water markets have inefficiencies due to large price differentials between agriculture and municipal users may be, in part, due to their participation in distinct markets. Although the actual geographic extent of the market for each water right could not be explicitly defined, the regression results in Table 7 provide more illumination on the effect of different basin characteristics on prices.

For the second question asked of this data, the model results show that the basin of transfer explains some of the variation in prices. Table 8 parses out what may be driving the effect of the basin controls included in the last regression in Table 7. The second column shows the effect of the population within a basin, proportion of water within a basin and degree of overallocation (the ratio of allocated groundwater rights to the perennial yield of the groundwater basin). The results show that, as expected, more populated basins had higher prices, a likely result of a greater number of water right

[10] Land defined by the NRCS Web Soil Survey as “Farmland of statewide importance, if irrigated”.

buyers. Basins with more water currently being used in agriculture had lower prices compared to basins with more M&I use. Basins with a large proportion of environmental rights had, surprisingly, much lower prices compared to those with more M&I use.

Table 8: Regression Specification Results With Basin Characteristics

	Dependent Variable: ln(Price/AF)		
	Base Model with Market Controls	Base Model with Basin Characteristics	Base Model with Basin Characteristics and Overallocation Interactions
Water Right Characteristics			
Years from earliest priority year	**-0.00412*****	**-0.00259*****	**-0.00339***
Full year use	**0.388*****	**0.279****	**0.280****
Certificated Status	0.0503	0.00988	0.0138
Has supplemental right	-0.0735	**-0.122***	**-0.128****
Surface water	-0.0634	0.0581	0.116
Distance to nearest metro area (miles)	**-0.00504*****	**-0.00489*****	**-0.00481*****
Buyer and Seller Characteristics			
Good farmland	-0.0617	-0.0997	-0.104
M&I Buyer	**0.120***	**0.128***	0.117
Mining Buyer	**-1.132*****	**-0.973*****	**-0.970*****
Other Buyer	**0.272*****	**0.285*****	**0.283*****
M&I Seller	0.0308	0.0414	0.0404
Mining Seller	0.574	0.451	0.455
Other Seller	-0.141	-0.213	-0.201
Volume			
1/Acre-Feet	**0.147*****	**0.145*****	**0.145*****
Basin Characteristics			
% basin water in Ag		**-0.812*****	**-0.827*****
% basin water in Env		**-1.151*****	**-1.155*****
% basin water in Other		0.154	0.150
% basin water in Mine		-0.283	-0.315
Population (10,000s)		**0.00438*****	**0.00445*****
Overallocation		-0.00781	-0.0584
Overallocation*Years from earliest priority			0.000630
Overallocation*Years from earliest priority*Surface water			-0.000437
Controls			
Year	X	X	X
Market	X		
Intercept	12.49***	13.09***	15.87***
N	1922	1922	1922
r2	0.468	0.331	0.333

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The proportion of water rights in agriculture and environmental uses all had a significant effect relative to the proportion of rights in municipal and industrial use. This means that basins heavy in municipal and industrial uses had much higher price premiums, likely due to the tighter supply of these rights. The findings suggest that a basin with 100% of the rights in agriculture should expect to see 82.7% lower prices than a basin with 100% M&I uses. This lends further support to the conclusion that the observed price differences between M&I and agricultural buyers is due to their participation in distinct markets.

Finally, the third question of the effect of transaction size on prices is addressed through an instrumental variable (IV) model. Table 9 shows the results of the IV regression, in which the size of the land parcel for the water right's place of use is used as an instrument for the total transaction volume. The IV model includes only those observations with a place of use area smaller than 200,000 acres. This excludes water rights used by several of the largest water municipalities in the state, such as Truckee Meadows Water Authority and Las Vegas Valley Water District, whose places of use include their entire service area rather than the specific location where the water right purchaser needed water rights.

Table 8 shows (1) the regression with market controls for the subset IV sample; (2) the first stage regression; and (3) the second stage IV regression. The first stage IV results show that the instrument, the total acreage of the place of use land parcel for each

water right transaction, is relevant, as it explains some of the variation in volume of water sold. We assume that it is valid,

Table 9: Instrumental Variable Regression Results

	ln(Price/AF) Main Regression (excl. parcels > 200k acres)	*1/Acre-Feet* First Stage IV Regression	*ln(Price/AF)* Second Stage IV Regression
Water Right Characteristics			
Priority Year	**-0.00419*****	-0.000953	**-0.00538*****
Full Year Use	**0.433*****	0.146	**0.438****
Certificated Status	-0.00817	0.0554	0.0175
Has supplemental right	-0.0993	**-0.0936***	-0.146
Surface Water	**-0.260***	0.0711	**-0.254***
Distance to nearest metro area	-0.00272	**-0.00665*****	**-0.0110****
Buyer and Seller Characteristics			
Good farmland	-0.0435	**0.135*****	-0.0205
M&I Buyer	0.0626	**0.167*****	0.143
Mining Buyer	**-0.970****	0.0456	**-1.173****
Other Buyer	0.112	0.00997	**0.208***
M&I Seller	-0.0613	-0.0875	-0.0597
Mining Seller	0.314	0.385	0.579
Other Seller	-0.237	0.106	-0.146
Volume and Instrumental Variable			
1/Acre-Feet	**0.280*****		
IV: Acres of Place of Use Parcel		**-0.00000239***	
IV: Predicted 1/Acre-Feet			-0.216
Controls			
Year	X	X	X
Market	X	X	X
Intercept	8.038***	8.006***	7.993***
N	1922	1922	1922
r2	0.460	0.124	0.220

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

as it is uncorrelated with the market price for water rights at any given time. The instrument is, however, only significant only at the 10% level, and does not pass the rule of thumb for a weak instrument, as the first stage F statistic is under 10. The model is still

informative, it just may be unreliable and an inconsistent estimator given the weak instrument.

The second stage IV results show that the significance of the effect of volume on prices disappears when controlling for the endogeneity between price and volume. This may suggest that the trend seen of large transfers being made at lower prices may be the result of buyers opportunistically purchasing large volumes of rights at lower prices, and making smaller purchases at higher prices to increase their water supply in smaller increments to meet short-term needs. There is also no observed effect of municipal & industrial buyers on prices compared to agricultural buyers. This may be due in part to TMWA, Las Vegas Valley Water District and any other large-acreage water service providers being excluded from the instrumental variable regression.

There are several other questions of interest to water managers that can be answered by this dataset. One important question is the degree to which overallocated basins may exhibit different water market characteristics or reflect different preferences for buyers and sellers. Overallocated basins are those where the total volume of groundwater allocated to users exceeds the perennial yield of the basin's groundwater system. The variable used in the regression is defined as the total allocated volume of rights divided by the perennial yield of the basin. In these models, the degree of overallocation does not have a statistically significant effect on prices, except in the IV model. This suggests that concerns over potential curtailment of use for groundwater rights in overallocated basins have not yet been incorporated into prices.

Another aspect of the theoretical model addressed by this regression is the effect of transaction costs on sale prices. Although transaction costs are not explicitly observed for either the buyer or the seller, one of the largest transaction costs can occur if the buyer must apply for a change application to alter the place of use, point of diversion, or manner of use of the water. This can be a lengthy process and may involve legal fees if the application is protested. Thus, as a proxy for the buyer's transaction costs, whether or not there was a change application filed after the transfer was included as a proxy for transaction costs. The results of regression (2) in Table 1 show that transaction costs did not have a significant effect on prices. This may mean that transaction costs simply squeeze the range of potential transaction prices, but do not alter bargaining power and thus the agreed upon price remains similar regardless of transaction costs.

Finally, the role of bargaining power was explored in determining prices. Table 10 shows the regression results for the coefficients for M&I buyers and M&I sellers. Based on the structural model, the bargaining power term can be estimated by dividing the coefficient on the buyer variable by the sum of the buyer and seller coefficients. Because agricultural buyers and sellers were in the omitted group, it is assumed that M&I users were the best group to use to explain the bargaining power concept, given that they represent a large proportion of transactions. The average bargaining power term is 0.71, which means that sellers, rather than buyers, have greater bargaining power in transactions.

Table 10: Result of Estimation of Bargaining Power Term

Term	**Value, Table 7 (1)**	**Value, Table 7 (2)**	**Value, Table 7 (3)**	**Value, Table 7 (4)**
M&I Buyer	0.295	0.262	0.263	0.120
M&I Seller	0.144	0.177	0.0721	0.0308

Bargaining Power Term	0.67	0.60	0.78	0.80

Discussion

These results have important implications for western water markets. First, the results provide a different conclusion than the previous literature on the efficiency of water rights markets. Previous work has found that municipal and industrial buyers pay between 113% and 149% more than agricultural buyers for water rights, but little explanation has been given in the literature as to why this may be occurring. Overall, the literature has suggested that there may be inefficiencies in existing water rights markets given these findings (Brewer et al. 2007). Our results explore these observed price differences to better understand limitations on efficiency in water rights markets under prior appropriation. We show that within hydrographic basins in Nevada, municipal and industrial buyers pay prices that are only about 12% higher than agricultural buyers. Given that even within basins, infrastructure constraints mean that certain water rights, particularly those in more rural areas, are unlikely to be able to be moved into municipal use. While our study could not consider infrastructure limitations, it is believed that these may explain the remaining variation in prices paid between types of major buyers. If this is the case, then within each market where transactions occur, water rights in Nevada follow the law of one price, pointing to efficient pricing in markets. We argue that this result is due to our model controlling for the underlying water right characteristics and geospatial characteristics about where the water is being used. Due to a lack of detailed water right-level data, previous studies have not been able to piece apart these specific impacts on water rights pricing.

The implication that water rights markets in Nevada follow the law of one price has a crucial implication for making decisions about water infrastructure and management. Within an area where physical water is likely to be easily transferred between users (either through wells accessing the same groundwater or conveyance infrastructure to transport surface water or pumped groundwater), water rights are likely to be freely reallocated between users through private voluntary exchanges to move water to uses where it provides the most benefit to people. While alternative institutions for reallocating water may be useful in some areas, investing in infrastructure to expand the scope of regional water markets may be a better use of resources to maximize efficiency of transfers under existing institutions.

Second, based on the Nash bargaining framework, these results imply that sellers hold more bargaining power than buyers. This result confirms the experiences of water rights agents involved in brokering transactions. For example, many smaller municipal water suppliers lack the infrastructure or expertise to independently assess water right values. So, when purchasing water rights, sellers have more leverage to dictate sale prices (personal communication M. Warren, MAI, 12/9/20). Further, private actors have a stronger profit maximizing incentive than public agents who are not spending their own money. Thus, it is expected that most transactions between private producers or organizations and public water suppliers are likely to garner a higher sale price.

Third, while the results give the intuitive result that as priority dates become more junior, their value decreases, in reality the reduction in value in response to priority is not linear. Curtailment decisions often occur based on cut-off dates in priority that will vary

considerably across basins. For example, a priority year of 1920 in the Humboldt Basin may be more subject to curtailment than a right of similar priority date on the Walker River. Further, systems like the Humboldt, which are lie entirely within the state, are managed differently than those like the Carson or Truckee Rivers, which are partly managed by federal decree. NDWR (2021) shows that Humboldt curtailment decisions are based on seasonal flows, period of use of water rights, and location along the river. Many irrigation rights on the Humboldt River are able to be used only during brief periods. Rights with a period of use during March and April are less likely to be subject to curtailment than late-season rights, which have a lower cutoff flow rate for triggering curtailment. This means that priority date also interacts with period of use to determine price in the Humboldt River, but such a relationship likely does not hold in most other basins in Nevada.

Finally, this paper only considered permanent transfers of water rights where the water right was the sole asset traded. This excludes transactions where land was purchased with the intention of acquiring the appurtenant water rights, which comprised about 54% of total title transfers identified in this dataset. This dataset also excludes all leases of water rights. Leases represent an important short- to medium-term solution to addressing water stress, particularly for agriculture producers. While lease markets are a ready alternative to purchasing water rights for some producers, data on these transactions could not be systematically collected. Leases, and the relationships between sales and leases, are an important component of water markets. Understanding the capitalization rate implied by lease transactions would provide further insight on the efficiency of water rights markets under prior appropriation (Brewer et al. 2007).

There are also several caveats to the findings in this paper. First, the data collection process relied partly on a data scraping procedure to collect information about each water right. While the process was effective at collecting information about each water right, it relied on a few assumptions to collect data on any changes to the water right after the transfer. First it is assumed that if the place of use or manner of use changed because of the trade, then an application to change the terms of the water right was filed by the new owner. Second, we use a fuzzy text matching software[11] to match the name of the buyer with the name of a partial owner of each water right. For the most accurate match, if a change application was filed, the new permit number was identified, and water right permit information from that change application permit number are assumed to be the terms of the new water right after the trade. If the new owner had multiple portions of the water right, then the change applications were manually searched to identify the one associated with the transfer in the dataset.

Second, parties in each transfer in the dataset were not contacted to verify prices paid or terms of the trade for this data collection. De Mouche et al. (2011) collected data on transfers in Las Cruces, NM by directly contacting parties involved in each trade in their study period. Further, *Water Strategist* data used in previous research was collected through reports of trades published in the *Water Strategist* journal (Brookshire et al. 2004; Brewer et al. 2007; Rimsaite et al. 2020). While the terms of transfers could not be verified, we believe that the incentive to accurately report transfers of title to the Nevada

[11] Fuzzy text matching refers to a process of scoring the similarity between two string variables in a dataset. This was accomplished in Python using the fuzzywuzzy package: https://pypi.org/project/fuzzywuzzy/

State Engineer and sales deeds to county recorders offices are sufficient to provide an accurate dataset[12].

Third, while a hydrographic basin is a good proxy for the market of transfer compared to previous state-level analyses, it is imprecise in defining where water can physically be moved. Further, expectations of future infrastructure development can drive water rights purchasing decisions. The example of the water transfers between Honey Lake in northwestern Nevada to Lemmon Valley, north of Reno, shows how water rights can be purchased out of basin with the intention of transferring the water into a new basin in the future (DeLong 2015). In this case, water rights were purchased by the Vidler Water Company prior to the development of infrastructure to transfer the water to Lemmon Valley. While previous interbasin transfers could be identified to map the potential basins where water could be moved between, future decisions regarding interbasin transfers are unknown. Thus, identifying the true "market" of transfer is complicated by an inability to know which out-of-basin purchases are made with an intention to move water into a new basin at some point in the future. In addition to this, even within a basin, not all water rights are able to be moved between agricultural users,

[12] The incentive to report title transfers to the State Engineer comes from several sources. First, new owners should verify that the person from whom they purchased the right actually had ownership. Applying to transfer ownership will ensure that the chain of ownership is verified. Second, any major water management decisions, including those regarding curtailment of use will be notified to the owner of affected water rights. Failure to update ownership could result in the owner not being notified of water management decisions, and any negative consequences that could result from a failure to comply. The incentive to report to county recorders is less apparent, although most brokered transactions are likely to be aided in filing by water rights agents involved in the transaction, which is expected to increase compliance.

or into urban or environmental use. Within a basin, there may be several distinct markets based on these limitations.

Conclusions

This research addressed several important questions related to water rights markets in the western U.S. Broadly we sought to explain differences in observed sale prices of water rights in Nevada. Specifically, we attempted to identify the effect of underlying characteristics of water rights and buyer and seller characteristics on sale prices. Second, we sought to estimate the effect of regional market characteristics on prices, using hydrographic basins as a proxy for markets. Finally, we described the bargaining process for water rights to identify the relative bargaining power of buyers and sellers in transactions.

We find that water right characteristics, buyer and seller characteristics, and regional market characteristics all have a significant effect on prices. Regarding water right characteristics, we find that buyers pay a premium for more reliable rights based on priority date and no price differences between groundwater and surface water rights. Municipal and industrial buyers pay about 29% more than agricultural buyers across the state, but this price difference decreases to only 12% when controlling for the basin where the transfer occurred. We believe that the remaining price difference between these buyers may be explained by conveyance infrastructure limiting the extent of the markets in which these different buyers can participate. Basin characteristics had a significant effect on prices. Basins with a higher proportion of existing groundwater rights allocated to municipal and industrial use, as well as those with a higher population tended to have

higher prices. We attribute this to scarcity of rights available for potential sale and a higher number of potential buyers, respectively. Finally, we find use a Nash bargaining framework to identify a bargaining power term through our regression model. The term suggests that sellers, rather than buyers, have more bargaining power in water rights transactions.

This research has important implications for water managers, municipal water utilities, agricultural producers, and other western water market participants. Water rights markets can function as a voluntary, private means of efficiently reallocating water between users (Zachary Donohew 2009). While allowing water prices to be subject to market forces can create equity concerns (Libecap 2010), markets have the potential to cheaply and effectively move water to its highest socially-valued use. Previous research has concluded that most water rights markets fail to operate efficiently at moving water to its highest-valued use (Howe and Goemans 2003; Brookshire et al. 2004; Brewer et al. 2007; Pullen and Colby 2008; Rimsaite et al. 2020). These conclusions have been based on consistent findings of large price disparities between agricultural, environmental, and municipal uses of water, as well as the complex nature of most water rights. Our study finds that water rights generally obey the law of one price for rights with similar characteristics within a hydrographic basin. This suggests that water rights markets in Nevada are efficient at transferring water to its highest-valued use.

This finding of the efficiency of Nevada water rights markets supports the need for investing in infrastructure to expand the spatial extent of water rights markets in areas where water stress is particularly high. By expanding infrastructure, more water rights

holders are able to participate in markets to buy and sell water rights, improving water allocation across a larger space. Additionally, this suggests that proposals for alternative water allocation institutions or variations in water markets should be weighed against current water market operations and potential benefits of infrastructure, rather than institutional, investments.

Future work should seek to better define markets, verify accuracy of publicly-reported terms of water rights transfers, and explore the role of infrastructure and institutions in water rights market activity in Nevada. Further, the approach of data collection and analysis in this study may be able to be replicated in other states with similarly accessible online public records of water rights and deeds of sale.

Works Cited

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Appendix 1: Additional Tables

Table 11: Comparison of Total Number of Rights, Transferred Rights, and Rights Transferred Separate from Land

Hydrographic Region	Number of Active Rights	Total Number of Rights Transferred Between 2006-2019	Number of Rights Transferred Between 2006-2019, where sale was for water right only	Percent of Total Active Rights Sold
Northwest	756	417	17	0.02
Black Rock Desert	3075	1292	32	0.01
Snake River Basin	3091	595	11	0.00
Humboldt River	6625	3442	264	0.04
West Central	227	96	24	0.11
Truckee River	8582	5273	1329	0.15
Western Region	743	385	76	0.10
Carson River	4873	2496	466	0.10
Walker River	1921	1307	315	0.16
Central Basin	12621	7919	664	0.05
Salt Lake	759	487	1	0.00
Escalante Desert	12	2	1	0.08
Colorado River	5224	1932	103	0.02
Death Valley	656	380	102	0.16

Table 12: Comparison of Sale Characteristics for Rights with Supplemental Rights and Those Without Supplemental Rights

Type of Right	Number of Transfers	Price	Priority Year	Years from Priority	Ag Buyer
Supplemental	550	6,973	1969	103	0.32
No Supplemental Rights	1375	12,863	1921	61	0.26

Table 13: Comparison of Rights where Terms of Use were Changed

Right Details	Number of Transfers	Average Volume of Bundle (Acre Feet)	Average Price/Acre-Foot	Average Priority Year
Filed Change Application	651	76.7	$8,650	1953
Did not File Change Application	1274	168.7	$12,473	1927

Appendix 2: Data Gathering Process for Nevada Water Rights Transactions

Overview

Most existing published research work has utilized data reported in Water Strategist and proprietary data held by WestWater Research LLC. Part of the data recorded in Water Strategist from 1987 to 2010 has been made available publicly through Zack Donohew and Gary Libecap at UC Santa Barbara.

While the dataset has a fairly extensive compilation of large-scale water rights transfers, it is acknowledged to be highly incomplete, as only large transactions that were reported in Water Strategist are included. Only 159 sales of water in Nevada from 1987 to 2010 are recorded in the dataset, with an average duty of 1300 AF annually. The dataset also does not specify whether each transaction is for the paper water rights or for actual water delivered.

Few existing studies have collected original data on water rights transfers. Of these, the scale was mostly very small- typically focusing only on a single basin (Ward et al and Colby et al). Ward et al (2010) used data publicly available on the New Mexico State Engineer's website to identify water rights transactions in Las Cruces, NM in an effort to value water rights owned by NM State University. Following this, a list of all water rights databases for each state was created. Given the location of UNR and interest in Nevada water issues for this project, Nevada was chosen as the first state to identify water rights transfers.

Background Research/Preparation

To create a process of constructing a dataset of water rights transfers in Nevada, first a number of subject matter experts were consulted. First, the Nevada Deputy State Engineer, Adam Sullivan, was consulted to assess the viability of this research effort and to obtain contacts to help with the process. An initial consultation meeting with Shawnee Clayson, Engineering Technician V for the NDWR, who deals with filing reports of conveyances (ROCs, which are applications to change ownership) for water rights in northern Nevada. The initial meeting was followed by an onsite meeting at the NDWR office in Carson City. This meeting showed the functionality of the NDWR website, how to search for different water rights transfers and understand permit information, and clarifying on where and how ROCs are required to be filed.

Follow-up consultations were made with licensed water rights agents David Hillis of Turnipseed Engineering, Mark Warren who was contracted to appraise water rights for National Fish and Wildlife Foundation Walker Basin Restoration Program, and Chris Facque of Farr West Engineering. Each of these agents has experience in appraising water rights, helping clients file ROCs, and working with the NDWR staff. These conversations informed how to use county recorder websites to search for sales records, identifying relevant information that influences the value of water rights, and clarifying the process through which an individual or company may sell their water right. The process below is based heavily on that followed by Mark Warren in his valuation of water rights in the Walker Basin, prepared for NFWF (Warren and Schiffmacher 2014).

Process to Collect Price Information

Nevada is divided into 14 hydrographic regions and 230 hydrographic basins across the state, based on physical topography. Permitting determinations are made within each basin by the State Engineer, and permits may only be transferred within each basin except under extreme circumstances approved by the state engineer. Permit holders must file a report of conveyance with the State Engineer to update ownership. If either the point of diversion, manner of use or place of use will change, a change application must also be filed. Both of these processes can take several months before approved. There is no enforcement mechanism requiring an ROC to be filed if a change app is not going to be filed. This means two things. First, ROCs are usually filed after the water right transaction occurred and second, the state engineer does not have a complete record of all water rights transactions. However, the State Engineer has the most complete record of all water rights transfers filed for the previous year so it was used as a starting point for developing a dataset of transactions for each basin.

Transfer data was collected at a hydrographic region-year level for each of the 14 hydrographic regions in Nevada from 2006 to 2019. Data was collected from February to August 2020 using the following procedure.

First, a spreadsheet of all ROCs filed within a year in a hydrographic basin was created and downloaded from the NDWR “Titles Search” function located at http://water.nv.gov/titles.aspx. Individual basin numbers were manually entered in the “Basin” search box, separated by commas and including leading 0’s. The date range was set by the date the ROC was received (not necessarily approved), from January 1 to December 31 of the year where data is being collected. The spreadsheet was cleaned,

with new columns added to identify the assessed value, tax value, acre feet on deed of sale, and the type of transfer (water right-only, transfer with property, or transfer into trust).

Next, an attempt was made to locate the deed of sale for each transfer. The geographic extent of each hydrographic region covers multiple counties, defined by NDWR (http://water.nv.gov/hydrographicregions.aspx). The online records search for each county in the basin were searched. For each county recorder website, a search was conducted to find the deed of sale for the water rights. Records dated between two year prior and one year after the date the ROC was recorded were searched. If an option for searching by document type was available for the county being searched, then "Water Rights Deed" was checked to narrow results. If this was not an option, "Deed" was checked, as searches by name confirmed this is likely how water rights are recorded by the counties.

Depending on the number of search results, for each permit, the "New Owner" was typed into the "Grantee" search box, or the page search function was used to locate new owner. While this process works well for individuals or standalone companies, there were many instances where the name filed with the State Engineer and the county were not the same. In these cases, variations of the name were tried, subsidiaries of the company were identified and searched, and finally individual transactions were inspected to try and match up a permit number listed in a transfer with the permit number listed in the deed. If a water right record could not be identified, the search was expanded to include any document filed with the county under the name of the new owner, as a majority of ROCs

are associated with property where the water rights were bundled in the transaction. Once located, the declaration of value form was used to confirm if the deed of sale was for the water rights only (box “Other” checked with “Water Rights” written in) or if the water rights were bundled with property. In some other cases, water rights were being transferred from an individual to a trust. Unless explicitly recorded as a purchase, these were flagged as transfers into trust and not recorded as pure water rights sales. Any records that could not be identified were noted along with any relevant information relating to the search.

Once a deed was successfully identified, the following information was recorded from the deed of sale and declaration of value forms for water rights deeds (not any transactions for trusts or land/property): total annual duty of water transferred, total value/sales price, transfer tax, date of sale. A link to the deed was copied into the “Deed link” column of the spreadsheet and any additional notes were recorded. Notes may include things like if the combined duty of water rights in a transaction was less than the sum of individual rights (often due to certain rights being supplemental), if anything besides a water right may have been included in the transaction, or if the transaction was not taxed and provided a reason for exemption.

Often times with larger purchases of water rights, multiple rights are purchased together under one sale. In these cases, the total value of the sale was recorded, along with the acre-feet of each water right. Later in R, the value of the total sale was divided by the total acre feet sold to calculate the price per acre foot of the rights included. Price was allocated evenly across all the rights included. Later analyses could then treat these as

separate transactions or bundles of individual purchases. Additionally, if only the tax value was recorded, not the deed of sale, the tax was divided by 0.0039, the average tax rate on real property transfers of water rights, in order to back out the original sale price.

Once the data gathering process from all hydrographic areas studied was completed, a data scraping procedure was completed in Python to collect all relevant information on the permits that were transferred.

Data Scraping Procedure to Collect Water Right Permit Information

The Nevada Division of Water Resources maintains a database of all water rights in the state, searchable by permit number at http://water.nv.gov/permitsearch.aspx. A data scraping procedure was developed in Python to collect all data related to the water right.

The scrape was developed by Adam Cornachione, with some helpful consultation with Dr. Ethan Grumstrup prior to creating the process. The Selenium web driver tool was used to navigate in Google Chrome to access permit information for each permit. The text parsing package “beautiful soup” was used to pull the HTML code for the webpage and search for components of the permit page. There were two special cases that required additional data gathering.

The first case occurs when there are multiple owners of a single water right. A right may be divided up into many owners each claiming a share of the total duty of the water right, and all subject to the same terms of the permit. If the permit has multiple owners, a fuzzy text matching software was used to identify the portion of the water right that was updated in the titles transfer from the “Ownership and Title” tab on the permit page. If no

change application was filed, then all the permit information on the base right is used for the portion of the right whose title changed.

The second case comes from a similar situation. ROCs are filed for the permit that existed at the time of the transfer. However, if a change application is also filed, then a new permit is created from the base (original) right that has either the place of use, point of diversion, or manner of use (or all three) updated and changed, along with the new owner. If a change application has been filed, the new owner will show up on the base right, but there will be a link to a change application in the "Ownership and Title" tab. This can be the case for rights with multiple owners or with just a single owner. For any rights that had this link, both the original right permit information and the "changeBy" permit information are recorded. This is the case when a right is transferred from agricultural to municipal use, for example.

For rights that could not be matched successfully using the text matching procedure, the actual right was searched for and permit information was entered manually.

Defining Additional Variables

Variables were created to characterize each transfer. Variables for the type of use before and after each transfer were created by grouping manners of use. Municipal and industrial users are those for whom the manner of use was "Municipal", "Quasi-Municipal, "Industrial", or "Commercial". Agricultural users are those for whom the manner of use was "Irrigation" or "Stockwatering". Mining users are those for whom the manner of use was "Mining and Milling". Environmental use was defined as those where the manner of use was "Recreation" or "Wildlife". For any decreed rights, the use is typically not

specified. In these cases, each decreed right was reviewed to determine what the decreed water was used for before and after the sale. New uses were determined by reviewing the name of the new owner. If the water right was owned by a municipal water provider, such as Truckee Meadows Water Authority, it was assigned a Municipal use. If the right was owned by a real estate development company, such as Centex Homes, it was also assigned a Municipal use. Other uses were similarly determined- rights owned by the US Fish and Wildlife Service were deemed "Wildlife", while those owned by a farm or ranch were deemed "Irrigation". The original use was more difficult to identify, since users can change on the base right. To stay consistent with the rest of the dataset, only those decreed rights that had a change application filed from the base right were reviewed. The original use was determined based on the same criteria as the new use described above, only reviewing the original owner rather than the new owner.

Surface water rights were defined as those where the source was "Stream", "Lake", "Spring" or "Other Surface Water".

For any rights where a change of use application had not been filed, all variables for new place of use, manner of use, point of diversion, and characteristics of water right were filled in as being the same as the base water right.

Collecting Additional Variables

Control variables were collected using spatial information about each water right. The latitude and longitude coordinates for each point of diversion was merged with spatial data in ArcGIS. The following control variables were collected, from the data source listed:

- Historical average annual precipitation at place of use: NRCS Geospatial Data Gateway (https://gdg.sc.egov.usda.gov/GDGOrder.aspx)
- Historical maximum and minimum temperature at place of use: NRCS Geospatial Data Gateway (https://gdg.sc.egov.usda.gov/GDGOrder.aspx)
- Soil characteristics at place of use: NRCS Web Soil Survey
- Land classification at place of use: National Land Cover Database
- Elevation at place of use: Nevada digital elevation models (https://www.nbmg.unr.edu/Geothermal/Data.html)
- Land parcel size at place of use: NV County Parcel Shapefiles (https://hub.arcgis.com/search?owner=ssnider_NDWR)
- Population in basin: US Census Bureau (zip code-level)
- Distance from point of diversion to nearest population center: calculations in ArcGIS by Ryan Smith, with town locations from EPA dataset: (https://archive.epa.gov/esd/archive-nerl-esd1/web/html/nvgeo_gis9_towns.html#map)
- Perennial yield and area of basin: Nevada Division of Water Resources Hydrographic Basin Summaries
- Allocation of groundwater rights to different uses as of Jan 2021: Nevada Division of Water Resources Hydrographic Basin Summaries

Data Cleaning and Quality Control

Data was cleaned in R statistical analysis software. Several steps were taken to ensure the data scraping procedure worked properly.

First, water right transfers where the new owner of the right owned multiple portions of the base right were reviewed individually to determine which portion of the base right had been transferred. This was identified by matching the acre-foot value of the transfer with the portion of partial ownership. In cases where there were multiple portions with the same owner, changed applications were reviewed and the owner and acre-foot value of the changed right was reviewed to determine the portion of right that was transferred. If the portion could not be identified, the new use was assumed to be identical to the base right transferred.

Second, transferred rights frequently have supplemental rights associated with them, both of which often have the same acre-foot value, but the total amount of water able to be used is equal only to the acre-feet of the base right. To identify cases where the sum of annual duty was different from the actual volume of water able to be used, observations with the same filing receipt from the NDWR and the same acre-foot value were identified and reviewed. In cases where the deed of sale or water rights detail page specified the total duty of water under the bundle of rights and supplemental rights as different from the sum of the bundle of rights traded, the bundled acre foot value was adjusted.

Third, transactions were bundled based on the filing receipt with the NDWR. In many cases, buyers purchased rights from a number of different owners through a broker. These sales are often filed in a single deed in the county recorder office but are filed in multiple different reports of conveyance with the NDWR. This results in multiple receipt numbers for each bundle of rights. Such cases were identified by flagging observations with the same assessed value, basin, and year of transaction, but a different price per acre foot of bundled transaction.

Finally, remaining observations were reviewed and flagged as outliers if the price per acre foot was either over $50,000 per acre foot or under $100 per acre foot. These are anomalous transactions based on conversations with Nevada water rights agents. The deed of sale for each of these observations was reviewed to determine if data had been mis recorded. Frequently, these outliers were due to an incorrect sum of all acre-feet of bundled water rights, or to bundled land and property transactions being mistakenly recorded as water rights deeds.

All other observations are assumed to be accurately reported by the NDWR and correctly input and scraped from the data collection procedure.

Table 14 County Recorders Web Links

County	**Website**
Carson City	https://landmark.carson.org/LandmarkWeb/
Churchill	https://landmark.churchillcounty.org/landmarkweb
Clark	https://recorder.co.clark.nv.us/recorderecommerce/
Douglas	https://recorder-search.douglasnv.us/Recording/
Elko	https://records.elkocountynv.net/Landmark
Esmeralda	http://recorder.accessesmeralda.com/DigitalResearchRoom/?mode=Advanced
Eureka	https://recording.eurekacountynv.gov/DigitalResearchRoomPublic/?mode=Advanced
Humboldt	http://recorder.hcnv.us/?mode=Advanced
Lander	https://selfservice.landercountynv.org/web/
Lincoln	http://recording.lincolncountynv.org/DigitalResearchRoom/?mode=Advanced
Lyon	https://records.lyon-county.org/recorderweb/user/disclaimer
Mineral	https://records.mineralcountynv.us/web/search/DOCSEARCH202S1
Nye	https://nyecountynv-web.tylerhost.net/web/search/DOCSEARCH2633S1
Pershing	https://selfservice.pershingcounty.net/web/search/DOCSEARCH140S1
Storey	https://selfservice.storeycounty.org/recorderweb/search/DOCSEARCH206S1
Washoe	https://icris.washoecounty.us/ssrecorder/search/DOCSEARCH1174S1
White Pine	http://recorder.whitepinecountynv.gov:9005/DigitalResearchRoom/?mode=Advanced

Table 15: Coding for Water Right Variables of Interest

Variable Name	***Code***	***Values of variable corresponding to each coding***
Status	Application	Application
	Permit	Permit
	Certificated	Certificate
	Other Active Rights	Decreed; Ready for Action; Ready for Action (Protested); Revocable Permit; Vested Right
	Inactive Rights	Abandoned; Abrogated; Cancelled; Denied; Expired; Forfeited; Rejected; Relinquished; Superceded; Withdrawn
Source	Surface water	Lake; Stream; Reservoir; Spring; Storage; Other Surface Water
	Groundwater	Underground; Other Underground; Geothermal
	Other	
Use	Agriculture	Irrigation; Irrigation-DLE; Stockwatering
	Environmental	Recreational; Wildlife
	Municipal and Industrial	Commercial; Construction; Domestic; Industrial; Municipal; Quasi-Municipal
	Mining and Milling	Mining and Milling; Dewatering
	Other	Storage; As Decreed