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Institutional Adaptation to Water Scarcity in Utah Irrigation Companies

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INSTITUTIONAL ADAPTATION TO WATER SCARCITY
IN UTAH IRRIGATION COMPANIES

by

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ABSTRACT

Institutional Adaptation to Water Scarcity

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A review of how water institutions in the American West have changed in response to arid conditions as a means of examining the possibility of further change as an adaptation to climate change induced water scarcity. Two institutions are examined, prior appropriation and shares.

While much of the American West operates under prior appropriation formally, irrigators have found Coasian methods of lowering transaction costs by forming irrigation companies. Irrigation companies own appropriative rights and redefine them, typically as shares. Lower transaction costs allow irrigators to trade more freely within companies, though trades between companies still face high transaction costs.

Using a dataset of Utah's 1100+ irrigation companies collected from the Utah Division of Water Rights, I measure the extent to which these companies have internalized transaction costs. Because most, if not all, irrigation companies transform appropriative rights into some form of shares, regions facing more water scarcity should be more likely to manage water by using shares rather than appropriative rights. I test the hypothesis that an increase in water scarcity makes trade more valuable and thereby increases the relative opportunity costs of managing a river through appropriative rights versus shares. (40 pages)

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Grant Patty

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"The Coasean solution to a Coasean property rights problem is the firm, and the settlers of the West turned to the firm [...] to reduce transaction costs associated with irrigation." (Bretsen & Hill, 2006, p. 286)

"By the very act of organizing into larger groups, individuals can often gain considerable political power over state and federal water policy." (Thompson, 1993, p. 681)

Much of the literature on water institutions in the American West has focused on both the innovative efficiencies and path-dependent inefficiencies of prior appropriation (Johnson, Gisser, & Werner, 1981; Libecap, 2007, 2011; Leonard & Libecap, 2017; Edwards & Libecap, 2015; Heinmiller, 2009). The transaction costs from beneficial use and multiple owners of return flows have been well documented (Burness & Quirk, 1979, 1980; Bretsen & Hill, 2009). A focus on how the formal, legal institutions that govern water impose transaction costs is incomplete without examining how irrigators have innovated institutional arrangements that reduce these transaction costs. The most important of these institutional arrangements are irrigation companies and irrigation districts.

Although some scholars have turned their attention to irrigation companies and districts, there is a lack of quantitative work that tests how these institutions have been created as a response to the arid conditions that increase the transaction costs of prior appropriation. The following is a test of the hypothesis that irrigators in Utah have created institutions that reduce transaction costs as a response to the state's arid climate. The empirical analysis presented here offers evidence that this is the case.

INSTITUTIONS FOR GOVERNING WATER

How Institutions Change

Like other resources, water is managed through institutions, which Nobel Laureate Douglass North (1991) defined as the "humanly devised constraints that structure political, economic and social interaction" (p. 97). Institutions that manage water structure how people are able to obtain, use, and trade water. Property rights, like other institutions, are often established out of a need to encourage investment by reducing uncertainty over who has the right to use resources. Frequently, the process of establishing of property rights involves negotiation and contracting among the many users of the resource (Libecap, 1989). In other cases, property rights are imposed by higher-level institutions.

The outcome of this process can produce long-lasting constraints on the plausible choices available to future users of the resource. North (1990) argues that institutions can have considerable staying power as people adapt to them. Adaptation includes learning how the institution works and what opportunities are available. Entrepreneurs, both economic and political, pursue opportunities afforded by current institutions. When these opportunities depend on the continued existence of the institutions that created them, entrepreneurs can become vested interests who devote resources into preserving the institutional status quo. This process of institutions creating space for interests that protect them can make long-standing institutions exceptionally difficult to change, a state often termed “institutional lock-in” (Garrick, Whitten, & Coggan, 2013; North, 1990).

When change does come, it is frequently sparked by changes that come from outside the institutions themselves. These changes can be described as price shocks, because they change the opportunity cost, or price, of preserving the institutional status quo. Potential sources of price shocks can include new technologies, climate and environmental change, or demographic and cultural shifts. When the potential opportunities offered by alternative institutions become greater than the costs of maintaining current institutions, entrepreneurs have an incentive to invest in institutional change (Edwards & Libecap, 2015).

Importantly, it is not enough for alternative institutions to offer superior sets of opportunities. The benefits of the new institutions must be greater than the benefits offered by current institutions after the costs of transitioning to the new institution are accounted for. Institutional “lock-in” can substantially increase the costs of changing institutions (Garrick, Whitten, & Coggan, 2013).

Institutional change is difficult to achieve and there is no guarantee that it will be beneficial. Considerations of costs and benefits to change only matter to those who have the ability to cause change, or in price terms, those who can afford to invest in the costs of changing the institution. The public choice model of “politics as exchange” illustrates that lower-level institutional change, when pursued within a set of political institutions, is subject to the constraints imposed by politics. This leaves open the real possibility that price shocks may not always lead to beneficial institutional change when short-sighted policymakers, an uninformed public, and vested interest groups have the ability to exploit price shocks for their own benefit.

How Water Institutions Have Evolved

Property rights over water have been the primary institution used to allocate water resources in the American West. Property rights can be defined in many different ways, however, and not all ways of defining them are equally well suited to every environmental or economic goal. Accordingly, how water rights are defined matters a great deal in determining how people will use, or not use, water resources, which in turn determines how their economies and communities grow and develop.

Property rights over water have taken many forms, but three ways of defining water rights, riparian rights, appropriative rights, and water shares, have been used widely throughout the English-speaking world. Accordingly, these three institutions will be compared here. The effects of path dependence mean that understanding the possibility of institutional change requires understanding how these institutions were developed in the first place. Two regions are particularly instructive, the American West and Australia's Murray-Darling Basin, as both redefined property rights over water from riparian rights to either appropriative rights or water shares (Heinmiller, 2009). The different approaches taken by each country resulted in differing abilities to capture gains from trade (Grafton, Libecap, Edwards, O'Brian, & Landry, 2012) and respond to drought (Garrick, Whitten, & Coggan, 2013).

Riparian Rights

Riparian rights are a fairly simple way to structure water use. Under this institution, anyone who owns land adjacent to a stream has the right to withdraw as much water as they need from a stream so long as they do not impact the ability of other similarly-adjacent users to do the same. Riparian rights were developed in the relatively wet climate of England and are a traditional feature of English common law. As the British colonized other parts of the world, including Australia and North America, they brought with them their legal institutions, including riparian rights.

In a climate where water is abundant, riparian rights can work fairly well. If precipitation is frequent and bodies of water are common, then most users will have access to ample water. In more arid regions, however, the requirement that all water users be adjacent to the source of the water they use makes riparian rights ill-suited for economic growth and development. This was the problem faced by the colonizers of the American West. While the eastern United States had enough water abundance for riparian rights to be viable, the arid western landscape did not. Precipitation was rare, rivers were few and far between, and water was often needed far from where it was available. In response, the colonizers developed a new institution, prior appropriation, which evolved from private decentralized agreements that eventually were formally codified.

Prior Appropriation

Property rights for water, as defined by prior appropriation, guarantee the owner a fixed volume of water (typically measured in acre-feet[1]) so long as all others whose rights have priority receive their full allocation first. The priority of these rights is ordered by seniority, in the order in which they were established by diverting water from the source. Along a given source of water, such as a river, rights that were created from early diversions are referred to as "senior" water rights, and those that were created from later diversion are referred to as "junior" water rights. Because those at the front of the line receive their full quantity first, they are generally likely to receive their allocation even under drought conditions, while those at the end may be lucky to ever see any water at all.

Gary Libecap, and others, have extensively traced the origins of prior appropriation rights in the American west (Libecap, 2007; Libecap, 2011; Leonard & Libecap, 2017). Early colonizers of the western US faced climate and governance conditions entirely unlike what they had experienced in the eastern half of the country. The semi-arid climate required diverting water to where it would be used, often over long distances. This was especially true for industries like mining, where water was needed far from the only available sources. Not surprisingly, miners were some of the first water users to abandon riparian rights in favor of prior appropriation.

The change from riparian rights to prior appropriation was rapid and greatly contributed to the American West's economic development. Prior appropriation gave entrepreneurs confidence that investments they made would be secure. It allowed the creation of contracts and trade among the new colonizers, facilitating discovery of the

[1] An acre-foot is enough water to cover an acre of land in a foot of water, or about 325,851 gallons.

most productive uses of the region's natural resources (Leonard & Libecap, 2017). As more people moved to the region, emerging state governments codified prior appropriation rights, endowing the privately developed institution with the force of law.

Water Shares

The British colonizers of Australia faced similar challenges as the those in the American West. Riparian rights were not a useful way to define property rights in the dry climate of Australia. Change only materialized after a number of factors came together in the 19th century, including urban populations unable to easily obtain the water they needed through riparian rights, rural settlers facing conflicts over who had the right to use water, and miners making heavy use of water in the mid-century gold rush (Ward, 2009).

These conflicts came to a head in the 1886 *Irrigation Act*, which granted each state full ownership and control over water within its boundaries. The act rejected both riparian rights and prior appropriation, which had been established in the western US by this time, in favor of centralized administration of water (Ward, 2009). Users were granted privileges, known as entitlements, to appropriate a certain percentage of the yearly flow, but were unable to sell or trade these entitlements without also selling the land where the water was used. States issued entitlements to private individuals and organizations guided by an explicit goal of maximum water resource utilization and economic development (National Water Commission, 2011).

Prior appropriation was developed in the mid 19th century before state and federal governments had the ability to project power and enforce contracts over the large areas of the west. The relatively low enforcement costs required by prior appropriation made it an attractive institution. In contrast, Australia remained a British colony during this time and did not reform its institution of riparian rights until the end of the 19th century. By that time the government had the ability to monitor water usage, and could therefore centralize water allocation, something that was not possible in the middle of the century in western North America.

An Australian-style, centralized institution in the American West was unlikely, given the conditions and technology available at the time of its colonization. As Libecap (2011) notes, "Defining water rights in terms of shares rather than in fixed, diverted quantities would have required knowledge of total flows, information only more recently available" (p. 76). In Northian terms, defining property rights over water as a percentage of the seasonal flow, as Australia did, did not lie within the American West's "opportunity set".

The decentralized property rights developed in the American West differed fundamentally from the centralized institutions developed in Australia's Murray-Darling basin. After abandoning riparian rights, the new Australian "rights" were not really rights at all, and their name, entitlements, reflected this. They did not allow the owner to modify, sell, or exchange them without also modifying, selling, or exchanging the land to which the rights were attached. They were little more than the permission for an owner of a particular piece of land to use a certain amount of water on that land (National Water Commission, 2011). American water rights, on the other hand, often separated the ownership of land from the use of water. While American water rights remained usufructuary, they could be modified, sold, and exchanged separately from the land on which they were used.

Eventually a series of intense droughts combined with diminishing returns from additional dams forced Australia to change water entitlements to water shares. This was accomplished through a series of reforms that unbundled water use from land and encouraged trade. The modern Australian water market is now one of the most active in the world. It is unlikely that Australia's successful wholesale institutional transformation can be replicated in the American West, however. Australia's National Water Commission (2011) has noted that the centralized institution of water resource management became "a significant precursor to the later establishment of clearly specified and tradable water entitlements because it gave government the power to limit total extractions and to define relatively homogenous rights to the resource" (p. 20). A complete transformation to a water market based on shares may be more difficult when "each right is different and location-specific," (National Water Commission, 2011, p. 20) as are rights in the American West.

TRANSACTION COSTS OF PRIOR APPROPRIATION

Adaptation of the American West's water institutions happened in a much more local, private way, than Australia's complete overhaul. Institutional change was driven by incentives to reduce the transaction costs inherited from prior appropriation. These costs include unequal distribution of risks from drought, rules allowing third-party users to block changes in water use if it would affect their water right, and in some cases, the legal doctrine of beneficial use. The primary way these issues have been addressed is by associations of users contracting to form private irrigation companies, and later by voting to form public irrigation districts. These organizations purchased appropriative rights and redefined them, typically as shares. Redefining appropriative rights to shares alleviated many of the transaction costs inherent in prior appropriation, at least within the organizations. Consequently, water trade in the American West within irrigation companies and districts (where transaction costs have been internalized) is more common in than the formal rules of prior appropriation allow (Grafton, Libecap, Edwards, O'Brian, & Landry, 2012).

Beneficial use, colloquially known as "use-it-or-lose-it", stipulates that water can only be used for a "beneficial" use as defined by the state. This was originally developed to protect from speculators diverting an entire water source with the sole intention of selling it back to later users at a monopolistic price. If a user does not put their water right toward a use that the state designates as beneficial, the state revokes the right. This has the unintentional effect of encouraging wasteful uses of water and discouraging investments in efficiency, as water users cannot sell the water saved through conservation efforts.

Because under prior appropriation water rights are prioritized in order of seniority, holders of junior rights face more risk from drought than holders of senior rights (Burness & Quirk, 1979; Burness & Quirk, 1980). Shares, on the other hand do not face this problem. While allowing competitive markets under prior appropriation can theoretically, in the long-run, see users trading this risk in a way that results in the same risk distribution as shares, other aspects of prior appropriation, including rules that protect holders of rights from third-party effects, make this uncommon in practice (Johnson, Gisser, & Werner, 1981).

The inability to trade stems primarily from users that have rights over return flows. Most uses of water do not consume all, or even most, of the resource. Water that is not consumed generally flows back to the source from which it was diverted. Other appropriators can then divert the return flows back from the source and incorporate it as part of their own water right. If the original appropriator changes their use of water, by selling it to another user, for example, any user whose right includes the return flows will lose their use of that water, and is therefore legally entitled to challenge the sale. As the American West developed over time, many overlapping and interconnected rights were created. This has been described as a “tragedy of the anticommons” (Bretsen & Hill, 2009), in which many users all have a property right over the same resource, preventing any change from occurring without the consent of all users.

There is likely no single best approach to overcome this problem. While one possible solution is to redefine water rights from the amount diverted to the amount consumed, this may encourage users to engage in uses that consume more water, and as environmental law scholar Barton H. Thompson Jr. (1993) notes, “states would need to calculate the return flows of *all* water rights *immediately* in order to quantify the consumptive rights - a tremendous administrative chore that no state would want to undertake without a compelling reason” (p. 707).

Much of the water literature has focused on changing the formal rules of the game, such as eliminating beneficial use requirements, for example. Unfortunately, these reforms are surface-level, and do not consider how local institutional innovations have circumvented the formal limitations on water markets (Thompson, 1993). It remains a possibility that in regions that have largely internalized the transaction costs of prior appropriation, that legal reforms, while potentially beneficial, could do little to change the actual opportunities and constraints faced by water users.

HOW IRRIGATION COMPANIES INTERNALIZE TRANSACTION COSTS

American water rights began as a decentralized system of property rights, and cannot easily transition to the more efficient institution of shares as a result. As Libecap (2011) argues about the western American development of water institutions:

> The institutions that emerged to facilitate agriculture in response to the region's aridity raise the costs today of reallocating water to higher-valued uses and of flexibly responding to hydrological uncertainty due to climate change [...] these institutional restrictions on markets illustrate how past arrangements to meet conditions of the time constrain contemporary economic opportunities. They cannot be easily significantly modified or replaced ex post. (p. 66)

Furthermore, Edwards and Libecap (2015) argue that "A shift from prior appropriation to shares is unlikely to be widespread in the US West unless water becomes much more valuable" (p. 468), and that "Only when the costs of the current arrangement become so high that the status quo is no longer tenable will the rights system be changed voluntarily" (p. 469). This is why obstacles to trade have been primarily overcome in a decentralized way through the formation of irrigation companies.

The first private organizations to develop irrigation infrastructure were what Bretsen and Hill (2006) refer to as "commercial" irrigation companies. They were often speculative ventures that invested heavily in constructing the infrastructure required to irrigate an area, with the expectation of charging monopolistic prices to the future irrigators that would settle on the land served by the infrastructure. Commercial irrigation companies were frequently backed by Eastern investors with little knowledge or expertise in the difficulties of Western irrigation. As farmers began irrigating with water purchased from commercial irrigation companies, many of these companies began to charge exorbitant fees or engage in predatory business practices toward those whom they believed were captive customers. Bretsen and Hill (2006) cite an observer who noted that commercial irrigation companies could sell land to a farmer, provide water while the farmer improved their property for a few years, briefly cut off water to kill the farmer's crop, and then confiscate and resell the improved property when the farmer failed to make their water payments. These short-term practices eventually destroyed commercial irrigation companies when their customers realized they had both monopsony power to refuse to purchase water, and political power to effectively outlaw commercial irrigation companies (Bretsen & Hill, 2006).

Commercial irrigation companies financed much of the irrigation infrastructure that developed the American West, but collapsed when they were unable to efficiently manage and operate their own irrigation systems. In an effort to overcome the free-rider problems that came with irrigation infrastructure, farmers formed mutual irrigation companies to construct, maintain, and administer that infrastructure. Bretsen and Hill (2006) argue that mutual irrigation companies were successful at "reducing or eliminating transaction costs in areas where the commercial irrigation company had failed" (p. 302). Mutual irrigation companies (referred to as simply "irrigation companies" for the remainder of this paper) acquired appropriative water rights, either from other companies or from the members themselves, and redefined those rights as shares. These shares often did, and still do, represent a single acre-foot of water that can be traded freely. Thompson (1993) notes that irrigation companies with plentiful water supplies are more likely to have regulations that can discourage trade, but as water becomes scarcer, or as the opportunity costs of not allowing trade increases, they tend to find innovative ways of lowering transaction costs.

Thompson (1993) argues that two important characteristics of irrigation companies drove their adoption: ownership by the water users and vertical integration. Local control enabled the water users to incorporate local knowledge about their region's particular geographic, climatic, or social attributes in their custom-designed "rules of the game". Vertical integration, an ownership structure where the users of water are also the owners of the infrastructure that delivers it, allowed irrigators to avoid facing potential monopoly pricing from the only source of nearby irrigation.

Towards the beginning of the 20th century, irrigators began to form, with the blessing of state and local governments, larger public organizations known as irrigation districts. Irrigation districts had many of the features of mutual irrigation companies but with added powers that included "eminent domain, the power of taxation, the power to issue bonds, and exemptions from state and federal income taxes" (Bretsen & Hill, 2006, p. 316). As the federal Bureau of Reclamation began constructing large irrigation projects, including dams and pipelines, it contracted with irrigation districts who gained exclusive distribution rights to Reclamation water. Today, irrigation districts deliver water to both individual water users and to irrigation companies who then reallocate the water to their members.

METHODOLOGY

My hypothesis is that irrigation companies will have control over more water in regions that are more arid. Theoretical work by Burness and Quirk (1979; 1980) and Johnson, Gisser, and Werner (1981) demonstrated that, along a river managed by prior appropriation, an increase in water scarcity increases both the value of trade and the relative opportunity costs of managing a river through appropriative rights rather than through shares. Because most, if not all, irrigation companies transform appropriative rights into some form of shares, regions facing more water scarcity should be more likely to manage water by using shares rather than appropriative rights. In other words, because the transaction costs of prior appropriation are greater in more arid regions, these same regions should have internalized transaction costs to a greater extent.

I use a series of OLS regressions to test if this is the case. To do this, I use three dependent variables. The first is the average acre-feet owned by a company in a county, and the second and third are market concentration indices defined in terms of acre-feet and irrigated acres, respectively. The independent variable of interest is the yearly average precipitation in a county.

Utah has 29 counties. All data was aggregated by county, so each county is a single observation in the following tests. Summary statistics for Utah can be found in table 1.

Table 1

Utah Counties Summary Statistics

Variable	N	Mean	St. Dev.	Min	Max
Precipitation	29	19.307	9.181	6.560	47.140
Population	29	101,472.500	225,743.800	1,117	1,091,742
Acre-feet per Company	29	3,877.724	5,691.112	0.000	25,898.130
Acre-feet - HHI	29	5,089.620	3,233.563	0.000	10,000.000
Acreage - HHI	29	4,825.514	3,493.896	0.000	10,000.000
Subsidy per Farm	29	8,007.724	4,192.045	2,371	20,572
Farm Sales	29	116,528.000	190,123.800	17,906	1,041,519
Median Farm Size	29	75.103	114.081	6	623
Farm Value	29	994,920.800	442,714.100	452,336	2,606,137
Acre Value	29	2,428.138	1,636.627	374	6,484
BoR Projects	29	0.828	1.537	0	6

The three dependent variables were derived from data collected from the Utah Division of Water Rights database of irrigation companies. Each irrigation company has a page on which several attributes of the company are recorded, including the county (or counties) and water right area (or areas) in which they operate. Also included are the main source of the company's water, the number of irrigated acres serviced by the company, the number of shares issued, the contact information for the operators and owners of the company, and a list of all water rights owned by the company.

Attributes of the individual water rights include the priority date, source, and amount, defined as either a quantity (acre-feet) or flow (defined as cubic feet per second).

The total acre-feet or CFS controlled by a company can be calculated by adding these rights together.

Frequently, an irrigation company's DWR page will contain comments from DWR employees. These comments often spell out the unique forms of governance used by the company. The DWR also occasionally indicates if a company has been sold to another company or is defunct. Utah has roughly 1100 irrigation companies, but almost half of these companies are listed as owning no rights, issuing no shares, and irrigating zero acres. I did not include these companies in the calculations to create the dependent variable. Also omitted from the data were the eight irrigation companies that span more than one county.

The three dependent variables are intended to test how much irrigation companies in a county have internalized transaction costs. Because this is difficult to observe directly, I use three dependent variables as proxies for transaction cost internalization. The first dependent variable, acre-feet per company, was calculated by adding the acre-feet of every irrigation company in a county and then dividing that by the total number of irrigation companies in that county. In other words, this variable measures the average quantity of water (defined as acre-feet) controlled by an irrigation company in a county. If it is the case that as this measure increases that transaction costs have been more internalized, then this variable can serve as a proxy.

The second and third dependent variables are based on the Herfindahl-Hirschman Index (HHI), a common measure of market concentration. It works by taking the market share of all companies in an industry (40% market share = 40, for example), squaring them, and then adding them. The final value is a number between 0 and 10,000. Values between 1,500 and 2,500 are considered by the US Justice Department to be "moderately concentrated", and values greater than 2,500 are considered "highly concentrated" (United States Department of Justice, 2015).

Two HHIs are used as the second and third dependent variables. One defines market share as the percentage of acre-feet controlled by an irrigation company in a county, and the other defines market share as the percentage of irrigated acreage in a country that is served by an irrigation company. The market shares of each irrigation company in a county are then squared and summed to create a total HHI for the county. In the context of irrigation companies, if a higher HHI value is correlated with a higher degree of internalization of transaction costs, then these variables can serve as proxies. In other words, the more concentrated the market for water is in a few irrigation companies, the more transaction costs of prior appropriation have been internalized.

The main independent variable of interest, precipitation, was calculated by adding the monthly average precipitation in a county to get a yearly total average. Snow inches were converted to rain inches by dividing the total by 10, a commonly accepted conversion rate (Madaus, 2010). This is the variable of interest because a negative relationship between precipitation and the three previously discussed implies an association between aridity and the need to internalize the transaction costs of prior appropriation.

The other independent variables are the population of each county; subsidy per farm, or the value in government funds received by the average farm in the county; the median farm size, in acres; farm sales, or the value of sales of all agricultural products for the average farm in a county; the estimated total value of the average farm in a county, including land and building values; and the estimated value of the average farm acre in a county, also including land and building values and finally, the number of dams built by the Bureau of Reclamation in a county.

Population was chosen as an independent variable because counties tended to be settled in greater numbers when they had more water available. This data was collected from the State of Utah's 2014 estimates (Governor's Office of Management and Budget, 2015). The number of dams built by the Bureau of Reclamation was included because irrigation companies may depend on Reclamation water through contracts with irrigation districts. This data was collected from the Bureau of Reclamation (Bureau of Reclamation, 2018).

The financial variables, including subsidy per farm, median farm value, farm sales, farm value, and acre value are all intended to test for an association with the value of farms in particular regions with irrigation company control of water. It is possible that the value of farms in a region motivate the internalization of transaction costs, not precipitation. Finally, the median farm size is included because some agricultural activity, such as cattle ranching, can require less water but more land, which may affect the decision to place water in under the control of irrigation companies. The financial and farm size data was collected from the USDA 2012 Census of Agriculture (United States Department of Agriculture, 2012).

Tables 2, 3, 4, and 5 are regression tables that show the results of these tests. Table 2 shows all three dependent variables regressed against all of the independent variables. Table 3 shows eight regressions with the dependent variable acre-feet per company and the independent variable precipitation, along with a single additional independent variable. This process is repeated in tables 4 and 5, with the Herfindahl-Hirschman Index (HHI) defined in terms of acre-feet as the dependent variable in table 4, and the HHI defined in terms of acreage as the dependent variable in table 5. Robust standard errors were used in all regressions.

Table 2

Average County Acre-feet per Company, County HHI Defined as Acre-feet, and County HHI Defined as Acreage

	Acre-feet per Company	Acre-feet - HHI	Acreage - HHI
Precipitation	-329.353**	-121.586**	-140.134*
	(124.259)	(57.105)	(72.686)
Population	0.004	-0.003	-0.002
	(0.003)	(0.002)	(0.002)
Subsidy per Farm	0.218	0.139	-0.125
	(0.253)	(0.196)	(0.219)
Median Farm Size	-7.701	0.626	-9.511
	(10.696)	(5.820)	(6.600)
Farm Sales	-0.007	0.005**	-0.005**
	(0.004)	(0.002)	(0.003)
Farm Value	-0.003	-0.003*	0.005**
	(0.003)	(0.001)	(0.002)
Acre Value	-0.807	-0.275	0.159
	(0.838)	(0.316)	(0.402)
BoR Projects	386.213	-474.667*	-756.841**
	(428.588)	(242.060)	(325.433)
Constant	13,647.590***	9,974.389***	5,806.062***
	(4,693.480)	(1,987.600)	(1,770.344)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 3
Average County Acre-feet per Company

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Precipitation	-258.469**	-269.470**	-258.999**	-289.705**	-318.832**	-290.611**	-237.473**	-279.940**
	(114.327)	(119.858)	(117.726)	(127.447)	(128.598)	(122.545)	(107.649)	(104.732)
Population		0.002						
		(0.001)						
Subsidy per Farm			-0.016					
			(0.180)					
Median Farm Size				-10.519*				
				(5.372)				
Farm Sales					-0.010**			
					(0.004)			
Farm Value						-0.003***		
						(0.001)		
Acre Value							-0.328	
							(0.544)	
BoR Projects								554.434*
								(300.888)
Constant	8,867.960***	8,909.508***	9,010.185**	10,261.050***	11,191.430***	12,796.330***	9,259.259**	8,823.660***
	(3,017.212)	(3,094.952)	(3,555.811)	(3,558.769)	(3,542.739)	(3,905.613)	(3,347.615)	(3,000.781)
Note:								*p<0.1; **p<0.05; ***p<0.01

Table 4
County HHI Defined as Acre-feet

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Precipitation	-180.147***	-163.815***	-179.059***	-182.341***	-161.766***	-188.299***	-162.679***	-164.100***
	(47.837)	(46.633)	(48.818)	(50.709)	(50.583)	(49.950)	(51.009)	(52.305)
Population		-0.002*						
		(0.001)						
Subsidy per Farm			0.034					
			(0.135)					
Median Farm Size				-0.739				
				(3.425)				
Farm Sales					0.003**			
					(0.001)			
Farm Value						-0.001		
						(0.001)		
Acre Value							-0.273	
							(0.265)	
BoR Projects								-414.363*
								(233.959)
Constant	8,567.702***	8,506.016***	8,275.527***	8,665.561***	7,860.200***	9,563.975***	8,893.244***	8,600.810***
	(1,082.186)	(1,055.738)	(1,448.820)	(1,212.795)	(1,266.321)	(1,481.946)	(1,233.457)	(1,132.598)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5
County HHI Defined as Acreage

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Precipitation	-151.515***	-145.370***	-151.830***	-150.525***	-162.688***	-135.163**	-145.080**	-128.331**
	(50.881)	(51.733)	(50.500)	(52.681)	(53.951)	(52.768)	(58.635)	(56.505)
Population		-0.001						
		(0.001)						
Subsidy per Farm			-0.010					
			(0.132)					
Median Farm Size				0.333				
				(3.707)				
Farm Sales					-0.002			
					(0.002)			
Farm Value						0.002*		
						(0.001)		
Acre Value							-0.101	
							(0.337)	
BoR Projects								-598.653**
								(248.463)
Constant	7,750.798***	7,727.587***	7,835.398***	7,706.633***	8,180.877***	5,752.196***	7,870.722***	7,798.631***
	(1,139.275)	(1,149.388)	(1,290.042)	(1,252.833)	(1,278.526)	(1,603.312)	(1,227.985)	(1,172.905)

Note: *p<0.1; **p<0.05; ***p<0.01

RESULTS

In every regression, precipitation is negatively correlated with the dependent variables, meaning that a decrease in the average precipitation of a county is associated with an increase in the average acre-feet controlled by a company, as well as an increase in a county's Herfindahl-Hirschman Index defined in terms of acre-feet and acreage. Not all regressions show the same degree of significance, nor do they show the same magnitude of effect. All have the same direction for the coefficient on the precipitation variable, however, and in all cases but one the precipitation variable is significant to at least $p<0.05$, and in the single exception it is significant to $p<0.1$.

The differences between the regressions appear to be mainly driven by the choice of dependent variable. The most robust dependent variable appears to be the HHI defined in terms of acre-feet, as all but one of the regressions that use this variable are significant to $p<0.01$. This result makes theoretical sense, as HHI defined in terms of acre-feet represents what is traded in irrigation companies (water), as opposed to HHI defined in terms of acreage. HHI defined in terms of acre-feet also makes use of a technique that places greater importance on the presence of large firms, as opposed to the dependent variable acre-feet per company, which is just a simple average.

The results suggest that aridity may have an effect on the opportunity cost of prior appropriation relative to shares, and is empirical evidence that supports the conclusions of prior theoretical work suggesting that transaction costs increase under prior appropriation when water is scarce. This, however, is not the only possible explanation for the data. Ownership of water may be more concentrated in drier regions if water itself is more concentrated in a few sources.

A better statistical test would look at how ownership of water rights has changed over time, but historical streamflow data can be wildly inconsistent from year to year, and water rights data can be incomplete, making a time series analysis unlikely to yield meaningful results.

DISCUSSION

As stated earlier, irrigation companies have found many unique ways of internalizing the transaction costs associated with prior appropriation. While they typically redefine their water rights as shares, the particular rights associated with owning a share vary from company to company. Shares can represent a quantity of acre-feet, a percentage of a water source's flow, or a quantity of time to access a source at a defined flow rate. Additionally, irrigation companies may have unique ways of allocating their water locally.

The Utah Division of Water Rights publishes information about each individual irrigation company, including occasional notes left by DWR employees that detail the unique ways that water rights are defined within the company. For example, in a note about the Ricks Creek Irrigation Company, an employee recounts a phone conversation with the company president:

> There are two sides to the creek: North and South. Weber Basin WCD owns most of the South side water. The LDS church owns some South side water, Bill Rigby owns 80 shares North side, his brother owns about 24 shares, or hours, North, or something like that. [...] George has some stock, probably 24 hours, but they can't find the certificates (Utah Division of Water Rights, 2012).

Local knowledge appears crucial to the management of some irrigation companies. This includes local knowledge about the layout of water infrastructure, as implied by this comment on the Henefer Irrigation Company:

> [T]he company`s shares are worth 3 acre-feet each; usually when someone hooks up to the city water they turn over a third of a share valued at 1 acre-foot; and the number of shares in the company is 975. [...] I see the slight inconsistency with this valuation compared to the 1157.5 acres the water right says it is worth, but I guess the difference is made up on the ground with the availability / unavailability of water and the need for some carriage water to stay in the ditches to the end of the line (Utah Division of Water Rights, 2011).

Many companies issue shares that change depending on the streamflow, such as the East Bench Canal Company (Utah Division of Water Rights, 2014). Others issue different classes of shares with more or less exposure to drought risk, as does the La Sal Irrigation Company, whose acre-feet per share amounts are dependent on the yearly runoff (Utah Division of Water Rights, 2016a). Different classes of shares can also be defined for times of the year, as in the Indianola Irrigation Company, where, “Class A shares are entitled to receive water, if it is available, for the entire irrigation season. Class B shares are high water shares to divert early season flood water as it may be available without reducing the water allocated to the Class A shares” (Utah Division of Water Rights, 2016b).

The water source also matters for how the rights can be used. Bureau of Reclamation water is generally restricted to agricultural uses, as noted in this comment for the Enterprise and Stoddard Irrigation Company:

> Bench Canal Stock CANNOT be used for domestic, industrial, or municipal purposes. Bench Canal shares are based on Echo Reservoir storage, which has restrictive covenants under the Weber River Project (Bureau of Reclamation) to be used solely for agricultural purposes [...] Contrast this with Field Ditch shares, which are based on Weber River Decree 180 [...] and which may be changed more freely. (Utah Division of Water Rights, 2013)

Irrigation companies that do not use Reclamation water are more able to sell their water to higher valued uses, including municipal and industrial users. Some irrigation companies have even been bought entirely by cities, such as the Granite Water Company, which was purchased by Sandy (an urban suburb of Salt Lake City) in 2010 (Utah Division of Water Rights, 2011).

As urban populations grow, transfers of water from agricultural to urban users may become increasingly valuable. Libecap (2011) argues that if current projections of long-term decreased precipitation and snowpack due to climate change are correct, some form of adaptation will be necessary, and water markets, if they function well, should be able to mitigate water supply uncertainty. Transfers of water from agricultural to urban uses will be necessary to accommodate and encourage the significant economic and population growth of the American West. Thompson (1993) notes, however, that irrigation districts “have often opposed and successfully blocked such trades" (p. 703). Blocked sales are generally more likely to occur in large irrigation districts where property rights are less clearly defined and less easily traded than in irrigation companies.

The challenges of large irrigation districts that prevent their users from transferring water, often for political reasons, can be contrasted with the many irrigation companies that allow users who are not members to purchase their shares, which allows water to be transferred outside of the original set of irrigators who formed the company. Irrigation companies with this structure have allowed many transfers of water from agriculture to urban users, especially in Utah and Colorado (Thompson, 1993). Because water in an irrigation district is owned more collectively, an outside trade from an irrigation district may harm the other members of the district while only benefitting the seller. An irrigation company, however, internalizes both the profits and losses to buyers and sellers of shares (Thompson, 1993).

Furthermore, the mechanisms by which outside trades can be prevented in irrigation companies and irrigation districts differ. In an irrigation company that allows the sale of shares to municipal users, for example, an irrigator who wishes to prevent an outside sale must purchase the share at the market price. In an irrigation district, however, an irrigator who wishes to prevent an outside sale only needs to vote to prevent it. Irrigators in an irrigation district may be able to prevent trades where the benefit to the irrigator of preventing the outside sale is less than the gains from trade to the seller and buyer, a situation unlikely to occur when irrigators are forced to face the full costs of preventing trade.

If irrigation companies are indeed redefining appropriative rights as a response to water scarcity, then irrigation companies will likely continue to be important adaptive institutions in the event of climate change-induced water scarcity. Unfortunately, local resource governance institutions can be threatened by policymakers who impose one-size-fits all solutions that crowd out, or even destroy local adaptations (Ostrom, 1990). Building additional water projects in an effort to overcome the problems of water scarcity may delay and obscure the price signals that irrigation companies rely on. This danger is made real by policymakers who face political incentives, rather than market incentives. Conspicuous structures of concrete and steel that hold back lakes or networks of pipelines that move water over, around, and through mountain ranges may provide policymakers with political benefits while simultaneously preventing local institutions from adapting to water scarcity. For example, Garrick, Whitten and Coggan (2013) point to the case of a series of droughts in the Colorado River Basin, which, while prompting minor reforms that allowed for more flexible markets, also resulted in maladaptive "infrastructure investments and water-use patterns that reinforced powerful vested interests and raised the costs of future institutional transitions" (p. 202).

Overbuilding infrastructure may also be constrained by the limited ability to supply new water at any price. As additional projects hit hard resource limits that no feasible dams or pipelines could overcome, access to additional water through institutional change will be more attractive. Unfortunately, designing institutions that can evolve with changing circumstances may be an especially difficult task when institutional change requires buy-in from powerful interests with an incentive to become vested in the new institutional arrangement. In light of this, policymakers should be especially careful to avoid destroying existing institutions and organizations that successfully adapt to water scarcity.

CONCLUSION

The colonizers of the American West were faced with tremendous geographic, climatic, and institutional challenges that forced them to repeatedly innovate new institutions and forms of governance, first from riparian rights to prior appropriation, and then from prior appropriation to irrigation companies. Those regions with the most water scarcity, and therefore the most to gain from trade, internalized the transaction costs of prior appropriation to a greater extent. Irrigators organized to solve the collective action problems of water trade, creating vibrant markets that allow water to be freely traded between agricultural users, but some of these same organizations, primarily irrigation districts, have evolved into special interest groups that prevent water from being traded to more valuable urban uses. This paper offers evidence that institutional adaptation in water resources is associated with water scarcity. As a growing population and changing climate continue to affect water scarcity, allowing for continued adaptation will be crucial to using water resources efficiently.

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