Temporary Transfers and Water Use Efficiency for Prior Appropriations Agricultural Surface Water Rights: Empirical Evidence from Northwestern Nevada[1]

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Abstract

Abstract

Irrigated agriculture in the semi-arid western U.S. depends heavily on priority-based water rights, which in drought years face state-mandated curtailments of water to lands with rights with lower (junior) priority claims. We present evidence of two forms of unobserved temporary water transfers used by agricultural producers to transfer irrigation water during periods of curtailment. The first is transfers between lands with water rights owned by a single owner as part of a portfolio of senior and junior rights. The second is transfers between lands with different landowners, who negotiate arrangements through which owners of senior rights transfer a portion of their water to landowners with junior rights facing curtailments. Because no State approvals or permits are needed for these temporary transfers, they are not recorded and thus not observed directly. We identify these transfers using a 10-year set of panel data from Nevada's Carson River Valley, where surface irrigation is the major source for agricultural production, and during which drought results in curtailments. The data describe 477 land parcels with surface water rights. As surface irrigation is necessary agricultural production in the region, we identify temporary transfers through observed satellite changes in irrigated cropland acreage in years when water use is curtailed. Controlling for additional factors that influence irrigation decisions, our model shows that, annually, these temporary transfers redistribute 3.1 % to 3.5% of total surface irrigation water to lands with junior rights, and representative of more productive croplands, thus suggesting improved water use efficiency during drought years. Our findings suggest that prior empirical estimates may under-represent the capacity of unreported, and thus unobserved, temporary water transfers to mitigate potential agricultural water use inefficiencies resulting from water curtailment under prior appropriation.

Key words: water transfers; agricultural water rights; irrigation; prior appropriation doctrine

JEL codes: Q25, K32

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1. Introduction

This paper examines the role of unrecorded temporary transfers of agricultural irrigation surface water governed by Prior Appropriations Doctrine from the place of use specified in the formal water right to another place of use when surface water supply falls below expected annual yield. We quantify such transfers as they occur between different owners and across lands owned by the same owners within irrigation districts at a study site in northeastern Nevada. Lee et al (2020) show how permitted transfers of perpetual water rights in the study area have increased the overall value of water used for agricultural irrigation, while suggesting that the total number of previous transfers falls short of what would bring about further gains. This study focuses on the roles of the two types of unrecorded temporary transfers of place of use in managing intermittent supply shortages without incurring the transactions costs and long-term shifts in capital assets involved in permanent transfers of places of use of perpetual water rights.

The Prior Appropriation Doctrine defines most agricultural irrigation water rights in the Western U.S. through specifying an agricultural surface water right in terms of its source, allowed use, the specific land boundaries and acreage where the water may be used, and the historical date that each claim was established (Whittlesey and Huffaker 1995; Huffaker et al. 2000. Quantity claimable is typically a fixed proportion of acreage in the claim, with the total amount of water associated with a claim called its "duty". When water supplies are normal, all lands receive the full duty associated with their claim. When supplies fall below expected yields, priority is determined by the date each water right was first established (Waskom et al 2014). Thus, an 1875 water right has a higher priority than a 1920 water right. Lands with senior rights receive their full duty first, with lands with most junior rights receiving no water. The total supply and the amounts associated with each claim in order starting with the most senior determines the "cutoff" priority date; lands with priority dates more recent than the cutoff are subject to curtailment. Key features that determine the value of a prior appropriation right are its source (including the variability of flows from that source), priority date, location of permitted use, number of acres associated with the claim, and number of claimants to the same source. Strategies to manage water at the farm level include permanent transfers of the place of use of water rights with their priorities from other locations to new locations (see Lee et al 2020), purchasing lands with water rights to create a portfolio of land and priority dates through which portions of water duties from lands with senior rights are moved to irrigate the most productive portions of parcels with curtailed junior rights, and negotiating with neighboring farm operators for temporary leasing of portions of water duties during periods of curtailment. Lee et al (2020) empirically explore the first strategy, while this paper focuses on the latter two.

Water rights places of use may be permanently transferred by application to state water authorities in a process that includes verification that the transfer will not negatively affect other water users, a process that can take several years. Transactions costs include assessments of impacts on other users (Lee et al 2020). While water rights transfers occur, unexpectedly slow development of transfers of ownership have been observed in regions where water market constraints have been relaxed or removed (Young 1986; Brown, 2006; Doherty and Smith. 2012; Hansen et al. 2014; Edwards and Libecap 2015; Hanak and Jezdimirovic, 2016; Regnacq et al. 2016).[3] Various types of transaction costs are considered as a key reason (Young 1986; Huffaker, et al. 2000; Carey et al. 2002; Regnacq et al. 2016). This paper provides empirical evidence that temporary water transfers limited to times of curtailment are an unexplored mechanism that has implications for the role of formal water markets. Our paper explores unrecorded transfers through an empirical analysis that relies on indirect observation of which areas are and are not irrigated by priority status, and find that on average, the percentage of water transferred within a year is aligned with that found in formal water markets. Our findings provide an additional explanation regarding the unexpectedly small scale of transfers in formal water markets – transfers may be also occurring using unrecorded mechanisms we describe here. Water transfer deregulation policies may not be as effective for improving allocation efficiency as the theoretical literature may suggest, particularly in regions where farm operators' long-term relationships, knowledge of each other's operations and land qualities, and opportunities to establish long-standing agreements to share water in times of stress can facilitate temporary sharing of water.

2. Temporary Transfers

Prior Appropriations water rights and place of use transfers are recorded and observable. Temporary changes of location of use below the same headgate generally are not subject to permitting, and thus specific arrangements are not directly observable. However, ample anecdotal evidence suggests that under curtailment one owner will 'lend' water to others. The amount transferred need not be the full amount of a water right duty – a percentage is retained for the

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[3] There exist some water transfers between or within water districts, but water exchange remains limited (Regnacq et al. 2016). For instance, water trade in California accounts for only 3% of water use (Hanak and Jezdimirovic 2016).

better-quality parts of the original parcel, and the amount leased out is used on the better parts of the receiving parcels with curtailed rights. In this case, the parcels that water was moved from and moved to would show "partial shares" irrigated, when normally, under prior appropriation, the entire parcel would be either irrigated or not. Because precipitation in our study region is so low that cultivation is not possible without irrigation, satellite images taken during periods of curtailment reveal irrigation patterns when overlayed with water rights parcel boundaries and priority dates. We expect that during years with full water, all areas would be irrigated and thus show as being irrigated (green), while during low flow years, if no temporary transfers occur, only parcels with senior priority should be irrigated while junior parcels would not be irrigated (brown). Transfers would be indicated if portions of junior righted parcels were green, while at least some proportion of more senior righted parcels are brown. This is the case for our study area, for which we create a variable indicating the irrigated portion of each parcel with a water right for a 10-year period that includes varying levels of full water supply and curtailment.

Irrigation infrastructure for allocating surface water uses headgates located at key diversion points along rivers to control water withdrawals (Waskom et al 2914). Based on measurements of water flow rates, state water authorities open and close headgates for the numbers of hours necessary to deliver water to lands with documented water rights. Water flowing through a headgate serves several water rights, each of which is further controlled by gates to divert specifically onto the lands associated with those rights. Water flows after main headgates are controlled by local managers who implement water delivery according to priority rights. Water can be easily transferred between lands with the same owner, or between lands with different owners through requests to headgate managers. Field interviews suggest the existence of both types of transfers. While details of this practice vary by state, state authorities verify that such temporary transfers of water between lands are allowed and often encouraged (e.g. Nevada Division of Water Resource and Idaho Department of Water Resources). Nevada Revised Statutes explicitly state that no applications for transfers are required for water rotated to different croplands with water rights owned by a single farmer (NRS 533.075).

To our knowledge, the existing literature does not discuss nor quantify the roles of unrecorded temporary water transfers during curtailments in systems using prior appropriation water rights to allocate surface water for irrigation. An empirical challenge is that these transfers are not directly observable. The existing empirical literature includes transfers in irrigation districts where approvals are exempted (e.g. Ghimire and Griffin 2014; Ji and Cobourn 2018). Similarly, Carey et al. (2002) use records from a California water district as an example for their theoretical analysis concerning differentiated transaction costs given social network relationships.[4]

Conceptual Model for Informal Temporary Water Transfers

Between-owner and same-owner water transfers have somewhat different economic implications. A transfer between different owners implies an initial effort to identify and negotiate with other owners of lands with sufficiently different marginal productivities and priorities so that the transaction is beneficial to both parties. The largest effort of between-owner negotiations may be initially, with arrangements then set up as contingent on intermittent future curtailments, so that initial transactions costs are higher than those occurring during curtailment periods – but overall, this process avoids the potentially higher costs of transferring perpetual water rights. Conversely, transfers between lands with the same owner may have involved high fixed costs for initial purchases of the lands with senior water rights, but close to zero variable costs for transferring water between owned lands during curtailment. In this case the costs to create the water portfolio is capitalized into the farm value. Thus, a farmer's optimization problem for a between-owner transfer is to what extent additional water should be exchanged with a variable cost to relax resource constraint; while for a transfer between lands with a single owner, at a given time t, the problem is how to optimize profit by allocating available water given the water right portfolio in hand while the variable cost is trivial. A water right portfolio is the result of a long-term dynamic optimization problem, which is beyond the scope of this paper. At a given time t, we treat the portfolio as fixed, treated as exogenous.

Moore et al. (1994), Li et al. (2018) and several other studies describe optimization problems concerning agricultural production water use decisions. Li et al. (2018) develop a model that further incorporates a water right's priority as a factor influencing a farm's water supply risk, and show that a water right with higher priority results in a greater proportion of cropland used for a higher-valued, irrigation-dependent crop. However, their model does not consider the role of unrecorded temporary water transfers. We extend Li et al.'s (2018) model to include these two additional types of temporary transfers. We follow the basic assumptions in this literature that farmers are price takers with a goal to maximize profit from agricultural production, and that each cropland i is associated with a surface water right. To address between-owner transfers, we consider that the total amount of water rights allocations, the total of all the duties, from all

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[4] As all transfers in the California water district are documented and administered, Carey et al. (2002) refer "informal transfer" as those made among relatives and market trades as those made beyond the networks of affiliated farms.

neighboring farms serves as a thin water market, in which the farmer of cropland *i* under curtailment may purchase water up to the total neighboring water right allocation. A transfer occurs when the marginal benefit of agricultural production for cropland *i* is larger than that in the neighbors' lands and when the neighbors have available water. Thus, while the optimization problem is similar to Li et al.'s (2018) for maximizing cropland *i*'s profit, with between-owner transfers, a farmer further choses to what extent additional water might be purchased and transferred from neighboring land parcels.

The intuition for a transfer among lands with the same owner is somewhat different. We assume a portfolio of water rights has been built exogenously. The water right attached to cropland land *i* is only a part of the portfolio that includes multiple water rights, priority dates, and croplands of varying productivity. Thus, the farmer seeks to maximize the profit from all croplands within the water right portfolio, instead of cropland *i* alone. Consequently, the amount of water with more senior priority is reallocated to the most productive portions of each cropland until the marginal benefits are equal. The remaining amount of water with more junior rights is used for the less productive portion of each cropland parcel. Note, that we allow for each cropland parcel to have areas within its boundary of varying productivity, so that under curtailment, each parcel may have only portions under irrigation. Water is allocated subsequently until total portfolio water received at time *t* is exhausted. Lefebvre et al.'s (2012) laboratory experiment study suggests that a higher diversity of water right priorities in a portfolio can help farmers to manage the risk for greater profit. We expect for our study site, that a more diverse water right portfolio under ownership of a single enterprise contributes to more irrigated land.

3. Study Area, Identification Strategy, and Data

Study Area

Our study uses data based on water rights in Carson Valley, Nevada. The adjudication of water rights in the Carson Valley generated accessible documentation of the boundaries, priorities, uses, locations of headgates, and owners (Alpine Decree 1980). The amount of irrigation water (acrefeet) per claim is constant on a per acre basis in this region, so that the amount of water that each water right is entitled to is proportional to the acreage of the associated parcel (Huntington and Allen 2010; Lee et al. 2020). Spring and summer melting mountain snowpack provides the source of the Carson River, the primary irrigation water supply for the Carson Valley. Annual variation in total snowpack and variation in daily temperatures throughout spring through summer strongly influence annual flow rates, as seen in recorded stream flows. Annual stream flows fell below average annual yield in 44 of the 79 years between 1936 and 2015, with flows in the lowest 10th percentile in 14 of these years. As a result, more junior water rights frequently face curtailment (James 2019). Morway, Niswonger and Triana (2016) use stream flow data to show that over 35-year simulations based on flow rates from 1981 through 2015, 23% of lands with water rights established after 1890 would have experienced curtailments in 3 or more years of the 35 years.

With average precipitation of less than 9 inches per year occurring mostly as winter snow at higher altitudes (Western Regional Climate Center, 2019), crop production is only possible through irrigation. Carson Valley producers grow two crops: grass hay for pastures for livestock operations; and alfalfa as the Valley's only significant cash crop, primarily for export outside of Nevada. In 2012, alfalfa and grass hay/pasture represented 92.43% of crop acreage in Douglas County, which includes Carson Valley (USDA-NASS 2017). Alfalfa is a perennial that requires rotation after 6 to 7 years, with another crop grown for a year between alfalfa plantings. A variety of low value crops including corn and wheat are grown in the year between alfalfa plantings. The costs to plant a new rotation of alfalfa are much higher than the subsequent costs to maintain it. Since alfalfa production is best in the first years and then drops off, the costs of losing a relatively new planting of alfalfa as a result of curtailment are higher than the costs of losing an older planting or a rotational crop between plantings. Any parcel dedicated to alfalfa may contain sub-parcels with up to 8 different rotational stages, where the potential costs to the farmer vary depending on the proportion of the parcel in each stage. Thus, partial transfers of water between lands with different priority dates, between owners and with the same owners, poses gains during curtailment.

The amount of water necessary for the two irrigated crops, alfalfa and grass hay, is the same per acre in the region. Soil characteristics vary across the region, tending to favor either grass hay and pasture, or alfalfa, but not both, so that alfalfa and grass each represent highest valued land use for their respective land types (Lee et al 2020). Alfalfa was introduced to the Carson Valley decades after senior water rights had been established on low lying grass lands (Townley 1980; Horton 1996). Because alfalfa prefers well-drained soils (Kettle, Riggs, and Davidson 2000) grass lands with relatively senior water rights could not be profitably planted in alfalfa (Lee et al. 2020). Alfalfa was introduced to newly claimed lands, establishing more junior water rights, even as it eventually became a more important cash crop with a protein content of about twice that of grass hay (Balliette and Torell 1993). On lands that can support alfalfa, production in tons per acre is about double that for grass hay on lands best suited to that crop (USDA-NRCS 2017). The average alfalfa price per ton is higher than that for grass hay in Nevada for almost every year between 1972 (when data are first available) and 2017 (USDA-NASS 2017). Even though production costs are somewhat higher for alfalfa than for grass hay, these circumstances suggest that alfalfa returns higher water use values on suitable land. During years with full water supply, all lands are used – but in years with curtailments, higher profit alfalfa lands may be affected more than grass hay lands. Lee et al (2020) show that previous recorded permanent transfers of place of water right use moved some, but not all more senior rights from grass lands to alfalfa lands. This paper demonstrates that under curtailment, the more productive portions of the remaining lower priority alfalfa lands are likely irrigated through temporary unrecorded transfers.

Identification strategy

Since neither applications nor permits are required for temporary transfers of water use, no systematic records exist for these transfers. To create a variable to indicate the amount of water transferred from senior to junior water righted lands, we use satellite images of the portions of parcels with water rights that are irrigated and assume that this acreage approximates annual water use. We identify the existence of unrecorded water transfers by using portion of parcels irrigated, controlling for other factors. With an average slope of 1.28% and a maximum of 4.33%, return flows are a trivial source of irrigation water under curtailment. While we cannot directly observe how much water is applied to a parcel, observed land use outcome is sufficient to approximate water use, as per acre consumptive use of water is about the same for alfalfa and grass (Huntington and Allen 2010). Afalfa and grass together account for more than 90% of croplands in the region (USDA-NASS 2017), with other crops grown as part of the alfalfa rotation. Since surface water is allocated primarily for these two crops, a focus on alfalfa land use proxies grass land use.

Data

We combine GIS data from several sources to build a panel data set from which we calculate several variables as described in detail below for each parcel served by irrigation water rights in the Carson Valley. Our source for land use data for alfalfa production is the USDA-NASS (2019) CropScape Cropland Data from 2008 to 2017, and for soil data we use the USDA-NRCS (2017) Web Soil Survey. The water rights data provided by the Nevada Division of Water Resources (NDWR) and the U.S. Geological Survey (USGS) identify precise land boundaries and acreages. The NDWR water rights data provide priority year, water right holder name, and headgate location. Tax Assessor data provides farm ownership and boundaries. We use NDWR's water right database supplemented with their satellite layer to identify and exclude non-agricultural land used for housing, public infrastructure, and other non-agricultural production uses. We use USDA-NASS (2017) crop price data to control for market variation over time.

NDWR water rights data show several cases in which a single original water right with one priority date has over time been split between multiple parcels through multiple land sales. In these cases, the original water right is split with each sub-parcel keeping the same priority date, with the amount of water based on the proportion of acreage in the sub-parcel. For the purposes of our data, we identify adjacent parcels with the same priority date owned by members of the same family (same last name) and assume these are managed within the same farm operation even as individual parcels are owned by different family members. The subdivision of original family farms into individual ownership by family members who continue to work as a single enterprise is a common practice in the west. Our data include 477 land parcels with irrigation water rights for agricultural production. With 10 years of cropland layers, we construct a panel data of 4770 observations.

Figure 1 illustrates the spatial distribution of water rights and the 2010 crop land layer. Table 1 describes the variables used our econometric analyses, with the choices of and construction of these variables described in Empirical Model section below. Table 2 reports summary statistics of key variables. Our data include drought years within the 2008-2017 period, including the historical droughts of 2014 and 2015, resulting in a significant portion of land left for fallow or as non-irrigated shrubs (27%) and herbaceous native plants (12%). The average percentage of parcels devoted to alfalfa (Alfalfa Land Share) is about 12%.

Table 1. Control Variables and Definitions

Variable	Variable Meaning & Unit
HGTot	Same Headgate Neighbors' Water Duty (100 acre)
WithinOStd	Standard Deviation of Farmland's Water Right Priority Years
StreamFlow	Standardized Stream Flow Deviation from Long Term Average
Priority	Standardized Priority Weighted by Water Duty (0~100)
AlfalfaProd	Alfalfa Productivity (tons per acre)
LandSize	Size of Place of Use (acre)
Slope	% Change of Altitude per Unit Distance (%)
PriceRatio	Price Ratio of Alfalfa and Grass Hay
DistRiver	Distance to River (1K feet)
SupWater	Index of Supplemental Water Source (0/1)

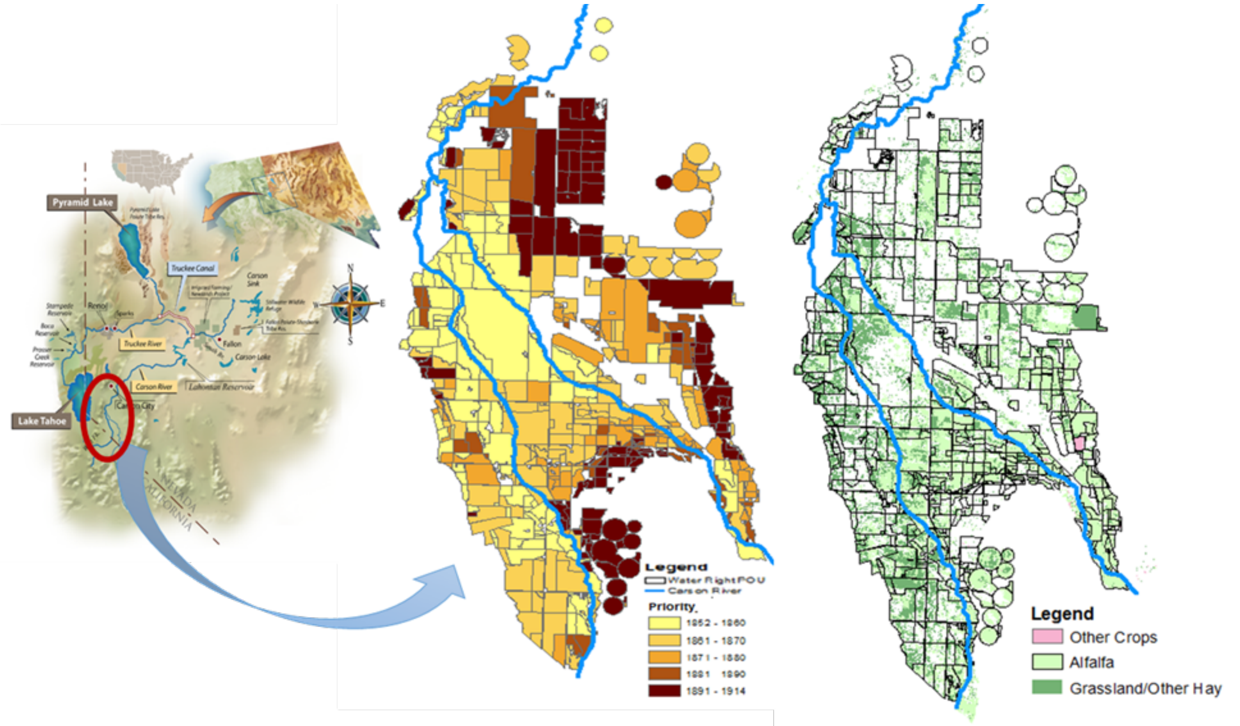

Figure 1. The Carson Valley Study area. From left to right: The Carson River Basin, the Alpine Decree Water Rights Allocation, and 2010 Cropland Layer.

Table 2. Summary Statistics (N= 4770)

	Mean	Std. Dev.	Min	Max
Alfalfa Land Share (%)	12.03	22.44	0.00	100.00
HGTot	4.59	12.39	0.00	72.56
WithinOStd	5.89	7.04	0.00	34.96
StreamFlow	-0.06	1.40	-1.44	3.62
Priority	51.64	28.08	0.00	99.87
AlfalfaProd	1.20	1.55	0.00	5.55
LandSize	68.33	115.68	0.41	1321.38
Slope	1.28	0.68	1.00	4.33
PriceRatio	1.12	0.17	0.87	1.45
DistRiver	3.30	3.49	0.00	19.45
SupWater	0.37	0.48	0.00	1.00

Stream flow ($SSFD_{s,y}$) captures total surface water supply variation in each of the three segments of the Carson River shown in Figure 1, by standardizing the annual deviation from the long-term average during 1939 - 2017 when data are available. That is:

$$SSFD_{s,y} = \frac{StreamFlow_{s,y} - \overline{StreamFlow_s}}{Std.Deviation_s}$$

in which $SSFD_{s,y}$ is the standardized stream flow deviation for river segment s of year y (measured in acre feet), $\overline{StreamFlow_s}$ is the averaged annual stream flow of segment s from 1939 - 2017, and $Std.Deviation_s$ is the corresponding standard deviation. The 10-year average for the standardized deviation of stream flow is -0.06, suggesting that streamflow in this 2008-2017 period is slightly below its long-term trend. Yet, there are also wet years in this period, as the maximum is 3.62 times the standard deviation higher than the average level.

4. Empirical Model

Our model predicts the percentage of each parcel with water rights irrigated each year (% Alfalfa Land Share) as a function of total water supplied each year, priority of the parcel, priority of all other parcels within the same headgate, the quantity of water (acreage of land) of all water rights within the same head gate, and priorities of other parcels within the headgate with the same owner, controlling for a variety of effects that would influence irrigation decisions. We construct two variables to measure potential capacity for same-headgate transfers. We use the total amount of water (a fixed proportion to irrigated acreage) of all other water rights sharing the same headgate with land parcel i as a measure of the potential for transfers between owners. A significant parameter estimated for this variable indicates that the quantity of water held by other water rights within the same headgate contributes to irrigation decisions, implying water transfers among parcels. With the standard deviation of priority dates of water rights held by a single owner as a measure of the potential for transfers between lands within a single farm portfolio, we expect the number of transfers to be increasing with standard deviation.[5] We include both variables in our regression models to identify the existence of unrecorded water transfers.

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[5] We determine farm enterprise by water right holders' names. For water rights owned by multiple holders with each having a significant portion, we divide the land parcel according to NDWR's data.

Following recent empirical studies (e.g. Li et al. 2018, Ji and Cobourn 2018, and Olen et al. 2015), we define dependent variable $Y_{c,i,t}$ as the proportion (percentage of acreage) of land parcel i irrigated for crop c during season t. We observe $Y_{c,i,t} = 0$ if its latent variable $Y^*_{c,i,t} \leq 0$, $Y_{c,i,t} = 1$ if $Y^*_{c,i,t} \geq 1$, and $Y_{c,i,t} = Y^*_{c,i,t}$ if $0 < Y^*_{c,i,t} < 1$, we therefore assume a function $G(.)$ such that $G\left(Y^*_{c,i,t}\right) \rightarrow [0,1]$.[6] We adopt a classic assumption for unobserved time invariant error $c_{c,i}$ and denote the idiosyncratic error by $\epsilon_{c,i,t}$. In equation (1), $\boldsymbol{W}$ denotes the vector of all control variables.

$$(1)\ Y_{c,i,t} = G\left(Y^*_{c,i,t}\right) = G(\boldsymbol{W}, c_{c,i}, \epsilon_{c,i,t})$$

$$(1')\ Y^*_{c,i,t} = \alpha + \boldsymbol{R_i r_c} + \boldsymbol{X_{i,t}\beta_c} + \boldsymbol{M_i\mu_c} + \boldsymbol{T} + c_{c,i} + \epsilon_{c,i,t}$$

Since water transfers between parcels is more likely to occur during scarcity and to higher productivity lower priority lands, we include a set of interaction terms to capture the heterogeneous effects of annual flow, water right priority, and soil productivity levels. In addition, the capacity for the use of water transfers between or within owners' parcels would have some influence on the other. Thus, we let the two variables indicating water transfer activity, between and within owners, to interact with each other by including $M_i^1 M_i^2 D_{i,t} P_i A_i$ in the model as shown in Equation (2).

$$(2)\ Y_{c,i,t} = G(\alpha + \boldsymbol{R_{i,t} r_c} + \boldsymbol{X_{i,t}\beta_c} + \boldsymbol{M_i\mu_c} + \delta_1 M_i^1 M_i^2 D_{i,t} P_i A_i + \boldsymbol{T\gamma_c} + c_{c,i} + \epsilon_{c,i,t})$$

Because dependent variable $Y_{c,i,t}$ is the percentage of irrigable acreage used for alfalfa, we estimate two econometric methods (Wooldridge, 2010). Li et al. (2018) use a two-limit Tobit model since the irrigated land shares are piled at 0 and 1, implying non-zero probability at the two corners (Wooldridge, 2010). Alternatively, a fractional response method can also be applied to estimate the proportion of parcels irrigated. Olen et al. (2015) adopt the method proposed by Papke and Wooldridge (1996) to estimate cross-sectional land irrigation decisions. We use a random effects Tobit (Wooldridge 2010) and a fractional Probit (Papke and Wooldridge 2008) for panel data for our 10 years of observations for each land parcel.

Alfalfa and grass are two major crops in the Carson Valley. We focus on alfalfa, the higher valued crop more heavily affected during a curtailment. We use M_i^1 and M_i^2 to denote between-owner and within-owner water transfers, respectively. The likelihood of parcel level curtailment

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[6] For alfalfa land size used as the dependent variable in the APPENDIX, $G(.)$ ranges from $[0, \infty]$.

is a function of the variation in annual stream flow $D_{i,t}$ (total water supply) and water right priority, P_i. We include these variables in vector $\boldsymbol{R_{i,t}}$. We define annual stream flow variation, $D_{i,t}$ as a standardized stream flow deviation from the long term mean of 1939 to 2017 annual stream flow data. The difference of annual stream flow from the long-term mean is divided by long term standard deviation calculated from historical data. As the study area is managed by three different river segments defined by the Alpine Decree, each observation *i* faces different total annual stream inflow determined by the segment it belongs to.

We index irrigation water rights by priority, with observation *i* = 1 denoting the land parcel with the most senior water right to create the variable $P_i = \frac{\sum_{i=1}^{i-1} W_i}{\sum_{i=1}^{N} W_i}$ as the ratio of the volume of water right entitlements with priority greater than i to the total volume of all water right entitlements for that source. P_i thus standardizes priority as a percentile ranking ranging from 0 to 99.87 in our data, with the most senior water right having access to its full entitlement with zero others having prior access, while the most junior water right experiences all other water rights as more senior and thus has least access to its full entitlement.

Other independent variables are included as controls following previous studies that estimate cropland and irrigation decisions (e.g. Li et al. 2018, Ji and Cobourn 2018, Olen et al. 2015, Hendricks and Peterson 2012). The vector $\boldsymbol{X_{i,t}}$ includes a set of control variables as adopted in previous empirical studies (e.g., Li et al. 2018; Li and Zhao 2018; Ji and Cobourn 2018; Olen et al. 2015, Hendricks and Peterson 2012), including soil characteristics that affect productivity of the parcel for alfalfa, A_i. Market conditions are captured by the alfalfa and grass hay price ratio, since grass. Slope, distance to river, groundwater source, and land size are also included in $\boldsymbol{X_{i,t}}$. Distance to river captures the potential return flow that land parcel i may receive from other farmlands. We include an index variable, S_i, to capture fixed effects in each water administrative segment. Year dummy variables ($\boldsymbol{T}$) are also included to capture unobserved effects specific for each year. We do not control for weather variables because: 1) land use decisions often are made prior to a growing season (Hendricks & Peterson, 2012); and 2) the study area is relatively small in size and so reflects only small weather variations.

5. Results

We report average marginal effects for between-owner and same-owner transfers. The coefficients in a nonlinear model generally indicate the direction of the effect of interest, with the scale measured as the average marginal effect (Wooldridge, 2010). We report full regression results from equations 1 and 2 in Appendix Table A.1 and Table A.2, which show that the coefficients for unobserved water transfers are significant and positive, suggesting both types of transfers contribute to greater portions of croplands used for alfalfa. Thus, we verify the existence of unrecorded water transfers as contributing to cropland irrigation decisions.

Since we are also interested in the scale at which temporary transfers reallocate water to the higher valued crop, we further estimate average marginal effects. Although in equation (1) we depict a linear relationship between independent variables, the marginal effects of each of the two transfer options is conditional on other independent variables (in vector $\boldsymbol{W}$) since *G(.)* is a nonlinear function. That is, $\frac{\partial Y_{c,i,t}}{\partial M_i^1} = G'(\boldsymbol{W}) * \mu_c^1$.

We first consider the average marginal effects of the two types of transfers under drought conditions to determine the role of unrecorded transfers (Table 3). To explore if the use of water on more productive lands motivates transfers, we further distinguish the effects by potential cropland productivity of alfalfa given drought (Table 4). Finally, we discuss the role of water right priority by distinguishing three priority categories (senior, middle, junior) for the average marginal effects (Table 5) for high productivity lands (alfalfa productivity > 4 tons per acre) under drought.

In Table 3, average marginal effects are estimated under normal streamflow level (i.e. long term average value) and under drought. A drought condition is defined as 1.4 standard deviations below the long-term average of the annual streamflow. This is close to the historical all time low level in Carson Valley. Both types of water transfers increase water allocated to higher valued alfalfa, even though the scales under drought are somewhat smaller than a year with regular stream flow. Results from the Tobit and Fractional Probit of quasi-maximum likelihood estimation (QMLE) (columns (1) & (2)) show that total streamflow can constrain the scale of temporary transfers, since the average marginal effects under drought is smaller than those under a normal year. The results from the Fractional Probit of the generalized estimating equation (GEE) show a different pattern. However, the marginal effect under drought is not significantly different from that under a normal year. We find the marginal effects are significant in both the Tobit and fractional Probit methods with and without interaction terms. These results suggest that unrecorded temporary transfers lead to more irrigated alfalfa cropland.

The results in Table 4 suggest that heterogeneity in alfalfa cropland productivity leads to more water transferred during droughts. In every column of Table 4, the marginal effect of between owner transfers for high productivity alfalfa land is larger than that for a low productivity land. Given the results of Wald tests, the differences are significant at the 99% level. This is also the case for within-owner water transfers and consistent with our expectations.

Table 5 reports average marginal effects considering three levels of water right priority for a cropland i, defined as senior priority being the first 1 percentile of lands to receive water, middle priority as the 50th percentile to receive water, and junior priority as the last 99th percentile to receive water. These effects are estimated under drought and with higher productivity land, as we are more interested in the role of priority under these conditions. The results suggest any priority level can benefit from temporary water transfers and increase alfalfa production. Although there is a pattern that cropland with senior priority may receive more water than that with relatively junior priority, the difference is only significant in the Tobit model results. The Wald test results for the estimated two Fractional Probit estimations does not reject the null hypothesis that the average marginal effects among the three priority levels are indifferent.

Tables 6 – 8 report average marginal effects under the above three scenarios using estimates from equation (2), which includes interaction terms for the two types of transfers with streamflow, priority, and cropland productivity. For instance, $E(\frac{\partial Y_{c,i,t}}{\partial M_i^1}) = E[\, G'(\boldsymbol{W}) * (\mu_c^1 + \delta_1 M_i^2 D_{i,t} P_i A_i)]$. Although the estimates are slightly different in terms of scale, the average marginal effects for streamflow level and cropland productivity in Tables 6 and 7 show a similar pattern to those in Tables 3 and 4, respectively. The major difference is in Table 8, which shows that for either a between or same-owner water transfer, the average marginal effect is larger if a cropland's priority is relatively junior. Although the estimates from the Tobit or Fractional Probit (both QMLE and GEE) all show this pattern, Wald tests suggest the average marginal effects under different priority levels are not significantly different.

Table 3 Average Marginal Effects on Alfalfa Land Share under Drought: Basic Model

	(1)		(2)		(3)	
	Tobit		Frac. Probit: QMLE		Frac. Probit: GEE	
BetwnOTransfer						
Normal	0.2759***	(0.0418)	0.3187***	(0.0908)	0.2930***	(0.0807)
Drought	0.1852***	(0.0353)	0.0347***	(0.0105)	0.1540***	(0.0503)
SameOTransfer						
Normal	0.3393***	(0.0337)	0.5080***	(0.1167)	0.4477***	(0.1031)
Drought	0.2277***	(0.0430)	0.0552***	(0.0146)	0.2354***	(0.0614)

Standard errors in parentheses

Note: Drought is defined as annual stream flow below 1.4 standard deviation of long term average.

$^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4 Average Marginal Effects on Alfalfa Land Share: Soil Productivity: Basic Model

	(1)		(2)		(3)	
	Tobit		Frac. Probit: QMLE		Frac. Probit: GEE	
BetwnOTransfer						
Low Soil Prod.	0.1632***	(0.0351)	0.0266***	(0.0089)	0.1229***	(0.0453)
High Soil Prod.	0.2450***	(0.0423)	0.0561***	(0.0154)	0.2410***	(0.0673)
SameOTransfer						
Low Soil Prod.	0.2007***	(0.0355)	0.0424***	(0.0119)	0.1878***	(0.0531)
High Soil Prod.	0.3012***	(0.0707)	0.0894***	(0.0251)	0.3682***	(0.0952)

Standard errors in parentheses

Note: 1. Soil productivity is defined by 0.1 ton/acre and 4 ton/acre; 2. Marginal effects are estimated under drought

$^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5 Average Marginal Effects on Alfalfa Land Share: Priority: Basic Model

	(1)		(2)		(3)	
	Tobit		Frac. Probit: QMLE		Frac. Probit: GEE	
BetwnOTransfer						
Senior	0.2722***	(0.0404)	0.0654***	(0.0199)	0.2532***	(0.0757)
Middle	0.2455***	(0.0422)	0.0564***	(0.0155)	0.2412***	(0.0673)
Junior	0.2189***	(0.0450)	0.0483***	(0.0139)	0.2293***	(0.0642)
SameOTransfer						
Senior	0.3346***	(0.0667)	0.1043***	(0.0321)	0.3870***	(0.1049)
Middle	0.3019***	(0.0706)	0.0899***	(0.0253)	0.3686***	(0.0953)
Junior	0.2691***	(0.0743)	0.0770***	(0.0227)	0.3504***	(0.0942)

Standard errors in parentheses. $^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: Marginal effects are estimated under drought with higher alfalfa productivity

Table 6 Average Marginal Effects on Alfalfa Land Share under Drought: Interaction Model

	(1)		(2)		(3)	
	Tobit		Frac. Probit: QMLE		Frac. Probit: GEE	
BetwnOTransfer						
Normal	0.1254***	(0.0185)	0.1951***	(0.0449)	0.1286***	(0.0291)
Drought	0.0845***	(0.0083)	0.0223***	(0.0061)	0.1403***	(0.0339)
SameOTransfer						
Normal	0.4172***	(0.0832)	0.6114***	(0.1372)	0.3522***	(0.0937)
Drought	0.2845***	(0.0427)	0.0731***	(0.0225)	0.3804***	(0.1060)

Standard errors in parentheses. $^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: Drought is defined as annual stream flow below 1.4 standard deviation of long term average.

Table 7 Average Marginal Effects on Alfalfa Land Share: Soil Productivity: Interaction Model

	(1)		(2)		(3)	
	Tobit		Frac. Probit: QMLE		Frac. Probit: GEE	
BetwnOTransfer						
Low Soil Prod.	0.1640***	(0.0191)	0.0266***	(0.0089)	0.1230***	(0.0457)
High Soil Prod.	0.2417***	(0.0333)	0.0564***	(0.0151)	0.2401***	(0.0659)
SameOTransfer						
Low Soil Prod.	0.2015***	(0.0603)	0.0424***	(0.0119)	0.1881***	(0.0534)
High Soil Prod.	0.2963***	(0.0926)	0.0900***	(0.0249)	0.3671***	(0.0945)

Standard errors in parentheses. $^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: 1. Soil productivity is defined by 0.1 ton/acre and 4 ton/acre; 2. Marginal effects are estimated under drought

Table 8 Average Marginal Effects on Alfalfa Land Share: Priority: Interaction Model

	(1)		(2)		(3)	
	Tobit		Frac. Probit: QMLE		Frac. Probit: GEE	
BetwnOTransfer						
Senior	0.2732***	(0.0426)	0.0654***	(0.0199)	0.2534***	(0.0763)
Middle	0.2424***	(0.0334)	0.0567***	(0.0153)	0.2404***	(0.0661)
Junior	0.2123***	(0.0251)	0.0488***	(0.0134)	0.2276***	(0.0612)
SameOTransfer						
Senior	0.3358***	(0.1077)	0.1042***	(0.0321)	0.3874***	(0.1053)
Middle	0.2991***	(0.0932)	0.0902***	(0.0251)	0.3680***	(0.0949)
Junior	0.2629***	(0.0790)	0.0776***	(0.0224)	0.3490***	(0.0932)

Standard errors in parentheses. $^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Note: Marginal effects are estimated under drought with higher alfalfa productivity

Percentage of Water Transferred

We use average marginal effects of all observations to calculate the approximate percentage of water transferred annually. The top panel of Table 9 reports the average marginal effects of the two types of transfers using streamflow, cropland productivity and priority. Thus, these marginal effects are not conditional on specific values we discussed above. By multiplying the average marginal effects of the two transfer options (Table 9) with the mean value of its corresponding transfer practice from Table 2, we obtain the average percentage of water transferred (Table10). The percentage of temporary water transfers ranges from 1.2 to 2.4, depending on transfer type and estimation method, with subtotals in the table referring to the percentages of water received from both types of transfers as ranging from 3.1 to 3.5. Using similar methods, Table 11 shows that in the extreme drought year of 2015, high productivity lands (alfalfa > 4 tons per acre) received 1.6% ~ 8.1% of additional irrigation water from the two types of transfers, with a total additional water received from both types ranging from 8.6% to 10.5%. Between owner transfers appears to be the larger portion of water loans during the extreme drought, while same-owner transfers appear to be slightly more prevalent overall. A plausible explanation is that extreme droughts are sufficiently rate that the costs of transferring perpetual water rights may avoided when lending relationships among neighbors can be counted on in these periods. There is value in the flexibility of such short-term arrangements for the temporary lending out of partial water duties.

To gain perspective on the amount of water transferred in Carson Valley, we compare with benchmarks. In the Carson Valley, the accumulated total permitted and permanent water right transfers occurring since water rights were first claimed over a century ago account for 17.24% of Alpine Decree agricultural water rights (Lee et al. 2020). In California, annual water trades amount to about 3% - 5% of total water used (Hanak and Jezdimirovic 2016; Regnacq et al. 2016; Hanak and Stryjewski 2012). This number, however, includes transfers to other manners of use such as municipal use. The transfers within agriculture, including both temporary and permanent ones, is less than 1.5% in recent years (Hanak and Jezdimirovic 2016; Hanak and Stryjewski 2012). Short-term transfers for all manners of use range from about 20% ~ 80% of annual water trades in California (Hanak and Stryjewski 2012). Thus, 1.5% is an upper bound for temporary within agricultural transfers in California. Comparing with this number, the estimated percentages of unrecorded temporary water transfers in Carson Valley is not smaller than those in California's formal water market.

Table 9. Average Marginal Effects of Transfer Options (Unit:%)

Marginal Effect	Tobit	FP_QMLE	FP_GEE
EQ1			
BetwnOTransfer	0.26203	0.25265	0.26067
SameOTransfer	0.32219	0.40272	0.39836
EQ2			
BetwnOTransfer	0.26205	0.25268	0.26051
SameOTransfer	0.32209	0.40268	0.39829

Table 10. Scale of Unrecorded Temporary Water Transfers (Unit:%)

Transfer Scale	Tobit	FP_QMLE	FP_GEE
EQ1			
BetwnOTransfer	1.2	1.2	1.2
SameOTransfer	1.9	2.4	2.3
Subtotal	3.1	3.5	3.5
EQ2			
BetwnOTransfer	1.2	1.2	1.2
SameOTransfer	1.9	2.4	2.3
Subtotal	3.1	3.5	3.5

Table 11. Scale of Unrecorded Temporary Water Transfers for Productive Land in 2015 (Unit:%)

Transfer Scale	Tobit	FP_QMLE	FP_GEE
EQ1			
BetwnOTransfer	7.2	7.4	8.1
SameOTransfer	1.7	2.3	2.4
Subtotal	8.9	9.8	10.5
EQ2			
BetwnOTransfer	7.0	7.5	8.0
SameOTransfer	1.6	2.4	2.4
Subtotal	8.6	9.9	10.4

6. Conclusions

We demonstrate using a unique set of data and conditions for the Carson Valley in northwestern Nevada, that temporary and unrecorded water transfers between neighboring farms and within lands owned by the same farm operation play a role in improving economic outcomes of water use, with magnitudes of transfers during drought years being in line with that observed in other studies using data from water markets. We consider that much of the previous literature expounding on the importance of the role of formal water markets, while observing fewer transfers than expected, may have missed the role of temporary and unrecorded transfers. Our data is somewhat unique because in the study region, cultivation is not possible without irrigation, so that the satellite image data can be interpreted more cleanly than might be the case in other regions of the west where dryland production may be an alternative during periods of curtailment. However, the general implications should hold for other regions, in which our method of inferring otherwise unobservable temporary water transfers is not feasible.

References

Beck, N. and Katz, J.N., 1995. What to Do (and Not to Do) with Time-Series Cross-Section Data. *American Political Science Review*, 89(3), pp.634-647.

Brown, T.C., 2006. Trends in water market activity and price in the western United States. *Water Resources Research*, *42*(9).

Burness, H.S., and J.P. Quirk. 1979. Appropriative Water Rights and the Efficient Allocation of Resources. *American Economic Review* 69(1): 25–37.

Cameron, A.C., and D.L. Miller. 2015. A Practitioner's Guide to Cluster-Robust Inference. *Journal of Human Resources* 50(2): 317–372.

Carey, J., Sunding, D.L. and Zilberman, D., 2002. Transaction costs and trading behavior in an immature water market. *Environment and Development Economics*, *7*(4), pp.733-750.

Cobourn, K. M., X. Ji,, S. Mooney, and N. Crescenti. 2017. Water Right Seniority, Economic Efficiency and Land Allocation Decisions. *Selected Paper Presented at the 2017 Agricultural & Applied Economics Association Annual Meeting, Chicago, Illinois*. July 30 – August 1, 2017.

Doherty, T., and R. Smith. 2012. *Water Transfers in the West: Projects, Trends, and Leading Practices in Voluntary Water Trading*. Western Governors' Association.

Elbakidze, L., Vinson, H., Cobourn, K. and Taylor, R.G., 2018. Efficient groundwater allocation and binding hydrologic externalities. Resource and Energy Economics, 53, pp.147-161.

Ghimire, N. and Griffin, R.C., 2014. The Water Transfer Effects of Alternative Irrigation Institutions. *American Journal of Agricultural Economics*, 96(4): 970-990.

Griffin, R.C. and Hsu, S.H., 1993. The potential for water market efficiency when instream flows have value. American Journal of Agricultural Economics, 75(2), pp.292-303.

Hanak, E. 2014. Allow Water Rights Trading for Farmers. New York Times. June 29, 2014. https://www.nytimes.com/roomfordebate/2014/06/29/the-water-crisis-in-the-west/allow-water-rights-trading-for-farmers

Hanak, E., and E. Stryjewski. 2012. *California's Water Market, By the Numbers: Update 2012*. Water policy Center, Public Policy Institute of California. Accessed: October 12, 2018, https://www.ppic.org/content/pubs/report/R_1112EHR.pdf.

Hanak, E., and J. Jezdimirovic. 2016. *Just the Fact: California's Water Market*. Water policy Center, Public Policy Institute of California. Accessed: October 12, 2018, https://www.ppic.org/content/pubs/jtf/JTF_WaterMarketJTF.pdf.

Hansen, K., Howitt, R. and Williams, J., 2014. An econometric test of water market structure in the Western United States. *Natural Resources Journal*, *55*(1), pp.127-152.

Hartman, L.M. and Seastone, D. 1970. *Water Transfers: Economic Efficiency and Alternative Institutions*. Baltimore: The Johns Hopkins University Press.

Hendricks, N.P. and Peterson, J.M., 2012. Fixed effects estimation of the intensive and extensive margins of irrigation water demand. *Journal of Agricultural and Resource Economics*, pp.1-19.

Huffaker, R., N. Whittlesey, and J.R. Hamilton. 2000. The Role of Prior Appropriation in Allocating Water Resources into the 21st Century. *International Journal of Water Resources Development* 16(2): 265–273.

Huntington, J.L., and R.G. Allen. 2010. *Evapotranspiration and Net Irrigation Water Requirements for Nevada*. Available at: https://www.dri.edu/images/stories/divisions/dhs/dhsfaculty/Justin-Huntington/Huntington_and_Allen_2010.pdf

Ji, X. and Cobourn, K.M., 2018. The Economic Benefits of Irrigation Districts under Prior Appropriation Doctrine: An Econometric Analysis of Agricultural Land - Allocation Decisions. *Canadian Journal of Agricultural Economics,* 00(2018): 1-27.

Johnson, R.N., Gisser, M. and Werner, M., 1981. The Definition of a Surface Water Right and Transferability. *The Journal of Law and Economics*, 24(2): 273-288.

Lee, G.-E., Rollins, K., and Singletary, L., 2020. The relationship between priority and value of irrigation water used with Prior Appropriation water rights. *Land Economics* 96(3):384-398.

Lefebvre, M., L. Gangadharan, and S. Thoyer. 2012. Do Security-Differentiated Water Rights Improve the Performance of Water Markets? *American Journal of Agricultural Economics* 94(5): 1113–1135.

Li, H. and Zhao, J., 2018. Rebound effects of new irrigation technologies: The role of water rights. *American Journal of Agricultural Economics*, 100(3):786-808. https://doi.org/10.1093/ajae/aay001

Li, M., Xu, W. and Zhu, T., 2018. Agricultural Water Allocation under Uncertainty: Redistribution of Water Shortage Risk. *American Journal of Agricultural Economics*, aay058, https://doi.org/10.1093/ajae/aay058.

Libecap, G.D. 2011. Institutional Path Dependence in Climate Adaptation: Coman's "Some Unsettled Problems of Irrigation." *American Economic Review* 101(1): 64–80.

Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014. Estimated Use of Water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., http://dx.doi.org/10.3133/cir1405.

Moore, M.R., Gollehon, N.R. and Carey, M.B., 1994. Multicrop production decisions in western irrigated agriculture: the role of water price. *American Journal of Agricultural Economics*, *76*(4), pp.859-874.

Morway, E. D., Niswonger, R. G., & Triana, E., 2016. Toward improved simulation of river operations through integration with a hydrologic model. *Environmental Modelling and Software*, 82, pp.255–274.

Olen, B., Wu, J. and Langpap, C., 2015. Irrigation decisions for major west coast crops: Water scarcity and climatic determinants. *American Journal of Agricultural Economics*, 98(1), pp.254-275.

Papke, L.E. and Wooldridge, J.M., 1996. Econometric methods for fractional response variables with an application to 401 (k) plan participation rates. *Journal of Applied Econometrics*, *11*(6), pp.619-632.

Papke, L.E. and Wooldridge, J.M., 2008. Panel data methods for fractional response variables with an application to test pass rates. *Journal of Econometrics*, 145(1-2), pp.121-133.

Regnacq, C., Dinar, A. and Hanak, E., 2016. The Gravity of Water: Water Trade Frictions in California. American Journal of Agricultural Economics, 98(5): 1273-1294. https://doi.org/10.1093/ajae/aaw051.

Sarafidis, V. and Wansbeek, T., 2012. Cross-sectional dependence in panel data analysis. Econometric Reviews, 31(5), pp.483-531.

Townley, J.M. 1980. *Alfalfa Country: Nevada Land, Water and Politics in the 19th Century*. Reno, NV: Agricultural Experiment Station, Max C. Fleischmann College of Agriculture, University of Nevada, Reno.

U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). 2017. Quick Stats. Available at: https://quickstats.nass.usda.gov/

U.S. Department of Agriculture, National Agricultural Statistics Service (USDA-NASS). 2019. CropScape – Cropland Data Layer. Available at: https://nassgeodata.gmu.edu/CropScape/

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS). 2017. Web Soil Survey 3.2. Available at: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

U.S. Geological Survey. 2016. Digitized Map of Alpine Decree. Unpublished Data.

Waskom, R. E. Marx, D. Wolfe, and G. Wallace. 2014. Irrigation Ditches and their Operation. Fact Sheet No. 6.701 Natural Resources Water Series. Colorado State University Extension. 4 pp. https://extension.colostate.edu/docs/pubs/natres/06701.pdf

Western Regional Climate Center (WRCC), 2019. Cooperative Climatological Data Summaries: Minden, Nevada (265191). Accessed: 09/10/2019. Available at: https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv5191

Whittlesey, N.K., and R.G. Huffaker. 1995. Water Policy Issues for the Twenty-First Century. *American Journal of Agricultural Economics* 77(5): 1199–1203.

Wooldridge, J.M., 2010. *Econometric Analysis of Cross Section and Panel Data*. MIT press.

Xu, W., Lowe, S.E. and Zhang, S., 2014. An Analysis of Irrigated Agricultural Outcomes under the Prior Appropriation Doctrine: Hypotheses and Applications. *Applied Economics*, 46(22): 2639-2652.

Young, R.A., 1986. Why are there so few transactions among water users? *American Journal of Agricultural Economics*, 68(5): 1143-1151.

Appendix

Table A.1 Regression Results of Alfalfa Land Share: Basic Model

	(1) Tobit	(2) Frac. Probit: QMLE	(3) Frac. Probit: GEE
BtwnOTrans	0.533^{***}	1.471^{***}	1.540^{***}
	(0.090)	(0.381)	(0.430)
SameOTransfer	0.655^{***}	2.345^{***}	2.354^{***}
	(0.076)	(0.510)	(0.514)
StreamFlow	11.542^{***}	220.430^{***}	41.487^{***}
	(2.886)	(22.614)	(11.131)
Priority	-0.095^{***}	-0.195	-0.094
	(0.027)	(0.143)	(0.148)
Alfalfa Prod	3.734^{***}	10.889^{***}	13.347^{***}
	(1.347)	(3.015)	(3.282)
Size	0.012^{***}	-0.046^{*}	-0.042^{+}
	(0.003)	(0.027)	(0.028)
Slope	-5.517^{***}	-19.578^{***}	-19.413^{**}
	(1.617)	(6.081)	(7.708)
Price Ratio	643.480^{***}	9256.566^{***}	2143.534^{***}
	(119.615)	(893.784)	(450.828)
Dist. River	-0.218	-1.464	-1.560^{+}
	(0.287)	(1.273)	(1.050)
SupWater	-0.008	-0.056	-0.083
	(0.016)	(0.084)	(0.082)
2009.Year	2.681^{***}	39.150^{***}	8.884^{***}
	(0.502)	(3.798)	(1.919)
2010.Year	1.223^{***}	15.466^{***}	3.958^{***}
	(0.189)	(1.439)	(0.727)
2011.Year	-1.466^{***}	-18.781^{***}	-4.621^{***}
	(0.247)	(1.781)	(0.916)
2012.Year	0.333^{***}	6.989^{***}	1.165^{***}
	(0.085)	(0.734)	(0.348)
2013.Year	1.102^{***}	19.184^{***}	3.899^{***}
	(0.247)	(1.927)	(0.940)
2014.Year	1.163^{***}	20.139^{***}	3.706^{***}
	(0.277)	(2.069)	(1.025)
2015.Year	2.479^{***}	38.253^{***}	8.361^{***}
	(0.497)	(3.767)	(1.881)
2016.Year	1.796^{***}	27.544^{***}	6.095^{***}
	(0.363)	(2.703)	(1.344)
Constant	-8.135^{***}	-119.837^{***}	-28.501^{***}
	(1.520)	(11.449)	(5.775)
sigma_u	0.218^{***}		
	(0.011)		
sigma_e	0.189^{***}		
	(0.006)		
N	4770	4770	4770

Standard errors in parentheses

$^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.2 Regression Results of Alfalfa Land Share: Interaction Model

	(1) Tobit	(2) Frac. Probit: QMLE	(3) Frac. Probit: GEE
BtwnOTrans	0.533^{***}	1.472^{***}	1.539^{***}
	(0.095)	(0.381)	(0.430)
SameOTransfer	0.655^{***}	2.346^{***}	2.353^{***}
	(0.190)	(0.510)	(0.513)
StreamFlow	11.379^{***}	220.511^{***}	41.361^{***}
	(4.335)	(22.642)	(11.196)
Priority	-0.095^{***}	-0.195	-0.094
	(0.020)	(0.143)	(0.148)
Alfalfa Prod	3.736^{***}	10.888^{***}	13.349^{***}
	(0.463)	(3.015)	(3.282)
Size	0.012^{*}	-0.046^{*}	-0.042^{+}
	(0.007)	(0.027)	(0.028)
Slope	-5.519^{***}	-19.577^{***}	-19.421^{**}
	(1.498)	(6.081)	(7.707)
Price Ratio	637.861^{***}	9258.667^{***}	2139.439^{***}
	(163.523)	(894.430)	(452.968)
Dist. River	-0.218	-1.464	-1.558^{+}
	(0.410)	(1.272)	(1.049)
SupWater	-0.008	-0.056	-0.083
	(0.016)	(0.084)	(0.082)
2009.Year	2.657^{***}	39.159^{***}	8.867^{***}
	(0.699)	(3.801)	(1.928)
2010.Year	1.214^{***}	15.469^{***}	3.952^{***}
	(0.272)	(1.440)	(0.730)
2011.Year	-1.455^{***}	-18.785^{***}	-4.613^{***}
	(0.331)	(1.782)	(0.920)
2012.Year	0.328^{**}	6.991^{***}	1.161^{***}
	(0.139)	(0.735)	(0.350)
2013.Year	1.090^{***}	19.188^{***}	3.890^{***}
	(0.354)	(1.928)	(0.945)
2014.Year	1.150^{***}	20.144^{***}	3.696^{***}
	(0.380)	(2.071)	(1.030)
2015.Year	2.455^{***}	38.262^{***}	8.344^{***}
	(0.700)	(3.769)	(1.890)
2016.Year	1.779^{***}	27.550^{***}	6.083^{***}
	(0.503)	(2.705)	(1.350)
BtwnOTrans # SameOTransfer #Priority# StreamFlow #Alfalfa_Prod	498.042^{**}	-427.364	331.164
	(235.383)	(700.139)	(954.299)
Constant	-8.063^{***}	-119.864^{***}	-28.448^{***}
	(2.078)	(11.457)	(5.802)
sigma_u	0.218^{***}		
	(0.013)		
sigma_e	0.189^{***}		
	(0.003)		
N	4770	4770	4770

Standard errors in parentheses. $^{+}$ $p < 0.15$, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$