The Relationship between Priority and Value of Irrigation Water Used with Prior Appropriation Water Rights

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ABSTRACT *This article examines the relationship between water right priority and value of use for rights defined by prior appropriation, and tests whether this relationship is different for rights that have been transferred from their original locations to new locations, versus those that have not. We develop an empirical model using data for agricultural irrigation water rights and show that for transferred water rights, more senior (higher-priority) rights are reallocated from lower- to higher-valued agricultural uses. For water rights that remained unchanged, we find that priority order and potential profitability, as indicated by land characteristics, are not well aligned.* (JEL Q15, Q25)

1. Introduction

Agricultural irrigation accounts for the majority of water used in the western U.S., where water rights are defined predominantly by the prior appropriation doctrine (Leonard and Libecap 2016; Maupin et al. 2014).[1] A prior appropriation water right defines (1) the source for the water, with its expected annual yield; (2) the maximum quantity of water that the right-holder may request annually; (3) the specific location where the water may be used; and (4) the priority of the claim relative to all other claims to the same source, *defined by the date that each water right was initially assigned to its original location.*[2] Priorities date back to the mid-1800s when the U.S. west was originally settled, with seniority referred to by date of establishment; in other words, a particular water right is referred to as an "1865 right" or an "1898 right."

Priority determines the order in which claims are filled when available water for a given source is below average annual yield and insufficient to fulfill all claims. Water is delivered first, in full, to lands with the earliest priority dates, and then to lands with sequentially later priority dates. The total amount of water available annually thus determines the "cutoff" priority. Lands with priority rights before the cutoff receive full water claims, while priority rights after the cutoff receive no water, although some may become available through return flows from lands irrigated with more senior rights. As a result, lands with higher-priority rights are, on average, less likely to be affected by drought conditions, while lands with more junior rights generally face more variable water supply and receive

[1] Alaska, Arizona, California, Colorado, Hawaii, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington, and Wyoming follow the prior appropriation doctrine (Leonard and Libecap 2016).

[2] Two other rules associated with prior appropriation are "use it or lose it," whereby a water right unused for a period of time is forfeited; and "beneficial use," whereby the governing water authority may alter a water right if deemed beneficial to society. These rules have evolved so that the former is rarely used against agricultural water right holders (Doherty and Smith 2012), and the latter includes support of ecosystem services (Libecap 2011).

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on average less water (Burness and Quirk 1979; Libecap 2011).

In order that water be used in its highest-valued uses during periods of drought, and because water right seniority is not necessarily aligned with expected value for water used in the locations where those rights were initially established, most states permit the transfer of water rights from one location to another, as long as such transfers do not adversely affect third parties or pose significant environmental harm. Transfers of priority between locations is expected to improve welfare by realigning priority with the value of water used (Burness and Quirk 1979).

This article examines the relationship between water right priority and use value for a surface water source and tests whether this relationship is different for rights that have been transferred from their original locations to new locations, versus those that have not. There is little previous empirical evidence regarding the effectiveness of permitted transfers of priority to increase social welfare. We develop an empirical model using data from Carson Valley, Nevada, and show that for transferred water rights, more senior rights are, on average, reallocated from lower- to higher-valued agricultural uses, resulting in welfare improvements. For water rights that remained unchanged, however, we find that priority order and potential profitability, as indicated by land characteristics, are not well aligned.

Previous empirical studies (see, e.g., Libecap 2011; Grafton et al. 2012) quantify benefits of water transfers between different types of use, rather than values of transfers between locations for the same use (e.g., irrigation), and do not consider priority differentials. Lefebvre, Gangadharan, and Thoyer (2012) use a lab setting to demonstrate that priority-differentiated water rights increase expected profits in water allocation and water rights markets. The few econometric studies that include priority use it as an independent variable and show that seniority is associated with increased crop revenue (Xu, Lowe, and Zhang 2014), irrigation infrastructure investment (Leonard and Libecap 2016), and the overuse effect induced by the "use it or lose it" rule (Li and Zhao 2018).

Processes to verify no third-party injury can be costly and time-consuming, particularly if others protest a proposed transfer (Libecap 2011; Doherty and Smith 2012; Edwards and Libecap 2015). While the no-harm rule is intended to prevent external costs, the costs involved to verify no third-party harm may prevent higher-priority water rights from moving from lower- to higher-valued agricultural land uses (e.g., Whittlesey and Huffaker 1995; Huffaker, Whittlesey, and Hamilton 2000; Libecap 2011; Harris 2013). Huffaker, Whittlesey, and Hamilton (2000) note that policies that lower costs of transferring water rights between locations could improve allocation efficiency without the welfare redistributions and losses associated with more extensive institutional changes, as described by Libecap (2011) and Young (1986). We do not examine the costs of transferring water rights. Instead, we examine how transfers influence the relationship between priority and value of water use, thereby shedding some light on the potential gains from transfers. Our result, that priority and value are not well aligned for water rights that have not been transferred, suggests room for future research. This includes, for example, examining policies intended to facilitate transfers to improve welfare, including efforts to reduce costs of determining third-party effects and negotiations to mitigate such effects, should they arise.

We use data from the Carson Valley, Nevada, where the Carson River is the main source for agricultural water rights, the maximum quantity of water per acre assigned to each water right is more or less constant across all water rights, and transfers are not permitted to increase this amount per acre. Of the four prior appropriation water right characteristics described above, permitted transfers in the valley affect two: location of use and priority order. There are only two primary crops in the valley, grass hay and alfalfa, both of which require irrigation. Data that describe potential yields indicate that individual parcels favor either grass hay or alfalfa, but not both; that is, yields are negatively correlated. Further, while alfalfa is the higher-valued crop, historical circumstances led to comparatively more junior priority rights being assigned to the best alfalfa land, and the more

Table 1
Water Rights Transferred from the 496 Original Locations, with Priority Dates

Priority Date Ranges	Number of Water Rights as Initially Established	Number of Water Rights Transferred	Percent Transferred
1852–1860	100	20	20.0
1861–1870	122	21	17.2
1871–1880	119	17	14.3
1881–1890	60	15	25.0
1891–1900	73	17	23.3
1901–1916	22	4	18.12
Total	496	94	19.0

Source: Data from Alpine Decree (U.S. v. Alpine Land and Reservoir Co. et al.; Civil D-183, U.S. District Court, Nevada, 1980), NDWR (2017), and USGS (2016).
Note: Wald test results suggest no differences between priority groups, significant at the 95% confidence level.

senior rights assigned to lands best for grass hay. These features allow us to identify the relationship between priority and value of use for water rights that have been transferred and those that have not been transferred to new locations.

2. Study Area, Priority Agricultural Water Rights, and Locations of Use

Flowing eastward from the Sierra Nevada range, the Carson River is the primary agricultural irrigation water source in Nevada's Carson Valley. Overall, the water rights regime is representative of prior appropriation doctrine in other western states (Horton 1996). Carson Valley surface water rights were first established in 1852 and were fully appropriated by 1916, with 496 individual water rights claims on parcels of varying acreages located throughout the valley (Shamberger 1991).[3] Table 1 shows that 341 of the 496 original water rights (almost 69%) were claimed before 1880. Of these, 58 water rights were subsequently moved to new locations. The map in Figure 1 shows the 2010 locations of agricultural irrigation water rights and priority dates in Carson Valley, with lighter shading indicating more senior rights and darker shading indicating more junior rights (NDWR 2017; USGS 2016).

Variation in Flow Rates and Cutoff Priorities

The Sierra snowpack is the source of the Carson River. Annual fluctuations in winter precipitation and spring temperatures produce considerable variation in timing and quantity of Carson River flow rates throughout the spring and summer. As with other western surface water systems, Carson Valley irrigation district managers endeavor to deliver water according to priority by holding water behind headgates and then releasing it when sufficient flow volume or "head" is attained to move it the desired distance. Thus, the amount of water received at each location is determined in part by upstream flow rates and priorities, the amount of water available at various times within an irrigation season, and the force of gravity. Historical stream flow rates, measured regularly throughout each season using gauges throughout the Carson River system, show that between 1936 and 2015, annual stream flows fell below average in 44 out of 79 years, with flows in the lowest 10th percentile for 14 of the 79 years (USDA-NRCS 2019). As a result, cutoff calls frequently affect the more junior water rights.[4] Morway, Niswonger, and Triana (2016) develop a spatial model that overcomes practical difficulties by calibrating stream flow records for water allocated to each water right.[5] Their

[3] Resource constraints have limited issuance of supplemental groundwater permits over the last several decades.

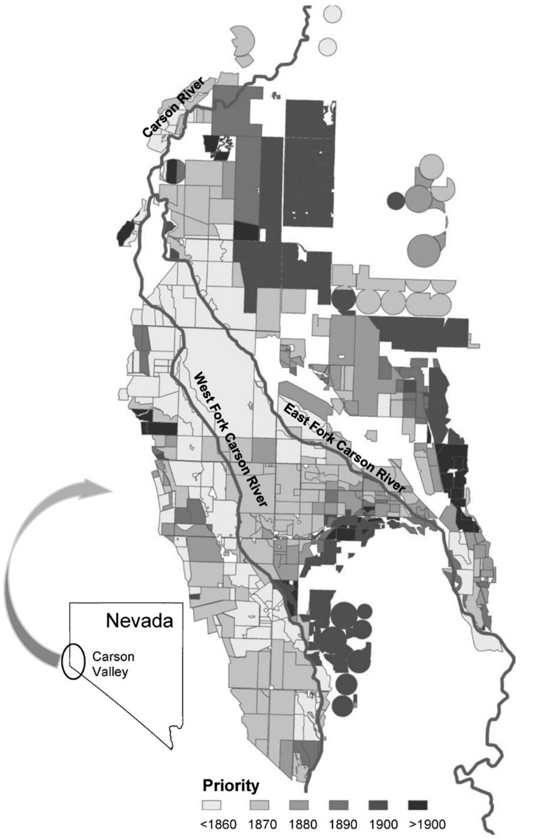
[4] E. James, Director, Carson Water Subconservancy District, personal communication, July 31, 2019.

[5] While streamflow rates and cutoff calls are highly correlated, there is substantial variation in flow rates, and thus cutoff calls, within a given year, between years, and in dif-

Figure 1

Water Right Locations and Priority Dates (Lighter Shading Corresponds to More Senior Priorities)

Source: Data from NDWR (2017) and USGS (2016).



model simulates the quantity delivered to each water right location in the study area. Their results approximate the impacts of cutoffs by estimating which water rights would have received no water during a 35-year simulation period based on flows from 1981 to 2015. Their results indicate that 23% of Carson Valley water rights established after 1890 would have experienced curtailment in 3 or more years out of 35 years. As explained below, this is also the period in which much of the land best suited for alfalfa production was claimed and water rights on these lands established. In particular, the simulation showed 23% (5% 0%, 1%, 7%) of water rights established after 1890 (and during 1880–1890, 1870–1880, 1860–1870, 1852–1860) would have experienced curtailment in at least 3 or more out of the 35 years.

ferent locations across the valley. Water delivery records for individual water rights and locations exist as handwritten logs, most of which do not explain why the quantity of water delivered to each location was less than its prescribed maximum amount; lower amounts may be the result of a cutoff call for that part of the river, or the producer may have called for less water due to other circumstances (Ed James, Director, Carson Water Subconservancy District, personal communication, July 31, 2019).

Crop Yields, Water Value, Priorities, and Transfers

The valley's two main crops are grass hay and alfalfa.[6] The maximum allowable amount of irrigation water that can be claimed is limited to a constant number of acre-feet per acre across the valley, and water rights transfers are not permitted to increase this entitlement beyond the set limit.[7] Therefore, total irrigable acreage in the valley is fixed.

Alfalfa was not introduced to Carson Valley until the late nineteenth century, after the majority of water rights had already been claimed (Horton 1996; Townley 1980). The more senior water rights were established on lands closest to the river for grass pastures using flood irrigation. Townley (1980) points out that with livestock as the earliest primary agricultural product, settlers would have favored land with good pasture productivity and river access.[8] Alfalfa, on the other hand, prefers well-drained soils located farther from

[6] In 2012, alfalfa and all other hays represented 92.43% of cropland in the county where the study area is located (USDA-NASS 2017). Oher minor rotational crops are cultivated as a necessary part of alfalfa production.

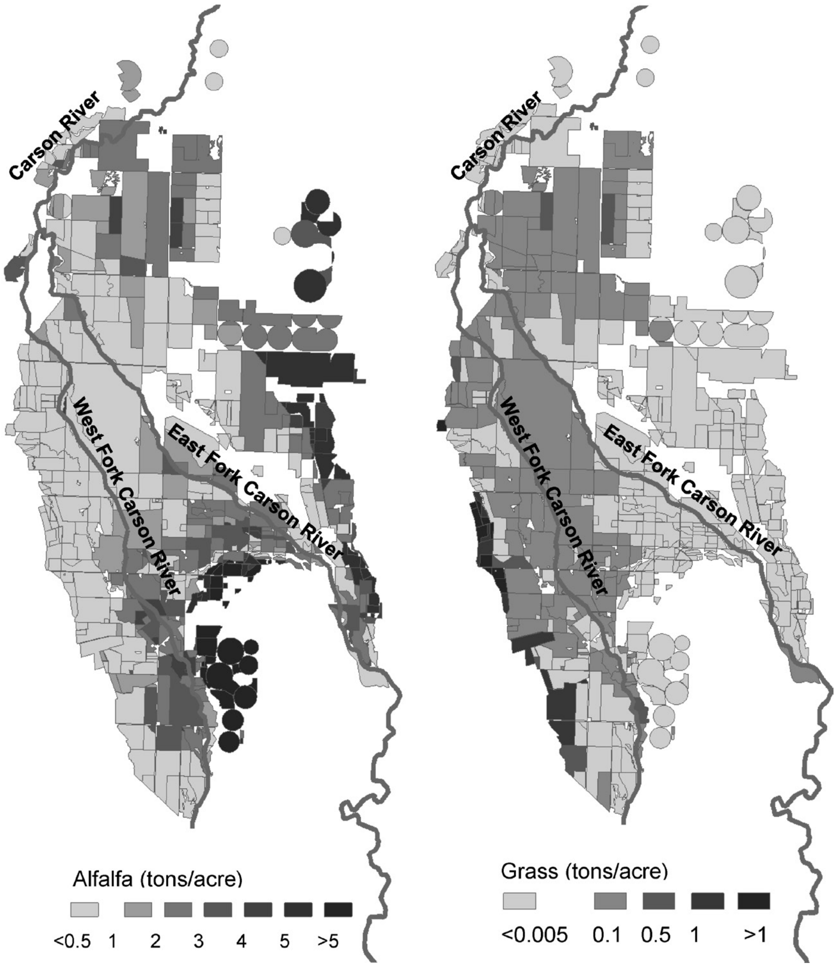
[7] The Carson Valley's constant amount of water per acre is set out in the Alpine Decree (United States v. Alpine Land and Reservoir Co. et al.; Civil D-183, U.S. District Court, Nevada, 1980; available at http://www.cwsd.org/wp-content/uploads/2014/07/AlpineDecree.pdf.) and the Nevada Revised Statutes § 533.3703 (2011) and is defined in accordance with beneficial use requirements, with the annual per acre irrigation requirements for alfalfa and grass hay in the valley being nearly identical (Huntington and Allen 2010). While per acre consumptive use for each crop is similar across the region, nominal quantity of water receivable by each water right may vary due to slope and soil conditions.

[8] Libecap and Hansen (2002), Hansen and Libecap (2004), and Crifasi (2016), among others, have argued the case that as European emigrants, early settlers of the region were unfamiliar with the arid western climate and would therefore

Figure 2

Potential Yields for Alfalfa *(Left)* and Grass Hay *(Right)* for Water Rights in the Carson Valley

Source: Data from NDWR (2017), USGS (2016), and USDA-NRCS (2017).



the river (Kettle, Riggs, and Davidson 2000). Investments in networks of ditches eventually extended irrigation infrastructure to these lands, where relatively more junior water rights were established for alfalfa cultivation (Townley 1980; Shamberger 1991).

Figure 2 illustrates *potential* yields (in tons per acre) for alfalfa and grass hay for lands in the Carson Valley, obtained from USDA-NRCS (2017) crop yield maps for the Carson Valley.[9] We overlay the GIS layers for crop yields with 2010 water rights boundaries (NDWR 2017; USGS 2016). For water rights boundaries that span more than one NRCS crop yield prediction, we calculate weighted average potential crop yields for each water right location. Figure 2 shows that lands with higher potential alfalfa yields are located farther from the river, while lands closer to the river and between the river forks show higher yields for grass hay. Figure 3 shows average land productivity for alfalfa and grass hay, by water right priority.

have lacked sufficient information to accurately pair the most profitable lands with senior water rights.

[9] NRCS uses soils, landscape, climate, and other data for the region to estimate potential crop yields based on observed data for crop yields from other lands with similar characteristics.

Figure 3

Average Alfalfa and Grass Hay Potential Yields for Water Right Priority Date Ranges and Number of Water Rights

Source: Data from NDWR (2017), USGS (2016), and USDA-NRCS (2017).

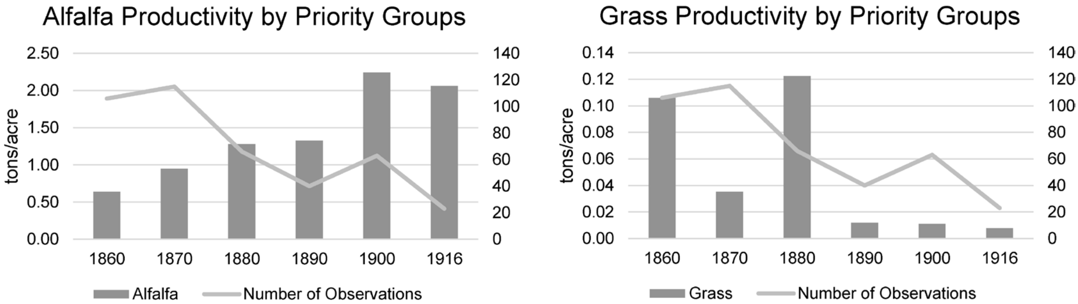


Figure 4

Grass Hay versus Alfalfa Potential Yields on All Land Parcels with Water Rights

Source: Data from Web Soil Survey (USDA-NRCS 2017).

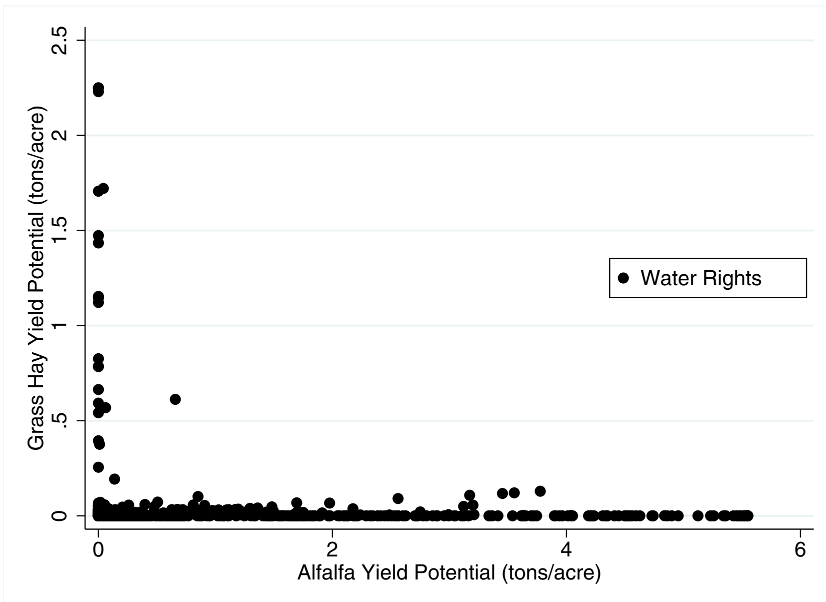


Figure 4 shows the relative productivity for alfalfa (horizontal axis) versus grass hay (vertical axis) for each location to which a water right is attached. We see that each location is higher yielding in either alfalfa or grass hay, with few locations showing similar yields for both, aside from observations with very low yields. Together, these data illustrate that more senior water rights were established initially on lands better suited to grass hay, while relatively more junior rights were established on lands better suited to alfalfa.

Alfalfa eventually came to be the major cash crop for Carson Valley, sold today mainly to out-of-state markets, while grass hay remains largely as pasturage for local livestock production.[10] Lands in the valley most suitable for alfalfa yield about twice as many tons per acre of alfalfa relative to grass hay (USDA-NRCS 2017). The protein content of alfalfa is about twice that of grass hay

[10] Townley (1980) describes late-nineteenth century changes leading to alfalfa surpassing grass hay production.

(Balliette and Torell 1993). For almost every year between 1972 (when data are first available) and 2016, the average alfalfa price per ton was higher than that for grass hay in Nevada (USDA-NASS 2017). Introduced later to the valley, alfalfa production was made possible by (1) switching from grass hay on land that already had water rights but was not as well suited for alfalfa, (2) through establishment of very junior rights on new locations best suited for alfalfa, or (3) through the transfer of senior water rights from lower-valued locations in the valley to new locations in the valley. Because land characteristics that favor highest yields for each crop are strongly negatively correlated, simply switching from grass hay to alfalfa on lands with senior rights may have been less profitable in some locations than incurring the costs to transfer senior rights to lands better suited to alfalfa. Additionally, the value of moving a senior water right to new land with high alfalfa yield potential may have been greater than the value of establishing a much more junior water right on that same land.

We identify the relationship between priority and potential profitability of the location where water is used for water rights that have and have not been transferred to new locations through a set of features unique to the study area. These are (1) a constant water duty per acre for all irrigated lands, (2) only two crops grown, representing lower and higher potential values, and (3) negatively correlated yields for each location to where the most senior water rights are initially allocated with lands with a lower-valued crop (grass hay), with more junior rights allocated to a higher-valued crop (alfalfa).

3. Estimation Approach

Our major interest is in the relationship between priority and irrigation water use values, and how this differs for water rights that have been transferred to new locations and those remaining in their original locations. Each observation represents a water right i, with a dummy variable indicating whether it has been transferred. We predict priority as a function of the agricultural value of water used at each location, proxied by soil and land characteristics. We hypothesize transfers have aligned water right seniority with potential value, and expect these to be more closely aligned for transferred rights, relative to rights that have not been transferred.

We use a linear regression model, equation [1], where dependent variable $Priority_i$ is the year the claim was established, from 1852 to 1916. A negative coefficient on an explanatory variable therefore indicates that a one-unit increase contributes to more senior priority, while a positive coefficient implies more junior priority:

$$Priority_i = \alpha + \boldsymbol{\gamma}\mathbf{Z}_i + \boldsymbol{\beta}\mathbf{X}_i + T_i(\boldsymbol{\gamma}_{\mathrm{T}}\mathbf{Z}_i + \boldsymbol{\beta}_T\mathbf{X}_i) + \delta T_i + u_i. \quad [1]$$

Water rights that have been transferred are indexed by T_i, where $T_i = 1$ for observation i if the water right was transferred (the location is different from where it was initially established), and $T_i = 0$ for observations with water rights that have not been transferred. We interact T_i with other independent variables to capture heterogeneous effects on water right priority. Noninteracted coefficients capture effects influencing initial establishment.

$\mathbf{Z}_i$ is a vector denoting potential yields for grass hay and alfalfa for each water right location. Potential yield is used to approximate the profitability differential at that location depending on which crop is grown. We expect the coefficient of alfalfa productivity for $\boldsymbol{\gamma}_T$ to be negative, because with permitted transfers, we expect the more senior rights (earlier priority dates) to be associated with lands with higher alfalfa yields. Vector $\mathbf{X}_i$ represents factors other than crop yields that influence profitability, described in more detail in the data section below.

The last term, u_i, in equation [1] is unobserved error. We use three models to address correlations in error terms potentially arising from two types of clusters within subgroups of our data, as described in detail in the last part of the data section below. The three models are an ordinary least squares (OLS) model with cluster robust variance-covariance estimators (CRV), a random-effects (RE) model, and a mixed-effects (ME) model. The latter two methods can be applied to nonrepeated

Table 2
Description of Variables for 2010 Water Rights ($N = 413$)

Variable	Description	Mean	Std. Dev.	Min.	Max.
Priority (year)	Year established	1874	15.80	1852	1914
Alfalfa (tons)	Average tons/acre alfalfa	1.22	1.52	0	5.55
Grass (tons)	Average tons/acre grass hay	0.06	0.27	0	2.25
Dist_River (meters)	Distance to river	1,192	1,090.1	3	6,454
Sup_Source (number)	Number of supplemental groundwater permits	0.50	0.93	0	5.00
WestFork (0/1)	West fork of the Carson River = 1	0.32	0.47	0	1.00
M_Carson (0/1)	Main Carson River = 1	0.04	0.20	0	1.00
LandSize (acres)	Acres associated with water right	81.08	140.4	0.45	1,683
Transferred (0/1)	Permitted transfer to this location = 1	0.14	0.35	0	1.00

observations clustered by groups, as suggested by Cameron and Miller (2015). The CRV and RE models address only one cluster level, while the ME model addresses two-level clusters. We provide further details regarding our empirical methods to address clusters in Appendix Section A.1.

4. Data

Our data include priority year, location, geophysical characteristics, and potential yields for alfalfa and grass hay at the location to which each water right is attached in 2010. Table 2 displays the variables used in our analyses. We determined which water rights had been transferred at least once by comparing GIS data for each right as it was initially established, as documented in the Alpine Decree (USGS 2016), with its location and boundaries in 2010 (NDWR 2017).[11] We use 2010 for our "current" water rights locations because the approval process for transferring a water right from one location to another in the Carson Valley can take up to five years. Our data include a small number of water rights with open transfer permit applications dated 2011 and later that had not yet been certified. We treat these as remaining at their 2010 locations.

[11] The Alpine Decree documents the locations of water rights as they were first established. While a water right may change its location several times since its establishment, the NDWR (2017) system includes only digital records for the most recent location. Most of the historical records are handwritten, making it extremely difficult to trace the path of individual water rights and transfers over time.

The third column of Table 1 shows that of the original 496 water rights established between 1852 and 1916, 19% were transferred out of agriculture by 2010, suggesting that a total of 413 remained in agriculture. Table 1 also illustrates the challenges with identifying precisely which water rights were transferred. Of the 402 original water rights not transferred out of agriculture, some were subsequently split with land sales. In these cases, an original parcel with a single water right was subdivided into smaller parcels, and each of the smaller parcels retained the original priority date, with a maximum water amount claimable based on the proportion of land in the subparcel. Through many iterations of this process over time, by 2010 there were a total of 413 water rights. Of these, 57 were transferred from their original locations to new locations. These 57 water right transfers are associated with lands that account for 17.24% of the total land area and 13.8% of observations. Because most of the historical records are handwritten, making it difficult to trace individual transfers over time, our data do not include the dates of transfers, locations from where water rights were transferred, nor whether multiple transfers occurred for a single water right.

Potential Yields

We use yield potentials for alfalfa and grass hay (*Alfalfa* and *Grass* in Table 2) as proxies for relative differences in land profitability. As explained above, we generate potential yields for alfalfa and grass hay by overlapping 2010 water right boundaries with USDA-NRCS (2017) Web Soil Survey layers, which provide predicted potential yield per acre by crop based on soils and landscape characteristics. We use satellite land use data (NDWR 2017) to identify land area that was paved, devoted to buildings, and otherwise clearly no longer used for irrigated agricultural production, which we omitted from the cultivated acreage for each water right location.

Other Factors Affecting Productivity

We use distance to the river (*Dist_River*) to represent variation in receivable return flows. We expect land closer to the river to have greater potential for receiving return flows from irrigated lands at higher elevations. Since the majority of lands in the valley are flood-irrigated and lands closer to the river are at lower elevations, this implies greater potential for receiving water from return flows from irrigated lands at higher elevations. We expect a negative sign on this coefficient without transfers, and a positive sign for its interaction term with transfers.

We include *Sup_Source*, the number of supplemental groundwater well permits associated with each water right location. While the majority of irrigation water in the Carson Valley is sourced from Carson River surface flows, agricultural water right holders may apply for permits to drill wells to access and use groundwater only when the surface water cutoff priority date precedes the priority date associated with the water right. Landowners bear the costs of drilling these wells and investment in irrigation technology to utilize supplemental groundwater. Multiple permits are required for larger parcels. The mean size of land areas for water rights with supplemental groundwater permits is twice that of water rights without supplemental permits. We expect a negative sign on *Sup_Source*, since the larger farms are presumably more reliant on alfalfa income and have the capital to invest in drilling wells. Recall, supplemental groundwater wells cannot be used to increase claimable water amount, only to provide some water during curtailment.

As illustrated by the maps in Figures 1 and 2, the Carson River separates into two forks, creating three river segments: Main River, East Fork, and West Fork. Irrigation water delivery is managed in three subdistricts according to these subunits. We create three variables to control for differences in water management by segment. In our regression models, the East Fork serves as the base, while *M_Carson* and *WestFork* identify the other two segments with which a water right is associated.

Acreage associated with each water right varies considerably in the Carson Valley. Total acreage of each water right parcel in 2010, $LandSize_i$, approximates unobserved owner endowments and/or access to capital. We expect more senior water rights to be associated with larger owner endowments (a negative sign).[12]

Common Point of Diversion and Owner Clusters

As is typical for surface water rights to many western rivers, irrigation ditch networks deliver surface water from various points of diversion on the river. A headgate at each point of diversion on the river controls the timing and amount of surface water delivered to lands through ditch networks. Shared headgates indicate shared infrastructure to move water to a new location, shared maintenance costs, and potentially cooperative water management practices among water rights holders, causing systematic correlation in our data. To control for these effects, we include the point of diversion for each water right in our data.

Our data also include several sets of adjacent parcels with different priority dates owned by a single agricultural operation. The choice for water right priority among these adjacent locations may differ from the nonadjacent parcels and those involving multiple owners. As the need for more senior rights is relevant only during drought years, single

[12] The data describe acreage of 2010 parcels to which water rights are attached. As noted by a reviewer, it may not be reasonable to consider acreage as a proxy for endowment during original establishment of water rights in the West. Relative to land grants in the Midwest, which were restricted to 160 acres (Libecap and Hansen 2002; Hansen and Libecap 2004), cash purchases of settlement lands west of the 100th meridian carried no acreage restrictions or residency requirements (Hibbard 1939), allowing for the acquisition of land tracts of varied sizes during settlement on which to establish water rights (Libecap 2007; Hibbard 1939).

Table 3
Regression Results for 2010 Water Rights Transferred to New Locations

	OLS-CRV	RE	ME
Alfalfa	2.829*** (0.533)	2.773*** (0.504)	2.442*** (0.469)
Grass	–5.139** (2.477)	–4.762* (2.443)	–4.170* (2.443)
Dist_River	0.007*** (0.001)	0.007*** (0.001)	0.007*** (0.001)
Sup_Source	–1.045+ (0.711)	–1.233+ (0.778)	–1.023 (0.774)
WestFork	–7.443*** (2.339)	–7.931*** (2.162)	–9.381*** (1.892)
M_Carson	–8.438* (4.995)	–8.265+ (5.101)	–6.983 (5.481)
LandSize	–0.014*** (0.004)	–0.012*** (0.004)	–0.009** (0.004)
Transferred	20.786*** (6.430)	20.556*** (5.986)	18.773*** (5.661)
Alfalfa_T	–3.534** (1.360)	–3.558*** (1.276)	–3.414*** (1.139)
Grass_T	6.295* (3.689)	4.399 (3.806)	0.932 (4.170)
Dist_River_T	–0.006*** (0.001)	–0.006*** (0.001)	–0.005*** (0.001)
Sup_Source_T	–11.043*** (3.458)	–9.607*** (3.374)	–7.931** (3.560)
WestFork_T	–19.618*** (6.861)	–17.282** (6.797)	–12.099* (6.947)
M_Carson_T	–15.796** (7.244)	–15.859** (7.059)	–15.623** (7.243)
LandSize_T	0.041*** (0.013)	0.036*** (0.013)	0.027** (0.014)
Constant	1,867.536*** (2.054)	1,867.732*** (1.951)	1,868.216*** (1.774)

Note: Variables interacted with *Transferred* are indexed with *_T*. Cluster robust standard errors are reported in parentheses in the OLS column. Heteroskedasticity robust standard errors are in parentheses in the RE and ME columns. Cluster is defined by common-owner cluster in the OLS-CRV and RE estimators. In the ME model, headgate is nested under common-owner groups. All models are jointly significant at the 0.01% level. ME, mixed effects; OLS-CRV, ordinary least squares with cluster robust variance-covariance estimators; RE, random effects.

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

owners of multiple parcels might temporarily reallocate water across their own parcels on an as-needed basis, instead of taking on the costs of a permanent permitted transfer. The optimal choice of water right priority of adjacent parcels thus may generate correlations in the data.

In either case, such circumstances that influence costs of water right transfers between locations within a single point of diversion, or for a single owner, suggest decisions within these groups may be correlated. For the purpose of this article, we refer to groups of adjacent parcels with a single owner as "common-owner clusters" and groups with a common point of diversion as "headgate clusters," with variables to identify these in our data.

The Appendix contains details concerning the two types of clusters in our data. Summarizing Appendix Table A.1, the frequency of water rights sharing a headgate range from a maximum of 66 water rights within a single point of diversion to 33 water rights with points of diversion shared with no other water rights. After 66, the next largest number of water rights clustered within a single point of diversion is 15, followed by 14, 12, 11, and 10. A total of 33 points of diversion service single water rights, followed by 15 points of diversion in which there are only 2 water rights, and 10 with just 3 water rights. As for water rights with common-owner clusters, 117 are not in common-owner clusters. The greatest numbers of water rights within a single-owner cluster is one cluster each with 22, 16, and 13 water rights.

5. Results

Our results show that priority and value of water use are aligned for water rights that have been transferred to new locations, but not for those that remain in their original locations, suggesting that transfers serve to align higher-value agricultural lands with more senior water rights. Table 3 reports coefficient estimates from equation [1]. Results using headgate clusters and common owner clusters are so similar that the we report only the OLS-CRV and RE results with common-owner clusters. For the ME model two-level clusters, the common owners are assumed to be the higher-level cluster and point of diversion as the lower-level cluster.[13]

Looking at variables without interaction—that is, for water rights that have not been transferred—the negative coefficients for grass hay yields (*Grass*) suggest seniority aligns with grass hay productivity, while the positive coefficients for alfalfa yields (*Alfalfa*) suggest potential misalignment between water use value and seniority. The positive coefficient on *Dist_River* indicates, as expected, that for rights that have not transferred, farther distance from the river is associated with more junior rights.

The coefficients on *Transferred* alone show that, all else equal, lands with transferred water rights have 18.8 to 20.8 years more junior priority, significant at the 99% confidence level, depending on the model used. That is, all else equal, transferred water rights are relatively more junior than those not transferred, indicating obstacles for transferring senior water rights. Third parties are more likely to oppose a transfer of the most senior water rights on the basis that such transfers can impact the original order of water deliveries on the river and alter return flows receivable (Johnson, Gisser, and Werner 1981; Bretsen and Hill 2009).

Looking at variables interacted with *Transferred* suggests that transfers have aligned priority with value, as approximated by potential yields and other land characteristics. Grass hay productivity for locations with transferred water rights, *Grass_T*, is no longer significant in explaining priority allocation, except for the OLS-CRV model, in which the estimate is slightly above the 90% significance level. Instead, the coefficients for alfalfa productivity conditional on transfer, *Alfalfa_T*, are all negative at the 95% confidence level, suggesting that a one-unit increase in potential alfalfa yield per acre on lands receiving transfers contributes to 3.41 to 3.53 years of increase in seniority of water rights transferred.

The negative sign on the coefficient for *Dist_River_T* suggests that greater distance of the new locations from the river lead to obtaining more senior rights, consistent with expectation of lower return flows. The small positive coefficient of *LandSize_T* implies that a one-acre increase in land parcel size is associated only slightly with more junior priority. One explanation for this result is that a larger operation faces greater challenges in obtaining senior water rights through permitted transfers, because a larger amount of water involved may increase the possibility of negatively impacting other water right holders.

Whether a water right has been transferred or not, one additional permit for supplemental groundwater (*Sup_Source* and *Sup_Source_T*) contributes to a more senior water right. These results are consistent with the observation that farms with the capacity to expand production prefer more senior water rights. We further verify that the transfer effects are robust to the supplemental water source by allowing it to interact with *Grass_T* and *Alfalfa_T*. Appendix Section A.4 describes in detail this triple interaction model and its results. Overall, our conclusions remain unchanged for observations without supplemental groundwater permits. We find that with greater alfalfa productivity, a farmer who is permitted to pump supplemental groundwater when surface water flows are insufficient may be indifferent to seeking a more senior water right. We find also that that one additional supplemental groundwater permit enlarges the permitted surface water transfer effect by associating more senior priority with greater alfalfa productivity.

Potential Gains from Permitted Water Transfers

Because our data do not track specific water rights as they were transferred between locations over time, we estimate welfare gains from transfers by comparing estimated annual agricultural revenues between two sets of observations: (1) parcels where water rights were initially established, but no longer have water rights as of 2010, and (2) parcels with water

[13] In the ME effects model, the variance-covariance structure of the unobserved constant intragroup effect is set to be exchangeable so that correlation between lower-level clusters is allowed with a constant covariance term. We check for robustness by altering assumptions regarding cluster choice and variance-covariance and residual structures, and find similar results, which are available from the authors upon request. Additional analyses concerning effective cluster numbers and potential spatial autocorrelation are provided in Appendix Sections A.2 and A.3.

rights in 2010 that were transferred from other locations. Among the locations where water rights were initially established, a total of 6,366 acres no longer have agricultural water rights as of 2010. Water rights associated with 592 acres were transferred out of agriculture in the Carson Valley prior to 2010, leaving water for 5,774 acres (91% of the 6,366 acres) bundled in 57 individual water rights remaining in agriculture to have been transferred to new locations in the Carson Valley. Of the 57 water rights transferred for agricultural use, two are associated with lands having senior water rights that were swapped with lands having junior water rights. The remaining 5,774 acres to which water rights were transferred did not have rights before 1916; that is, without transfers, these lands could not have been brought into irrigated agricultural production.

We first calculate potential annual yields for the old locations totaling 6,366 acres and the new or transferred locations totaling 5,774 acres, using yield potential data for each parcel from the USDA-NRCS (2017) Web Soil Survey. Irrigation intensity is irrelevant in this region, because the yields for alfalfa and grass hay in the area are based on similar water use (Huntington and Allen 2010). For a fair comparison, we use 91% of the yields from the lands where water rights originated, to account for water rights that were transferred out of agricultural use. We calculate revenues in the old and new locations using 2010 Nevada prices of $126/ton for alfalfa and $116/ton for grass hay. We assume each producer makes crop decisions based upon whichever of the two crops would yield greater revenues for each parcel. We thus obtain annual revenues of $1,044,637 if water rights were used in the old locations, and $1,484,681 if used on new (2010) locations, for a 42% increase in revenues. The 5,774 acres of new lands amount to 17.24% of total irrigated acreage (33,486 acres) and 29.44% of the total revenue. We calculate the total revenue in the same manner for all 2010 lands with water rights, including lands where there were no water rights transfers.

We note that this estimate is likely to be conservative since our calculation does not account for the benefit from transfers that prevent losses in alfalfa production during drought years nor for marginal lands that are likely fallowed during drought years. This ballpark estimate does, however, provide a reference point for economic outcomes that demonstrate the potential benefit from permitted transfers that align priority with land use values.

Limitations and Future Research

Our analysis to predict seniority of water rights as a function of value of water use for rights that have and have not been transferred is somewhat limited by data constraints. First, time-series dynamics are not observable in our data. Therefore, we are not able to estimate the improvements to production by tracking location changes for each water right over time. Also, the data do not capture water reallocation through temporary transfers of water between locations, and therefore the observed permitted transfer effects represent conservative results.

In addition, we cannot test hypotheses related to increased numbers of transfers occurring in more recent years with increasing occurrences of realized annual water supply falling below expected yields. This would be of interest given that the region has been experiencing warmer annual mean temperatures, less mountain snowpack, earlier peak snowmelt rates, and reduced soil moisture—factors that each contribute to less available surface water for irrigation.

Finally, our data do not include water rights transferred to nonagricultural uses and/or to other basins. As theory and indirect evidence from water trades generally suggest efficiency improvements from these types of transfers, our results capture only the outcomes of within-basin transfers intended for agricultural use, resulting in a conservative assessment.

6. Conclusions

This article empirically investigates the relationship between priority and value for water rights defined by the prior appropriation doctrine, where transfers allow for relocation of priority rights. We use a unique data set that includes water right geographic boundaries and priorities as they were established with the settlement of the Carson Valley in northwestern Nevada, and as they are over a century later in 2010, to explore the role of permitted transfers between locations in aligning priority with profitability of water rights. Our results show for our study area, for agricultural irrigation water rights that have been transferred to new locations, priority and profitability are well aligned; however, such alignment is not the case for water rights that remain in their original locations. We estimate the welfare gain attributable to the transferred water rights, relative to them staying in their original locations, to show that the transfers increased crop revenue by roughly 42%.

Our findings provide empirical evidence that suggests permitted transfers of water right location and priority can provide flexibility to align and redirect limited and variable irrigation water resources to higher-valued uses. We find also that for rights that had never been transferred, there was no discernable alignment between priority and value. This lack of alignment by itself does not necessarily imply that rights not transferred are not currently in their highest-valued uses, but it does not rule out that the costs of transfers and permitting may impede further welfare gains. Actions to facilitate and/or reduce costs associated with the water transfer application and permitting process may enhance welfare further. This includes developing more cost-effective methods to estimate how consumptive use and net return flows might change due to proposed transfers, as a measure of third-party injury (Johnson, Gisser, and Werner 1981; Bretsen and Hill 2009). Steps to reduce water rights transfer costs also include facilitation of negotiated outcomes to address potential third-party injuries. Additional steps that could lead to further transfers include investments in river-basin-scale hydrologic studies to identify the extent to which future water transfers may induce third-party injury or environmental damage and means to mitigate such damage.

Libecap (2011) points out that overly vague no-harm standards for transfers can generate additional transaction costs that ultimately limit transfers. Yet, unexpected third-party impacts from transfers can arise due to previously unknown hydrologic anomalies or as a result of a changing climate. Transfers that inadvertently generate externalities and subsequent conflict due to lack of conjunctively managed surface and groundwater supplies also can lead to presumptions that prior appropriation performs poorly as an allocation institution (Huffaker, Whittlesey, and Hamilton 2000; Libecap 2011).

As climate change and population growth continue to stress water supplies across the western United States, the efficiency of prior appropriation water allocation, as compared with alternative water allocation institutions, will continue to be a major discussion point. However, adopting and transitioning to alternative water allocation institutions that alter entitlements may lead to welfare redistributions that are not well understood and may be socially undesirable. Our analyses suggest that water allocation efficiency of water rights under the prior appropriation doctrine may be improved by facilitating transfers of water right location of use and priority ordering, while reducing costs associated with proving that such transfers will not cause third-party effects, and negotiated mitigation. Alternative institutions that transfer water rights without adhering to no-harm criteria cannot guarantee a net improvement in water allocation efficiency.[14] Priority is likely to play a larger role in areas of the West where fluctuations in winter mountain snowpack and increasingly early warming trends for spring temperatures may lead to occurrences of curtailments of agricultural water for water rights with increasingly earlier priority dates. This may lead to requests for further transfers from lower- to higher-valued locations, as well as increasing third-party effects from such transfers.

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[14] The correlated rights doctrine may be an exception (Edwards and Libecap 2015) but can be implemented only for water resources managed as a common pool.

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