Disturbances to Irrigation Systems in the American Southwest: Assessing the Performance of Acequias under Various Governance Structures, Property Rights, and New Entrants

by

Steven M. Smith

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M.A., University of Colorado, 2011

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By **Steven M. Smith**

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Professor **Lee J. Alston**, Chair

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Professor **Nicholas Flores**

Date: __________________________

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"Disturbances to Irrigation Systems in the American Southwest: Assessing the Performance of Acequias under Various Governance Structures, Property Rights, and New Entrants"

Dissertation directed by Professor Lee J. Alston

Abstract

I expand the common pool resource literature by creating and utilizing longitudinal data. I take advantage of historical happenings centering on the Spanish common property irrigation systems called *acequias* to study the economic performance of various irrigation institutions in the American southwest.

Following a detailed analysis of irrigation statutes and development in New Mexico, I compare and contrast the *acequia* organization with larger irrigation districts. Utilizing a Social-Ecological System framework, I highlight the distinction between irrigation districts and *acequias* before I conduct a difference-in-difference hedonic price analysis of counties that formed irrigation districts to those that did not. Using data from U.S. Agricultural Censuses, 1910-1987, I find the districts improve land values by nearly 12 percent due to increased production.

I then consider how the proportional water rights of *acequias* compare to the more prevalent seniority rights (prior appropriation). I derive testable hypotheses from a theoretical model. I test the model through a natural experiment where a*cequias* developed in New Mexico Territory later are divided by the formation of Colorado, exogenously forcing a subset to be subject to the priority system. Using annual satellite imagery from 1984-2011, I compare performance under various stream flow. As predicted, communal sharing generally performs better, though suffers more during drought.

Last, I consider the importance of population stability in a common-property management system. Empirical work has neither addressed these issues in a dynamic nature utilizing longitudinal data, nor addressed the endogeneity of the user group. Combining satellite imagery and water right transfer records, I build a unique panel data set of 50 *acequias* in Taos, New Mexico from 1984-2011. With these data I am able to identify the role of repeated interactions and diagnose the extent of omitted variable bias. The *acequias* are resilient to the new users but struggle to absorb additional users. Notably, there is a positive bias present in cross-sectional treatments—entrants self-select into well performing systems. The statistical results are corroborated through follow up surveys of 17 *acequias*.

Keywords: Irrigation; property rights; transaction costs; acequias; irrigation districts; common-pool resources

JEL Codes: Q15, Q25, Q28, N52

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Chapter One: Introduction and Background

1.1 Introduction

Settlement of the Western United States required addressing aridity. Commonly delineated by the 100th meridian, beyond this line water is scarce. The development and division of water sources produces unique issues due to the uncertainty, rivalrous, and non-excludable nature of water. In my dissertation, I study the institutions that developed address the problem of allocating water, primarily for irrigation. In all instances, the empirical study revolves around *acequias*. The *acequias* are communal irrigation systems developed during Spanish colonization of *Nuevo Mexico*, and continue to serve many communities in current day New Mexico. Having persisted by 400 years, they constitute a counter example to the "tragedy of the commons" which Hardin (1968) hypothesized as the inevitable fate of shared resources. Following standard neo-classical economics, rival, non-excludable common-pool resources are prone to overexploitation (Gordon, 1954). Counterexamples, such as the *acequias*, however question the policy panacea of conversion to private rights or centralized state control (Ostrom, 1990), challenging scholars to consider human behavior and institutions more carefully.

My dissertation expands on the CPR and water economics literature by considering the performance of common property irrigation systems in comparison to alternative institutions, namely state controlled irrigation districts and individual water rights, and user group disturbances. A primary contribution is the creation and use of longitudinal data on common-pool resource systems, not readily available due to the high transaction costs of gathering data, ***especially longitudinal***, on CPRs (Poteete et al., 2010).

Due to the commonality of *acequias* in Nuevo Mexico, I begin with a broad historic background on early irrigation development in New Mexico, covering development and changes from 1600-1900 in chapter two. In chapter three I compare the *acequia* organization to the large, centralized irrigation districts developed throughout the early to mid-twentieth century to better understand the relative and net advantages of moving from communal local governance to regional centralized control. In chapter four I compare *acequias* in New Mexico, employing proportional (communal) water rights, to those in Colorado that fall under the prior appropriation doctrine—dividing water based on seniority—assessing economic efficiency in the face of variable stream supply. Finally, in chapter five I consider the role of the user group in sustaining *acequia* performance, considering the robustness of *acequias* to a disturbance of new users with attention to the endogenous nature of the disturbance. In chapter six I offer a brief conclusion.

Chapter Two: The Role of External Legislation in the Development of Irrigation Institutions

2.1 Introduction

Acequias have often been used to exemplify successful communal management of a natural resource (Cox 2010; Ebright 2001; Rivera 1998). In the region of study they date back to the 16th century, having survived for over 400 years. However, the institution goes back further with connection to the Iberians coming way of northern Spain and Mexico (Rivera and Glick 2002). This chapter presents the basic principles which define *acequias* as a water institution. I provide information concerning the process by which water is divided and shared. This is coupled with historical background of the settlement of the American Southwest. The relevant points are reiterated in later chapters as needed. Finally, I look at the laws of New Mexico's territorial period. I assess their motivation and whether or not they encourage and support *acequias*. I then compare the timing of these laws with origination dates of *acequias* as well as alternative irrigation institutions. The analysis provides insight as to how external legislation impacts local irrigation institutions. Overall, the movement towards private rights and central administration through legislative encouragement of capital intensive projects choked off *acequia* construction and ultimately made it a challenge for those existing to persist.

2.2 Background/Methods

As a whole, the literature has focused on the local factors of communal management, i.e. user group characteristics, resource attributes and local institutional rules in place, at the expense of the external factors. Arun Agrawal (2003) indicates the reason for this oversight is driven by the research topic's nature; showing the importance of local authority to govern local resources. Study of external factors is not completely nonexistent, but is underrepresented across the literature.[1] Agrawal synthesizes the external variables which have been recognized as important from various research in the field. The first is technological, concerning the available mechanisms of excluding outsiders from appropriating the resource. The other is the government; particularly, the need for the central government to provide local users with autonomy and supportive sanctioning institutions, providing *de facto* local norms the bite of *de jure* law. Many times this does not occur and water (and other natural resource) legislation is at odds with local custom (Alston et al. 2012; Clark 1990). Evidence from New Mexico supports this hypothesis and illustrates how local autonomy suffered at the hands of legislative law and alterations in the court system. As the legal system constrained the *acequias* and came to favor other organizations, *acequias* became less prevalent.

External factors are difficult to study merely for the fact that they are often relatively constant across the time period of the studies, often cross-sectional snapshots. In this chapter I take advantage of the unique history of the formation of the United States in order to analyze variation in the external context with respect to time and the impact they have on local irrigation organizations. New Mexico, first settled by Spain, fell under Mexican rule for a short period before becoming a U.S. Territory and eventually the 47th state. During this progression the *acequias* faced a different set of laws and support from the court concerning irrigation practices. Some laws are more accommodating than others. Exploiting this variation I am able to show which external rules are strongly associated with successful common property irrigation systems as well as those which are not.

In order to assess the motivation and role of external rules on communal irrigation I conducted a large review of the historical literature on New Mexico and *acequias*. In addition,

[1] Ostrom (1990) highlights a Canadian fishery in which the *de jure* rights did not correspond to the *de facto* rights, leading to much conflict and inefficiency. This dynamic of conflict is explored in some detail in Alston et al. (2012)

legislative records maintained in the New Mexico Territorial Archives were searched for relevant statutes regarding irrigation. Finally, this is combined with three sources of data on irrigation enterprise formations to see the correlation of statutes and irrigation trends.

2.3 Settlement and Irrigation Practices

2.3.1 Settlement

Spanish colonization of *La Provincia del Nuevo México* began in 1598 with a settlement effort led by conquistador Capitán General Juan de Oñate. Travelling north along the *Rio del Norte*, today known as the Rio Grande, they settled at present day San Juan Pueblo. Among the first tasks undertook was to construct an irrigation canal. To do so, they enlisted the help of some 1500 Pueblo Indians. Digging the *acequia madre* required much work, as most historic ones ran for a couple of miles, 4-6 feet deep and 14-15 feet wide (Sunseri 1973). For some unknown reason, colonists abandoned this initial settlement and resettled a short distance away on ruins of a Tewa Pueblo, where the *Rio Chama* flowed into the *Rio del Norte*. Here, in what they called San Gabriel, they labored to build a canal to irrigate the fields to be cultivated.

Following a brief expulsion from the area due to a native uprising, the Spanish colonization resumed in full force from 1695 until 1821, at which point Mexico gained its independence from Spain. The settlements were guided by the Laws of the Indies issued by the Spanish crown concerning the development and occupation of newly discovered lands. It stipulated characteristics which should be considered in selecting settlement locations including fertile soil, abundant pasture land, and above all, with “good and plentiful water supply for drinking and irrigation” (Rivera and Glick 2002, p. 4). Once officials inspected the land, confirming its promise to provide for the settlement, the land grant would be conferred and the settlers would begin work. The irrigation infrastructure was typically the first undertaking, even prior to building the local church or government buildings (Rivera and Glick 2002).

The irrigation canals were essential to the survival of these early pioneers travelling miles into the arid climate west of the 100th meridian. The early settlers were also mindful of nature's limits. Many additional land grants were requested by those who had previously inhabited a settlement but felt the ecosystem could not support more people. José Rivera (1999) takes this to be indicative of the conservation and sustainable principles guiding the *acequia* institution. However, the necessity of the irrigation bears no impact on the chosen common property arrangement associated with *acequias* and its guiding principles of sharing. This was owed more to the Arabic roots of the institution.

Water apportionment in *Nuevo México* was driven by priority, but not as defined under the prior appropriation doctrine (in which priority is based on first-possession). Instead of first possession, disputes were settled based on other factors including just title, prior use, need, injury to third party, intent, legal right and equity (Brown and Rivera 2000; Ebright 2001). For instance, small gardens typically were given water prior to large alfalfa fields, independent of first use. Overall, it was a flexible community-based irrigation system in which rarely did anyone get all they asked for, but everyone got something. Malcolm Ebright (2001) concluded, "A rigid winner-take-all water system was inimical to community solidarity, and without community there was no surviving the harsh realities of frontier life" (p. 32).

The small settlements of the colonists persisted, the largest being around 400 families, most around 20 (Sunseri 1973), once Mexico gained its independence in 1821. When the area fell under U.S. jurisdiction in the 1840's, the Anglos began to move into the territory attracted by the economic potential. Many of the newcomers viewed the *acequias* as inefficient modes of irrigation. They felt, "[farming] has been pursued merely as a means of living, and no effort has been made to add science to culture in the introduction of an improved mode of husbandry" (Sunseri 1973, p. 334). Americans had no doubt they could manufacture more water, believing the water follows the plow and in the power of large dams. The American approach focused on profits, paying little attention to sustainability and conservation issues which served as guiding principles for the *acequias*. As word spread of favorable prices on agriculture goods in the region, the area was primed for a large migration of Anglo-Saxons to the area. The Mexican-Americans did not follow the advice of the Anglo-Americans and continued to farm for subsistence and not commercial purposes. With the arrival of the railroad in 1879, the Anglo-Americans came in droves, increasing the population by 170% over the next 30 years. The newcomers began to take over the land (and the territorial legislature) pressuring the Mexican-Americans to adopt new ways of irrigation and undercutting the *acequia* institution. Once under American rule, the fate of the local management of the *acequias* depended on the rules which the new governance would place upon it.

2.3.2 The *Acequia*

The word *acequia* itself has Arabic roots and means "to irrigate" (Rivera and Glick 2002). Rivera and Glick further argue that the common property management is rooted in the Islamic belief that water is sacred and must be provided to all who need it on the principles of sharing. It is the Muslim practice that irrigation canals are the shared property of all those who labor on it and could not be subdivided into private property.[2] It is believed this practice was adopted in the arid regions of Spain and subsequently transplanted to the new world. Community members were appropriated water in proportion to the maintenance and upkeep

[2] The irrigation practices in the new world are also melded with those in place by the native population. The main difference was in governance, the Pueblo tribes used a ditch chief for provision concerns and a cacique for appropriation matters (Sunseri 1973)

work they provide to the ditch. As communities grew in size, it became essential to choose an administrator of the *acequia* to organize maintenance and water distribution; this position had many names, but is now commonly called the *mayordomo*. Rivera and Thomas Glick believe a crucial condition for success is the discretionary authority entrusted to the *mayordomo* through the luxury of local control, supporting the hypothesis that local autonomy is important.

An *acequia* initiates by building a diversion point upriver using a simple dam which directs the water into the *acequia Madre*, or main ditch. The systems, generally comprised of unlined ditches and simple head-gates, are based on gravity. Actual irrigation is typically flood irrigation in which the fields are leveled such that water can pool evenly across the land. Farmers who help build and maintain the system are *parciantes*. During drought periods, users of a single *acequia* divide the water on a rotational basis (Rodríguez 2006). The use of *temporalis,* or time shares, is seen as an easy way to monitor and enforce division (Trawick 2001). In many regions, division among *acequias* who divert from the same stream also occurs on a rotational or at least proportional basis. By design, the water that is not absorbed into the soil will run off and return to the river at the bottom of the valley, allowing for more water to flow to downriver *acequias*.

The ditch itself is unlined; a feature which allows it to expand the riparian zone and recharge groundwater, but also requires considerable maintenance. Each spring it falls on the *mayordomo*, or superintendent of the ditch, to organize the members to fix up the ditch. This position, as well as three other commissioners, is democratically elected from within the *acequia* annually. In contrast to ditch companies where voting is often proportion to land, voting is most often done one vote per *parciente*, though other arrangements are sometime utilized (DeLara 2000). The cleanup takes 2-3 days per year and potential free-riding must be overcome. The *mayordomo* is in charge administering the flow of water throughout the irrigation season, designing the schedule for rotation when needed. The other officers typically include a president, secretary, treasurer who oversees the work done by the *mayordomo.*

The *acequias* have been a model for communal and ecological benefits which can be provided beyond the economic benefits of irrigation. For many, it is the most local form of government and builds a sense of community. Sylvia Rodríguez (2006) explores the community nature of the institution and its intimate relationship with religion. On the ecological front, beyond the extended riparian zone, *acequias* utilize renewable energy (gravity) to provide water, typically utilize riparian long lots rather than the grid system, rely on natural pest and weed control and utilize local landraces and polyculture (Peña 1999). In a sense, the communities have adopted methods with concern for the entire watershed, a practice advocated by General Wesley Powell (Stegner 1954). Stanley Crawford provides an excellent account of spending a year as mayordomo in his 1988 memoir.

2.4 Legal Evolution

New Mexico is the only the state still littered with *acequias* to this day.[3] While there is no conclusive data source of the number, it is estimated that the state hosts 800-1000 *acequias* presently, most of which established prior to 1900. What is now the state of New Mexico experienced four distinct phases; A Spanish colony from 1598 to 1821 when Mexico won their independence, making it a Mexican territory until 1848 at which point it gained status as a US territory following the Mexican-American War and eventually, in 1912, became the 47th state. In respect to water rights, these discrete alterations in sovereignty created little disruption. Instead, changes along the intensive margin of the law occurred throughout the US territorial period as

[3] Southern Colorado still has an *acequia* presence, but only New Mexico continues to have hundreds.

water law grew in complexity. I focus on this period, only briefing addressing the Mexican period and transition to U.S. control. Specifically, I consider the laws enacted and assess whether or not they have the features which appear to be conducive to local management of common-pool resources and explore the circumstance of their passage. I then compare the evolution of *acequias* in the changing legal environment, confirming the hypotheses.

2.4.1 Mexican Law

In 1821 Mexico gained its independence from Spain, giving the newly sovereign country the lands of *Nuevo México*. Mexico adopted looser colonization laws than Spain had, but did not disturb the laws and customs concerning the community *acequias* (Hutchins 1928a). In fact, the statutes of the territory under Mexican rule are quite sparse, numbering only thirteen, though nearly a third concern water, underscoring its importance (Provincial Statutes 1952). Arguably, all of them support the common property arrangement. §4 provides external support of the appropriation by fining anyone taking water out of turn 12 reals, 4 of which to go to the individual which was denied water through the transgression, providing incentive to report the infraction beyond the shortage of water.[4] Underscoring the community nature of endeavors in this time period, §5 requires all those in the community to labor on the mother ditch, among other community projects like the church. Failure results in a fine. Both these statutes provide the local authorities with external support to enforce their decisions.

2.4.2 Territorial Law

In 1846 Stephen Watts Kearny occupied New Mexico, claiming it for the United States. In doing so, he promised all persons of the province protection of their liberty and property in The Kearny Code. It states specifically, "laws heretofore in force concerning water courses,

[4] Part of the statute reads "from which effrontery regularly follow blows which always bring some sad result." Suggesting the transgression did not go unpunished without the statute, but with the official fine, perhaps violent solutions could be limited.

stock marks, and brands, horses, enclosures, commons and arbitrations shall continue in force" (Victory 1897, p. 90). The regulation of such things remained with authorities at the village level. Although some questioned Kearny's authority to make such claims, a similar protection was made official in the 1848 Treaty of Guadalupe Hidalgo (Clark 1987). The treaty officially gave the U.S. tenure of the area and protected the occupants prior rights; "property of every kind now belonging to Mexicans now established there, shall be inviolably respected" (Victory 1897, p. 31). The recognition of prior property rights left the *acequia* in a strong position.

The first territorial legislative sessions of 1851 and 1852 further enhanced the *acequia* rights by putting into statutory form many of the informal rules which had guided the water democracies for centuries. This came as little surprise as the legislature was comprised mostly of natives with only a few Anglo representatives (Clark 1987). The first eleven statutes relating to *acequias* crystallize the importance and priority of irrigation in this period. The first made it illegal to block any water ways, reasoning that "irrigation of the fields should be preferable to all others" (Victory 1897, p. 96, §1). The second established the right of eminent domain to construct ditches to get water from the closest source. They further forbade any disturbance to those ditches already in place. Overall, the *de facto* rights became the *de jure* rights in New Mexico during the first legislative session.

The legislature did not undercut the local authorities, and in fact, provided them external support, validating their authority. For example, any person in default for labor payments became subject to arrest the same as any other offenses against the territory (Victory 1897, p. 97, §13). The external threat of enforcement gave considerable gravity to the locally levied sanctions. The early statutes concerning the water law in New Mexico allowed for the *acequias* to operate largely uninhibited as well as with legitimacy.

By 1903, Hispanics no longer dominated the Territorial Legislature; based on surnames, 18 Hispanic representatives and 18 Anglo representatives made up the 35th legislative assembly.[5] The shift began before then, though. The first fundamental change in regard to irrigation statutes came in 1887. In this year the legislature established the right for incorporations to form for the purposes of irrigation. Following a three year hiatus, the 27th Legislature convened on December 27, 1886, greeted by a note from Governor Edmund G. Ross. He set forth the "need" for large scale irrigation, saying:

> "It is believed that legislative encouragement of the organization of incorporated companies for this method of developing water, and the supply of water for irrigation purposes to the lower lying lands, would result in bringing under cultivation very large areas of country now desolate and valueless and stimulate immigration, settlement and development to a degree now possible." (NMSRCA 1971, roll 6)

In response, Mr. Laughlin of Santa Fe County introduced Council Bill 80. The bill passed the council on a vote 10-2, with the two council members from Bernalillo County in opposition. With no records of ayes and nays, the same passed the House of Representatives on February 18, 1887. With that, "An Act to authorize the formation of companies for the purpose of constructing irrigating and other canals and the colonization and improvement of lands" became law and drastically altered the incentives in irrigation, welcoming speculation and large scale profit projects.

This new irrigation organization provided the means for capital to be raised for large-scale projects, though in reality many operations failed (Hutchins 1930; Ostrom 2011). The desire for such changes no doubt followed the arrival of the railroad in 1878, bringing droves of

[5] Surnames were classified as Hispanic if they were found in the top 1000 surnames of Latinos in the U.S. (Butler 2008)

Americans from the East. Water began to slip from the locals' grasps and move to business men and financers looking to turn a profit. In a case in 1897, the judge sums up the Anglo elites' view of the *acequias*; "'I do not underestimate the present ditch system, in some respects it is very good and so long as it is in existence its status and rights must be upheld by the courts; but it is not an economical system […] it would seem strange that a system more than one hundred years old could not be improved.'" (Baxter 1997, p. 95)

The scope of irrigation began to move beyond the local communities reducing local autonomy. As of the 1880s, many water disputes were no longer being settled by county probate courts and were increasingly falling on the docket of the territorial district courts (Baxter 1997). John Baxter argues that the use of district courts, of which the judges were federally appointed and knew little of local water administration compared to the locally elected probate court judges, favored the eastern businessmen speculating in water. The Hispanic population found themselves in an unfamiliar court system where often technicalities determined the outcome. Even in cases involving only Hispanic parties, it was often the Anglo lawyers and judges which determined the case, leaving the users merely as witnesses.

In addition to the change in water governance and judicial structure, the legislature continued to evolve the rules governing the *acequias* themselves. Only small changes occurred between 1851 and 1895, mostly small issues such as the obligation to build bridges over the ditch and when meetings should be held. On the surface, this trend appears positive, as the Anglo-style laws codify the traditional structure, but Brigette Buynak et al. (2009) and John Brown and Rivera (2000) point out that it simultaneously created a tension with autonomy. By writing tradition into law, the *acequias* became limited in their ability to depart from the customs when it might be prudent to do so. The external government began to create a one-size-fits-all solution, albeit based on historic tradition. However, in 1895 the legislative body passed new statutes altering the organization of the *acequias* which were not based on tradition.

House Bill 72 passed the house unanimously and passed the council 10-2, again, both dissenters hailing from Bernalillo County. The bill contained a number of statutes; most notably, three that fundamentally altered the structure of the institution; all *acequias* are now required to elect three commissioners in addition to the *mayordomo* (NMCC 2011, §73-2-12) as well as the procedure to be used to elect them (NMCC 2011, §73-2-14) and §73-2-21 defines the roles of the required officers. This final statute undermined the local traditions, placing the newly required commissioners above the *mayordomo* in terms of power.[6] Wells Hutchins (1928b) points out that the *mayordomo* remained important in concerns of maintenance and water delivery, but loss other administrative power. Finally, §73-2-25 altered the sanctions available to the *mayordomo;* no longer were fines permitted, but rather the denial of water became the sanction. Buynak et al. (2009) argues that the territorial legislature knew the community *acequias* were too entrenched to merely toss aside, so they instead legally recognized them and simultaneously tied their hands, creating room for other legal organizations to coexist, such as water companies and irrigation districts.

As Anglo doctrine was taking a stronger hold on the region the *acequias* power in water allocation dwindled. 1905 witnessed massive centralization of power in irrigation in addition to a move towards private water rights. During the 36th territorial legislature, House Bill number 98 adopted the prior appropriation doctrine. Under this doctrine, water rights are private, severable from the appurtenant land, measured by volume and based on seniority—conceptually orthogonal to Spanish practice of communal water, divided by time on a basis of need. Additionally, the water code established the Office of the State Engineer, charged to adjudicate

[6] Prior to this some *acequias* had commissioners; however, they were subordinate to the *mayordomo*.

and administer the newly created water rights. Urged by the governor Miguel A. Otero and the Irrigation committee of New Mexico, the act aimed to mimic water code in force in western states like Colorado and Wyoming. The ultimate goal was to create a legal environment to attract irrigation projects from the new Federal Reclamation program (NMSRCA 1971, roll 18). Water development was seen as the root of future growth and prosperity. Irrigation projects were to now come first, driving future settlement instead of being a product of settlement.

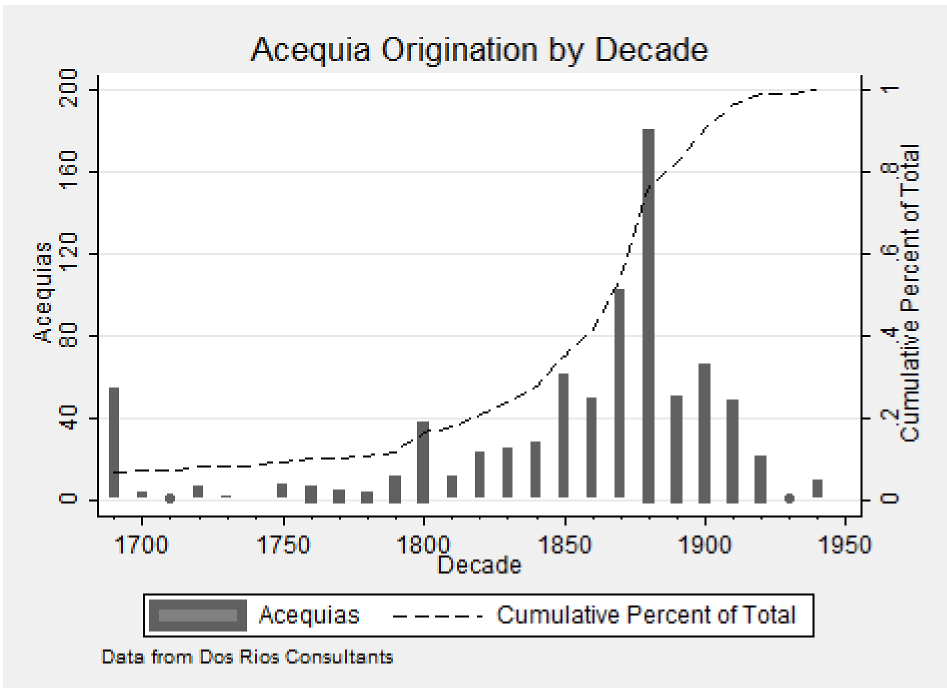
Prior appropriation gives priority in rights to water put to beneficial use the earliest. The law severs water's connection to riparian land and emphasizes private water rights, which do not align with *acequias* historical sharing practices. For instance, priority ignores need, reduces ability to share, and rights are in volume rather than time. As such, there was opposition in passing the law from those regions rich in *acequias.* The bill narrowly passed the council on March 15th in a 6-5 vote (NMSRCA 1971, roll 17). Notably, those opposed represent counties which account for over two-thirds of the *acequias* in New Mexico while it was introduced by Carl Dailies, representing district 10 with only 25 of the 1496 *acequias*. The centralization of power and adoption of prior appropriation posed a real threat to the *acequias* and was narrowly passed despite their opposition.

Further hurting their ability to operate in the new legal landscape, in the 1914 *Snow v. Abalos* case of the New Mexico Supreme Court, it was found that the *acequia* owned only the ditch and that individual *parciantes* owned the water rights privately, for it is they, not the ditch, who perfect the right by putting it to beneficial use. Not until 1987 did *acequias* acquire the ability to hold water rights themselves. Over the same time period alternative water organizations, set off by the statutes of 1887, gained power. Charlotte Crossland (1990) performs an analysis of the relative strength of alternative water groups in New Mexico based on the statutes governing them. She finds, despite being the oldest, the *acequias* are now among the weakest forms. For instance, all other institutions have a "necessary and proper" clause, but the *acequias* do not, a marked lack of autonomy. Wells Hutchins (1928b) also points out *acequias* have no ability to take on debt in order to finance operations, a luxury afforded to irrigation and conservancy districts. These alternative irrigation systems now have more statutory power in performing the same task of distributing and managing irrigation water than the *acequias* have. These changes in the external environment caused the *acequia* institution to be more difficult to operate, and thus, less popular relative to other organizational institutions available. By the end of the territorial period, *acequias* were no the premier irrigation institution due to external legislative efforts.

2.5 New Mexico *Acequia* Development

During this territorial period, there was a surge in irrigation construction in New Mexico, including the construction of *acequias*. In order to connect the pertinent changes in external law to the sustainability of *acequias*, my analysis focuses on the origination date of *acequias* to compare their relative prevalence under the various statutes. Two sources have been located on *acequia* formation. The first is found in Hutchins (1928a) and contains 480 *acequias*. The second, published by Neal Ackerly (1996) by basin in 25 year intervals, comes from raw data available Ackerly's company webpage (Dos Rios Consultant, Inc.). With the raw data I bin the origination dates by both county and decade. I present only the data from the latter source because it appears more complete and includes *acequias* that no longer exist, reducing left hand censoring due to survival. Qualitatively, the trends are similar in both data sets though absolute numbers vary. In total, Dos Rio Consultants identify 1496 *acequias* in New Mexico, over 1000 more than Hutchins tallies. Also of note, 608 *acequias* have no date and another 82 simply are dated pre-1900 which are dropped. The overall trends, I argue, are still valid. The implicit assumption is that the missing dates are likely biased towards older *acequias*, perhaps even randomly distributed, but unlikely to include many “newer” *acequias* built during the period under study. The data are displayed in Figure 2.1.

Figure 2.1: Acequia Formation



Recall, the transition from Spanish rule to Mexican rule provided very little change in the external government’s rules on irrigation. As predicted by the preservation of rules, the number of *acequias* originating in the Mexican period, 1826-1850, did not show any drop off from the prior 25 years under Spanish rule and in fact shows a small uptick from the 1810s to the 1820s, perhaps indicative Mexican’s laxer immigration policy. This lends empirical support to Hutchins (1928a) assessment that little changed concerning the *acequias* in this transition and the *acequia* remained the irrigation organization of choice during Mexico's short tenure of the region.

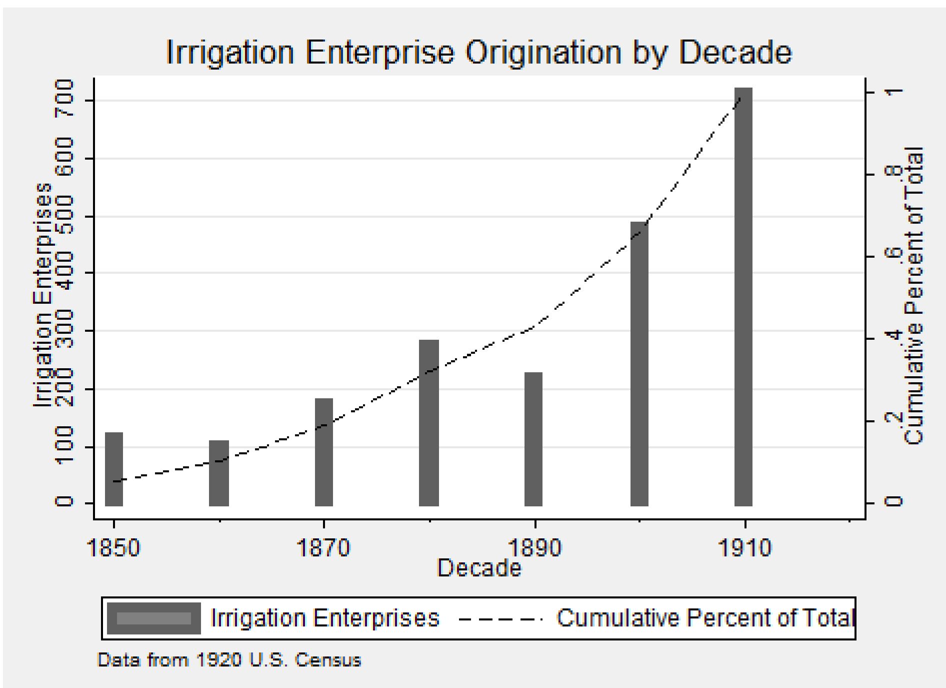
Following Mexico's tenure of the region, 62 new ditches were organized in the first full decade of U.S. rule, 1850-1859. The influx of new *acequias*, the most in any single decade up to that point, demonstrates that the original laws of the territory provided the *acequia* institution legitimacy. *Acequias* remained the preferred irrigation system. While the decade saw an increase of over 50% in the population, according to Baxter (1997) it was mostly from a natural increase of the native population, not immigration, making the use of *acequias* not that surprising.

Even as new the population began to grow from the inflow of Americans headed west, *acequias* continued to be constructed as New Mexico law did not yet favor other institutions. New construction grew to 102 in the 1870s and then peaked at 178 in the 1880s. Recall that the railroad arrived in 1878 and the territory's population increased from 91,874 to 160,282 from 1870 to 1890. The population growth is no doubt connected to the rate of construction, but I contend that the overall trend is more tightly tied to the legal status of *acequias*.

Three crucial laws which weakened *acequias* discussed in detail above were passed in 1887, 1895, and 1905. Beginning in the 1890s, new construction fell off to 49 and persisted at very low numbers, accumulating only 160 new *acequias* from 1890-1919. I argue this decline is due to the legislative changes, not a lack of population growth or construction of new irrigation systems. For one, from 1900-1910, the population grew 67.7, the largest absolute and percentage growth in the territorial period. The alternative explanation is that no new irrigation was needed. To address this issue, data from the US Census of 1910 and 1920 are utilized.

It could be that most of the new population moved to urban centers rather than farming, but over this same decade, 1900-1909, the number of irrigated farms increased 40.2% and total acreage under irrigation grew 126.5%, according to the U.S. 1910 Census.[7] Furthermore, data are provided in the 1920 Census concerning the number of irrigation enterprises originating each decade from 1860 on. This is presented in Figure 2.2. The growth in irrigated acres during the 1900-1909 came from 482 new irrigation enterprises, of which only 64 were *acequias*. And while new *acequias* from 1910-1919 only number 47, irrigation in general took off with 716 more new irrigation enterprises overall in that decade.[8]

Figure 2.2: Irrigation Enterprise Formation

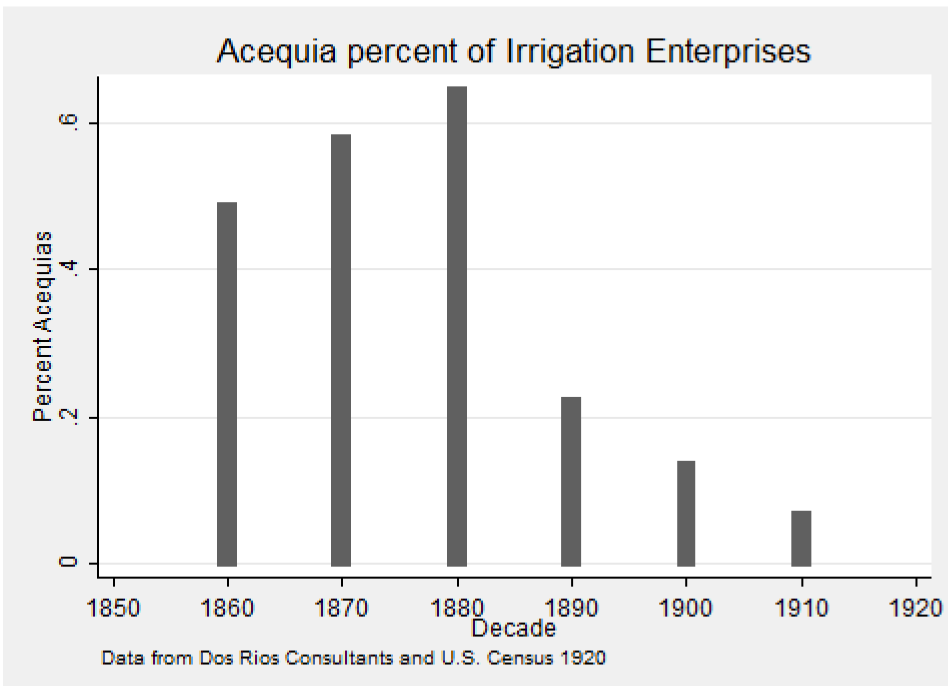


[7] The expansion in acres is over 3 times the expansion in number of farmers, suggesting a transition to larger scale farms in the area.

[8] Many of these appear to have failed or consolidated, as the same table in the 1930 Census, with another 10 years totals only 1620 compared to 2090 in the 1920 data.

Figure 2.3 combines the two data sources to show similar trends in relative terms. *Acequias* remain a relatively steady proportion of 40-60 percent of irrigation enterprises from 1860-1889. However, beginning in 1890, after the 1887 irrigation corporation law, the percentage fell to 22 percent. The trend continued with the additional laws. Following the water code in 1905, *acequias* amounted to only 6.5 percent of new irrigation enterprises from 1910-1919. Irrigation, therefore, did not fall off, but forms of organization other than *acequias* became the desired format following the alterations in law coming from the territorial legislature.

Figure 2.3: Acequia Formation as a Fraction of Total



2.9 Conclusion

External legislation is influential on local irrigation institutions. The case of *acequias* in New Mexico demonstrates how the institution was able to grow when given support from the external government, but that its role in water diminished as statutes began to favor other organizations. The transition, captured most clearly by the 1905 water code, was seen as a threat and opposed by *acequia* heavy counties at the time. Irrigation law continued to evolve during statehood with the framework for irrigation and conservation districts designed, subsuming many historic *acequias* (covered in detail in Chapter 3). With few additional *acequias* being constructed, the 20th century became about survival as one of the legally weakest irrigation institution. It should be noted that while power was slowly stripped away from *acequia* associations, many have persisted and still operate today, largely due to the fact that New Mexico did include their customs in shaping the water law and sought to offer them protection. Recalling the governor's request for irrigation corporations in 1887, he also said, "it will of course be necessary to have regard for the fixed nature of existing conditions in respect to the system of acequias now in operation" (NMSRCA 1971, roll 6). This special protection continues today. For instance, as the state attempted to adjudicate the water rights, a fund was set up for *acequias* to utilize to assist in litigation (NMCC 2011, §72-2A-1 through §72-2A-3), providing locals with state funds to protect their institutions. Ultimately, the *acequias* have worked with the state to maintain their historic communal ways despite the prior appropriation doctrine. The remaining chapters consider how the communal irrigation systems have done in their new legal setting.

Chapter three: From Communal Irrigation to Central Irrigation Districts: An Economic Assessment of New Mexico's Transition

3.1 Introduction

Settling and cultivating the arid portion of United States, generally delineated as west of the 100th meridian, required the use of irrigation. As Americans moved further into the frontier, government settlement programs often struggled due to poor irrigation infrastructure and institutions (Coman 1911). Stephen Bretsen and Peter Hill (2006) highlight the imposing transaction costs that make the endeavor difficult due to disparities in the optimal sizes of farms and irrigation systems. Elinor Ostrom (2011) calls attention to the lack of trust between the new users and poor institutional design. As the 20th century began, Irrigation and Conservation Districts formed to solve many of the transaction costs (Bretsen and Hill 2006; Libecap 2011). In contrast to the American experience, settlement of *Nuevo Mexico* by Spain from 1600-1821 developed irrigation arguably successfully, transplanting the communal ditch system of *acequias* from Spain. With over 700 *acequias* remaining in New Mexico today, many persisting over 200 years, they serve as counter-examples of the oft prescribed "tragedy of the commons" (Hardin 1968), continually cooperating with one another to overcome the private incentives to defect from the socially optimal outcome. However, successful avoidance of the "tragedy" does not eliminate the possibility an alternative arrangement would have done better.

Having to construct costly diversion structures and often carrying water over large distances, the economies of scale in irrigation seldom aligns with the optimal sized farm unit. To overcome this transaction cost obstacle, institutions developed to construct and maintain a shared delivery system ranging from *acequias* to mutual and commercial ditch companies to IDs. With strong statutory powers, IDs are able to solve many transaction costs and now deliver around 50 percent of western irrigation water (Bretsen and Hill 2006). By the 1970s, nearly 30 percent of irrigated acres in the West received water from an irrigation district, yet nearly 50 percent continued to be served by smaller communal systems (Leshy 1982).

Would the smaller systems be better served through a larger, centralized irrigation organization? New Mexico irrigation provides a unique setting to explore this question, having lost nearly half of the 1,400 *acequias*, many of which being agglomerated into one of the 14 irrigation districts. Leveraging New Mexico's partial transition from communal management to centralized management of irrigation districts (IDs), I assess the advantages and disadvantages of IDs in comparison to alternative, long-lived and successful communal enterprises. Other Western States adopted IDs, but few replaced well-established alternatives providing scant counterexample data. Though the desired question concerns that of management and decision making, the distinction between the two organizations extend beyond that, so while management is embedded within the results, it is never fully isolated.

IDs take many forms and may be viewed by some as self-governed systems. However, on the spectrum of communal property and public property, the districts lean heavily towards the public end, with water management decisions coming from a central authority over large areas of irrigated land. Accordingly, centralization does not indicate a level of government (as in the decentralization literature), but rather a scale of reach and power.[9] In many areas IDs started anew, but in New Mexico more tended to subsume existing irrigation institutions and structures (Hutchins 1931; Rivera 1998). In what follows the institutional differences and other correlated distinctions from communal ditches are discussed through a Social-Ecological System (SES)

[9] I wish to distinguish my terminology from that of the decentralization literature, in which a developing country divests power to more regional entities. Varieties of which are summarized by Rondinelli et al. (1983). The process explored here does not fit this typography well as both acequias and IDs are local forms of government. Rather centralization should be thought of as (irrigators/elected officials), providing a measure of scale.

framework (Ostrom 2009). Building on Michael Cox's (2014) application of the SES to *acequias*, I distinguish the elements altered when transitioning to an ID.

From 1910-1960 New Mexico experienced an increase in IDs. In many counties *acequias* lost local control and became a piece of a larger irrigation institution. To quantify the benefits and costs of IDs, counties that make the transition are compared to counties where smaller communal systems persist using US agricultural census data from 1890-1987. The primary analysis is grounded in the Hedonic pricing methodology, based on the assumption that agriculture land value will capitalize the value provided by the ID. Non-ID counties are used in a Difference-in-Difference (DiD) framework to provide a plausible counter trend conditional on a number of controls. My findings suggest the irrigators found IDs valuable on net, driving farm acreage values up 12%. To disentangle some of the benefits and costs, I consider additional outcomes within the DiD framework, finding that crop production increased (indicative of better delivery of water) but that irrigation costs and debt also increased. The results hold even when water storage and irrigated acres are controlled, indicating gains in management beyond the gains of the infrastructure.

For the analysis, I begin with the theoretical background of irrigation externalities to identify those more likely to desire an ID to deal with the issues. Section three provides historical perspective and uses Ostrom's Social-Ecological System framework to distinguish the *acequias* from the IDs. I then provide details on the data and methodology in section four before presenting the main findings in section five. Following the robustness checks of section six, I discuss the results in greater detail in section seven. Finally, I conclude in section eight.

3.2 Theoretical Background

The choice of organization is not random, driven by the expected net gains of internalizing decisions compared to the current transaction costs of decentralized management (Coase 1937). Irrigators drawing on a common source of water face two distinct common-property dilemmas. The first of which is appropriation. Water's fugitive nature makes it costly to define property rights to provide exclusion yet one user's consumption decreases the amount of water available to other users, yielding conditions ripe for negative externalities and over appropriation. Second, users struggle with provision of any shared infrastructure, whether physical or institutional. This second issue looks more like a public good problem in that the infrastructure is non-excludable and non-rival, providing temptation to free-ride, possibly resulting in non-provision. The theory set out below provides guidance as to those more likely to adopt an irrigation district, driven by factors that exasperate appropriation and provision issues.

3.2.1 Model

The decision to form an ID ultimately falls to eligible voters within the proposed borders. Often a simple majority, though the votes can be counted on an acreage basis. What type of farmer would vote to form an ID to address the appropriation and provision issues becomes the appropriate question. The simplistic answer is that those who stand to gain most will vote for it. More applicable, those subject to larger externalities and greater transaction costs should favor IDs. Drawing on the Coase Theorem, bargaining may be possible, as exhibited by some decentralized *acequias* arranging agreements. However, the Coase Theorem also states that sometimes transaction costs are too great and bargains cannot be struck easily. Negotiation becomes increasingly difficult with more users (Ostrom 1990; Coase 1960). For provision of public goods, free riding incentives are exasperated by an increased number of beneficiaries.

Therefore, one would expect counties with more farmers to have greater desire to form an ID, though this should be qualified at the county level. Farmers are only impacted by those who share a water source. Having more creeks reduces the need to organize into a centrally managed regime, as the biophysical nature is itself decentralized.

In this specific context, *acequia* farmers tend to oppose the large districts. The Hispano farming is done much more for subsistence rather than market. The historic irrigators fear not only the loss of local control, but also the financial demands that may accompany the ID formation. Given the institutional details, counties with greater population may also wish to form an ID. IDs are able to tax all those who benefit, which can easily be defined as non-irrigators. Therefore irrigators may be able to subsidize their needs, especially when voting is done on a per-acreage basis.

3.2.2 Model Support

Using data from the 1910 Census, the above model is tested empirically at the county level. Utilizing a simple linear probability model, I test what 1910 factors predict the later formation of an ID. Given the even mix of treatment (12 non-district to 14 district counties), the use of the linear model can be expected to perform well. Presented in Table 3.1a, the results largely support the theory. Those counties with more farms (more externalities) and fewer creeks are more likely to form an ID. In Column (2), the regression is run with farms per creek to emphasize this mechanism. A county with more irrigated farms, as a fraction of all farms, is more likely to organize into an ID. Interestingly, fewer irrigated acres as a fraction also increases the odds of forming an ID. Combined, these two results indicate that when many

Table 3.1a: 1910 Irrigation District Predictors

	(1)	(2)	(3)	(4)
VARIABLES	OLS	OLS	Logit	Marginal Effects
% Irrigated Farms	0.0237***	0.0193***	0.561***	0.139
	(0.00458)	(0.00374)	(0.217)	
% Irrigated Acres	-0.0175**	-0.0192*	-0.625*	-0.155
	(0.00644)	(0.0109)	(0.322)	
# of Farms	0.000474***		0.00703**	0.002
	(0.000143)		(0.00300)	
# of Creeks	-0.0471**		-0.943**	-0.234
	(0.0169)		(0.386)	
Farms/Creek		0.000529***		
		(0.000162)		
% Farm Acreage	0.00621	0.0102*		
	(0.00753)	(0.00562)		
# Historic Acequias	0.00112	-0.000436		
	(0.00200)	(0.00125)		
Population	-1.28e-05	-1.23e-05		
	(1.70e-05)	(1.65e-05)		
Longitude	-3.56e-08	7.27e-08		
	(1.70e-07)	(1.27e-07)		
Latitude	7.24e-08	3.00e-07**		
	(1.98e-07)	(1.36e-07)		
Constant	-0.770***	-0.404*	-21.26***	
	(0.240)	(0.189)	(7.979)	
Observations	25	23	26	
R-squared	0.683	0.713		

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Column (4) is calculated using the sample average probability (.538)

Table 3.1b: Logit Prediction Matrix

		Actual		
		District	No District	Total
Predicted	District	12	1	13
	No District	2	11	13
	Total	14	12	

Correctly Classified: 88.46%

irrigating farmers are currently irrigating relatively few acres, they see an opportunity to expand and want the ID to overcome the provision externalities.

The remaining controls are only marginally predictive. The fraction of farm acreage in the county increases the odds, as this increases the set of beneficiaries. The total population is imprecise, but negative, providing no evidence of large farms capable of adopting IDs to compel non-farmers to pay. The number of historic *acequias* also provides little predictive power. The empirical result is not all surprising, as more *acequias* indicate more irrigation but possibly more opposition to alternative irrigation organizations. Finally, geographic position (general north/south and east/west position) offers no additional predictive power.

Column (3) and (4) use the alternative logit model for estimation. Notably, the variables included were necessarily reduced given the statistical process and limited observations. The qualitative results remain with the marginal impacts reported in Column (4). The four variables included—percent of farms irrigated, percent acreage irrigated, number of farms, and number of creeks—prove powerful predictors, classifying 88 percent of the observations correctly. Further details are provided in Table 3.1b. As discussed below, while many of the outcome variables are similar across counties pre-treatment, this model helps to identify important controls to be utilized in the main analysis.

3.3 Context Background

3.3.1 New Mexico's Development

Beginning in 1598, Spanish settlers developed new communities centered on the *acequia* throughout of *La Provincia del Nuevo México*. The irrigation canals were primarily for their own subsistence and essential to the survival of these early pioneers. Growth and development of irrigation continued through the Mexican period (1821-1848). Sovereignty of the region transferred to the United States of America with the Treaty of Guadalupe Hidalgo, ending the Mexican-American War in 1848.[10] As studied in detail in chapter two, initial legislation in the territory focused on water law and placed many *acequia* customs into statute but began to drift as Anglos sought economic gains.

The turn of the 20th century had New Mexico working to "modernize" their water laws, most markedly with the 1905 and 1907 water code with an eye towards large scale irrigation projects with federal assistance. With commercial irrigation companies struggling past initial construction (Hutchins 1930), New Mexico continued to expand the legal framework.[11] New Mexico enacted its first ID law in 1909, followed by two more in 1919 to offer more structure to those wishing to contract with the Federal Government. This was followed in 1923 with legislation to form conservancy districts. Subsequently the use of the special water districts grew, expanding from 13,398 acres irrigated by such operation (under the Bureau of Reclamations control) in 1910 to 190,518 acres by 1950—an average growth rate of 6.9 percent per year. Table 3.2 provides a list of the districts, when they formed, and the counties they span.

3.3.2 Social-Ecological Systems

Irrigation systems can be viewed as a SES in which natural resource systems interact with human systems. Here I adopt the version developed by Ostrom (2009) to frame the institutional comparison. The first tier categories are the resource units, resource system, user group, and governance system. These, along with the second tier variables are reproduced in Table 3.3 Between *acequias* and IDs; the root difference is the governance system. However, the

[10] U.S. military occupation began as early as 1846, though the Kearny Code of that year claiming the area remains legally dubious.

[11] Commercial irrigation companies faced many transaction costs due to considerable asset specificity. Often they found themselves either over or under capitalized and subject to holdouts. See Bretsen & Hill (2006) for more details.

Table 3.2: Current New Mexico Irrigation Districts

District	**County(ies)**				**Year**
Middle Rio Grande Conservancy District	Bernalillo	Sandoval	Socorro	Valencia	1925
Vermejo Conservancy District	Colfax				1952
Arch Hurley Conservancy District	Quay				1938
Hammond Conservancy District	San Juan				1956
La Plata Conservancy District	San Juan				N.D.
Pecos Valley Artesian Conservancy District	Eddy	Chaves			1932
Antelope Valley ID	Colfax				1912
Fort Sumner ID	De Baca	(Guadalupe)*			1919
Elephant Butte ID (EBID)	Dona Ana	Sierra			1918
Carlsbad ID	Eddy				1932
Santa Cruz ID (SCID)	Rio Arriba	Santa Fe			1925
Bloomfield ID	San Juan				1912
Bluewater-Toltec ID	Cibola	(Valencia)*			1927
Pojaque Valley ID	Santa Fe				N.D.
*County in parentheses indicate inclusion based on 1910 borders, but not current borders					

governance system endogenously influences second tier elements in other categories, outside of the resource units. As the SES framework has been applied to the *acequias* already by Cox (2014), the main focus here is on IDs and how they differ.

Table 3.3: Social-Ecological System Framework (Ostrom 2009)

Social, economic, and political settings (S)

S1 Economic development, S2 Demographic trends, S3 Political stability,
S4 Government resource policies, S5 Market incentives, S6 Media organization

	Resource Systems (RS)		Governance Systems (GS)
RS1	Sector	GS1	Government organizations
RS2	Clarity of system boundaries	GS2	Nongovernment organizations
RS3	Size of resource system*	GS3	Network structure
RS4	Human-Constructed Facilities	GS4	Property-rights systems
RS5	Productivity of the system*	GS5	Operational rules
RS6	Equilibrium properties	GS6	Collective-choice rules*
RS7	Predictability of system dynamics*	GS7	Constitutional rules
RS8	Storage characteristics	GS8	Monitoring and sanctioning processes
RS9	Location		

	Resource Units (RU)		Users (U)
RU1	Resource unit mobility*	U1	Number of users*
RU2	Growth or replacement rate	U2	Socioeconomic attributes of users
RU3	Interaction among resource units	U3	History of use
RU4	Economic value	U4	Location
RU5	Number of units	U5	Leadership/entrepreneurship*
RU6	Distinctive markings	U6	Norms/social capital*
RU7	Spatial and temporal distribution	U7	Knowledge of SES/mental models
		U8	Importance of resource*
		U9	Technology used

Interactions (I) → outcomes (O)

I1	Harvesting levels of diverse users	O1	Social performance measures
I2	Information sharing among users		(e.g. efficiency, equity,
I3	Deliberation processes		accountability, sustainability)
I4	Conflicts among users	O2	Ecological performance measures
I5	Investment activities		(e.g. overharvested, resilience
I6	Lobbying activities		bio-diversity, sustainability)
I7	Self-organizing activities	O3	Externalities to other SESs
I8	Networking activities		

Related ecosystems (ECO)

ECO1 Climate patterns, ECO2 Pollution patterns, ECO3 Flows into and out of focal SES

*Subset of variables found to be associated with self-organization

3.3.2.1 *Acequias*

Acequias are characteristically similar to mutual ditch companies found in other states. However, they do maintain a distinctive legal space in New Mexico as political subdivisions of the state rather than incorporation. The communal irrigation system typically relies on diverting streams via simple earthen head gates and utilizing flood irrigation prior to letting the excess water return to the stream for other downstream users. The communal ditches tended to serve relatively small group of neighbors who voluntarily joined together to dig the ditch. Historically a mayordomo, elected by members, would oversee the operation and irrigation schedule, often delivered on rotation. Today, the ditches operate in similar fashion, though typically with a larger group of commissioners.

3.3.2.2 IDs

Each ID is unique in its organization, making the institution somewhat difficult to generalize. The broad concept is used here to refer to conservancy districts as well, which are broader in scope, but often seen under the same legal umbrella (Getches 2009). Wells Hutchins (1931) defines them as a "public or quasi municipal corporation organized […] for the purpose of providing a water supply for the irrigation of lands embraced within its boundaries" (p. 2). They have well defined geographic boundaries and are formed under authority of State legislature with the consent of a designated fraction of the land owners. Importantly, this aspect can compel parties to be involuntarily included. With the ability to place assessments on the land, once formed it is possible to extract funds in order to invest in large infrastructure, providing a mechanism by which farmers can engage in larger irrigation projects by compelling dissenting minorities to pay (Hutchins 1931; Leshy 1982).

While varying state to state, most ID legislation is similar to The Wright Act of California of 1887.[12] Objectors of early districts questioned the constitutionality of institution, but in 1896 the US Supreme Court confirmed its legality, finding the development of the private land of public interest. Following this ruling, other states adopted similar legislation, including New Mexico.

From 1890-1928, the number of districts formed in the US grew from just 17 to 801, though by 1928 nearly 300 were inactive. The failure of districts occurred much more often where entirely new development was the goal rather than expansion (Hutchins 1931).[13] By 1970, these special districts accounted for half of the water used in the 17 western states and around a third of all the irrigated land in the West (Leshy 1982). In 1922 the federal government strengthened the power of IDs by allowing them to be the local contracting party for Bureau of Reclamation Projects. In 1926, they became the only legal contracting party. Now a Reclamation Project often required the formation of a district while in other instances the district already existed and could contract for water from government projects under the Warren Act.

While specific details on the IDs are hard to come by, the larger Elephant Butte Irrigation District (EBID) and Middle Rio Grande Conservancy District (MRGCD) are well documented on their websites (EBID 2013; MRGCD 2013). EBID was the first district in the state. It formed in 1918 to manage the Elephant Butte portion of the large Rio Grande Project which the Bureau of Reclamation constructed to deal with interstate and international allocation issues on the river. Today it has 90,640 acres of water righted land across two counties under its purview, serving over 8000 constituents. In 1925 the first conservancy district was formed. The MRGCD stretches

[12] Utah passed ID legislation in 1865, but few formed with success and what remained in 1929 tended to operate as a mutual ditch company (Hutchins, 1931).
[13] Failures occurred for a number of reasons, often insufficient capital or inability to deliver on bond payments due to agricultural production and price fluctuations.

150 miles along the Rio Grande, serving 11,000 irrigators and 70,000 acres of cropland. It employs 200 people to operate the 1,200 miles of irrigation ditches.

The appeal of IDs as contracting parties was financial: 1) they have the legal ability to tax the landowners, providing a single central and reliable source for repayment; and 2) they have the ability to issue bonds, providing a mechanism to take on debt for such projects. Indeed, while early districts were formed to secure internal financing through assessments, later districts often formed to secure external financing through bonds (Leshy 1982). Overall, they served to reduce many transaction costs of irrigation projects (Bretsen and Hill 2006; Libecap 2011). In addition, the central administration also reduced transaction costs in arranging for division of water amongst ditches.

With many districts formed, they are all organized somewhat uniquely. They vary in size, voting rights, management, bonds issuance, assessment criteria, treatment of individual defaults, operation costs, and perhaps most importantly, success. While the west has many of these, I focus on those formed in New Mexico. From 1910-1960 only 14 districts were formed, making it a manageable number (California had 168 by 1929 with 18 forming in 1920 alone [Hutchins 1931]). More importantly, the majority of which did not start anew, taking control of (sometimes dissenting) communal irrigation ditches.

3.3.2.3 Difference in Irrigation Enterprises—Social Ecological Systems

IDs are substantially different from the older *acequias*, though both ultimately aim to deliver water to irrigators, though not exclusively. At present, economic performance is assessed. However, one should keep in mind that *acequias* serve other functions than delivering water as cultural, spiritual, and ecological institution (Peña 1999; Rivera 1999 Rodríguez, 2006). As irrigation systems, the root difference stem from the legislative distinctions in their legal standings, resulting in a number of variant features. The statutory powers are quite a bit different, with *acequias* being quite weak despite being the oldest irrigation institution (Crossland 1990). To structure the discussion, I use the SES framework, including in text parenthetical notes to reference the second-tier factors as identified in Table 3.3. For example, (U1) refers the "Number of users".

Acequias do not have the power of inclusion, they cannot tax, and they cannot issue debt. This is perhaps the most marked financial advantage the IDs have over *acequias* (GS7) (Hutchins 1931; Leshy 1982). In addition, in the 1914 *Snow v. Abalos* case of the New Mexico Supreme Court, it was found that the *acequia* owned only the ditch and that individual *parciantes* owned the water rights privately, whereas districts are allowed to hold rights, often exempt from the requirement of use, though individual rights do exist within IDs (GS4).[14] The democratic process also differs, as IDs vote similar to a corporation where power is more likely to be proportional to land holdings. *Acequia* members typically vote only once per person (GS6). The decision process is more centralized with the number of member/board ratio much larger among the IDs.

Division of water varies as well (GS5). For users in IDs, they place an order for their water and then it is delivered as soon as hydrologically possible, often simultaneously with other farmers. The centralized coordination between head gates should improve efficiency as suggested by Wesley Powell in managing large geographical basins (Stegner 1954). For *acequia* farmers, delivery is almost always done on a rotational basis in which they receive the full flow for a given amount of time. Amongst members on the same river, either priority or some sharing agreement divided inter-*acequia* water use—with the sharing being more common among the *acequias*. With water rights pre-dating U.S. sovereignty the Treaty of Guadalupe Hidalgo

[14] In 1987 *acequias* received this right as adjudication of water rights proceeds throughout the state.

protects the rights and many areas in New Mexico have agreed to forego the priority system during adjudication processes (Richards 2008). This yields a decentralized administration and monitoring of water division, different than the internally managed and monitored division of water by IDs. Across streams, the IDs have considerably greater ability to effectively sanction any rule breakers (GS8).

One of the largest legal distinction is the ability (and necessity) of an ID to contract with the Bureau of Reclamation (GS1) as stipulated by federal law (Leshy 1982). The burden of debt, though, also necessitated an emphasis on the use of fees and assessments rather than labor which is often relied upon in communal ditches (GS5). *Acequias* seldom took on large debt loads, relying on savings and individual contributions instead, often using sweat equity rather than cash.

Due to the large expensive projects, IDs tend to be much larger than *acequia* systems (RS3). This drastically increases the number of users (U1), often being magnitudes larger. Arguably, the larger boundaries resulted in clearer system boundaries by including a number of diversion points on a single stream previously operating independently. With the ability to tax all users in a large area (including non-irrigators), they tended to undergo projects which altered the resource system beyond the capability of smaller local organizations (Wozniak, 1997). Notably, canals were expanded; head gates were upgraded to concrete structures; and dams constructed for both flood control and storage (RS4 and RS8), providing more predictability of the system (RS7).

3.3.2.4 Difference in Irrigation Enterprises—Census Data (1950)

In order to better understand the differences between the organizations, I present data from the 1950 Agricultural Census. This was the last census in which statistics were provided based on the type of irrigation enterprise.[15] For New Mexico, the communal ditch category is primarily made up of *acequias*. The statistics are used to highlight the differences in some of the SES characteristics. Table 3.4 summarizes the designed differences based on the institutional structure. The scale of the operation is telling, as the communal ditches average 14 users while the IDs average 420. This is unsurprisingly related to the difference in coverage, with IDs serving 19,052 acres on average while communal ditches cover 278. The numbers are indicative of a much more centralized governance system.

Table 3.4: Institutional Designed Distinctions		
	Communal Ditches	**IDs**
Owners	Private	Public
Management (GS1)	Users	Elected Board
Water Rights (GS4)	Individual	Group/individual
Voting Rights (GS6)	One per person	Proportional to land
Bureau of Reclamation Projects (GS1)	No	Yes
Formation (GS7)	Voluntarily	Voluntarily or involuntarily
Purpose	Irrigation	Irrigation/Flood Control/International Obligations
Finance (GS5)	Labor and Fees	Bonds and Assessments
Monitoring and Enforcement (G28)	Within canals: mayordomo, denial of water	Across canals: ID employees, denial of water
Enterprises*	565	10
Acres Irrigated*	156,891	190,518
Average Users* (U1)	14.20	420.40
Average Acres* (RS3)	278.00	19,052.00
Average Irrigation Acres/Farm*	19.56	45.32
***Data from the 1950 U.S. Agricultural Census**		

Table 3.5 provides a number of summary statistics from the 1950 Census that are can be seen more as outcomes, though causality is not transparent. These are divided into three

[15] The data are only available at the State level. The Census provide no county statistics by enterprise beyond 1910, precluding such detail in the econometric analysis below.

categories; finance, infrastructure and water delivery. For the purposes here, the IDs were combined with those classified as Bureau of Reclamation enterprises, as control of these often fluctuated between the local ID and the federal bureaucracy (Wozniak 1997). In terms of debt, the IDs far outstripped the communal ditches, averaging 350 times the amount of debt. Only 4 percent of the communal ditches have farmers reporting debt compared to 60 percent of IDs. The larger debt did accompany infrastructure improvements. With larger storage capacity the amount of irrigated land within IDs had access stored reserves. Diversion structures were also much more likely to be more solidly constructed out of concrete. These improvements were not without their own issues, as the districts often struggled to maintain the expanded infrastructure, raising fees often (Wozniak 1997).

Table 3.5: Institutional Outcome Distinctions*

Finances (I5)	Communal Ditches	IDs
Capital Investment	$ 5,589,490.00	$ 34,801,248.00
Total Indebtedness	$ 214,849.00	$ 18,131,576.00
Indebted Enterprises	25	6
Average Debt Reported	$ 8,593.96	$ 3,021,929.33
Infrastructure (RS4)		
Storage (AF)	128,430	3,006,800
Percent acres with Storage	0.23	0.95
Percent Concrete Diversions	10.8	72.7
Water (RS5)		
Cost of Water	$ 386,273.00	$ 1,138,107.00
Cost/Acre	$ 2.46	$ 5.97
Cost/Acre-Foot	$ 1.15	$ 1.05
Water Obtained (AF)	461,512.00	1,599,925.00
Water Delivered (AF)	334,625.00	1,082,096.00
Water/Acre	2.94	8.40
Water Delivered/Acre (O1)	2.13	5.68
Conveyance Loss/Water	0.25	0.30

*Data from the 1950 U.S. Agricultural Census

An important question is whether or not the centralized IDs were able to turn these scale and financial advantages into better water delivery. This could be addressed at the extensive margin (expanding irrigated acreage) as well as the intensive margin (delivering more water per irrigated acre). On the extensive margin, it appears clear that they were effective in expanding irrigated land. Mesilla Valley consisted of 11 ditches in 1890 that managed to irrigate 31,700 acres. This declined to 24,260 by 1903. Once the EBID formed in the region, the Mesilla Valley jumped quickly to 45,995 irrigated acres by 1917 and nearly doubled to 88,714 by 1945.[16] The IDs perform well on the intensive margin as well. Based on the 1950 census data, while cost of water increased on a per acre basis, IDs delivered more than twice the water of communal ditches. On net the cost of water per acre-foot was less in IDs than the communal ditches. These statistics do not necessarily imply the IDs are better at delivering water, as they often form where water was more abundant to begin. In fact, on the efficiency measure of loss water in conveyance, the IDs fare worse than the communal ditches on average, though have larger systems. To better understand the causality of IDs, I now turn to panel data.

3.4 Data and Methods

3.4.1 Data

The main source of data comes from publicly available records of US Irrigation and Agricultural Census from 1890-1987, though the regression relies on nine Censuses from 1910-1978.[17] Initial collection of census data came from manual entry from the original (electronically available) county reports (U.S. Department of Agriculture 2012; U.S. Census Bureau 2011). Additional census data was later added from the Interuniversity Consortium for Political and Social Research (Haines 2005; Gutmann 2005). Historic county shapes were downloaded from

[16] Figures tabulated from data reported in Wozniak 1997.
[17] Census years are 1910, 1920, 1925, 1930, 1940, 1945, 1950, 1954, 1959, 1964, 1969, 1974, and 1978

the Minnesota Population Center's National Historical Geographic Information System (2011). In addition, reports from the Office of the State Engineer in New Mexico are utilized to identify various IDs and *acequias* (Saavedra 1987). A number of sources are referred to in order to place a date of formation on the IDs and *acequias* (Block 2014; Clark 1987; Dos Rios Consultants 1996; U.S. Department of Interior 2004). Pertinent literature was reviewed for historic background. Additional data for controls come from Dustin Frye (2014).

3.4.2 Method: County Level Difference-in-Differences

The main analysis tool is a Hedonic valuation utilizing a Difference-in-Differences (DiD) framework at the county level to leverage a quasi-experiment. The specification is as follows:

$$Y_{ct} = \beta_1 \times PostDistrict_{ct} + \beta_2 \times District_c + Census_t + X_{ct} + \varphi_c + \epsilon_{ct} \qquad (3.1)$$

Conceptually, DiD is akin to subtracting the change of the treated group before and after treatment, and then subtracting off the before and after difference of a control group. The latter step removes any changes overtime that are universal—unrelated to treatment. In the specification above, subscript c refers to the county and t refers to the year.

The primary outcome (Y_{ct}) considered is the logged price per acre of agricultural land. The methodology follows a number hedonic value studies, relying on a related market to back out the value put on a component that does not have a market itself. With the inclusion of numerous other variables that likely effect agriculture land value, the remaining portion is attributed to the presence of the ID. The measure should capture the net gain or loss. The method has been applied to agriculture land for water rights (Crouter 1987; Faux and Perry 1999; Petrie and Taylor 2007), groundwater access (Hornbeck and Keskin 2011), irrigation management (Edwards 2014) and market access by interstates (Frye 2014). Inclusion of implicit water supply controls further attempts to isolate the component of the ID related to water delivery management from water supply expansion. Though data limitations admittedly truncate the extent to which the conclusions of specific mechanisms can be made. For instance, if the added value is from production smoothing due to storage, this component is not explicitly differentiated in this analysis due to insufficient "pre-treatment" observations to measure variability.

I consider other outcomes for Y_{ct}, all of which in log form, in order to distinguish some of the benefits and costs of IDs to better understand the change in land valuation. Primarily, I look at the crop value sold, a more general measure including animal products as well, irrigation costs and debt levels. On the production side, concentrating on the average by acre rather than farm helps to identify the increased productivity without concern for changes of farm size and number. Debt and irrigation costs are available for a shorter time-series, not extending beyond 1940. The measure of debt pertains to the farmers, not the relevant irrigation organization.

β_1 is the coefficient of interest, capturing the impact of the interaction term, $PostDistrict_{ct}$ indicating the county has a district formed. Rather than a discrete indicator variable, I utilize a continuous treatment measure based on the percent of irrigated acres by the districts in the county compared to the total number of acres in farms. IDs rarely encompass an entire county, causing a simple indicator variable to drastically overstate the extent of treatment at the county level. The measure is based off 1987 data, a year with county level data on the extent of IDs. Accordingly, I utilize 1987 farm acreage as well, causing this measure to remain constant over time despite the likelihood that it varied in reality.[18] Given the non-random

[18] Evidence suggests that farm acreage decreased in district counties. This implies the measure would overstate the presence of IDs in the past, possibly leading to an overstatement of the magnitude. Alternatively, regressions

placement of IDs, particularly related to irrigation, I can only advance the estimated impact as the treatment on the treated.

$District_c$ is a dummy as to whether the county received or will have an ID. $Census_t$ represents a series of dummy variables for the various census years, capturing macro shocks: crop prices; inflation; available technology; general weather conditions. φ_c are county level controls that do not vary over the sample period. These include the average elevation and ruggedness, latitude and longitude measures, as well the presence of railroads within the county. These controls, along with $District_c$, are no long longer explicitly controlled when county fixed effects are included. X_{ct} contains additional controls which vary overtime and are likely to influence agricultural land value and production. The fraction of irrigated farms, irrigated acres, total number of farms, and the number of creeks are all included, as these were significant predictors of ID formation. I include the total population and farm acreage, primarily to control for land scarcity. A count of dams in the county is included to remove some of the infrastructure gains. An indicator for the eventual presence and the presence of Interstate 25 addresses the concern that I-25 closely follows the Rio Grande and may impact agriculture value through increased market access (Frye 2014). Finally, I include measures of the main crops—wheat, hay, oats, corn, and beans—as a fraction of county acreage to address differential yields and prices. This inclusion is more intended for the production outcomes, as the value of the land should not be beholden to the current crop mix, though the crop mix may indicate the suitability to certain crops.

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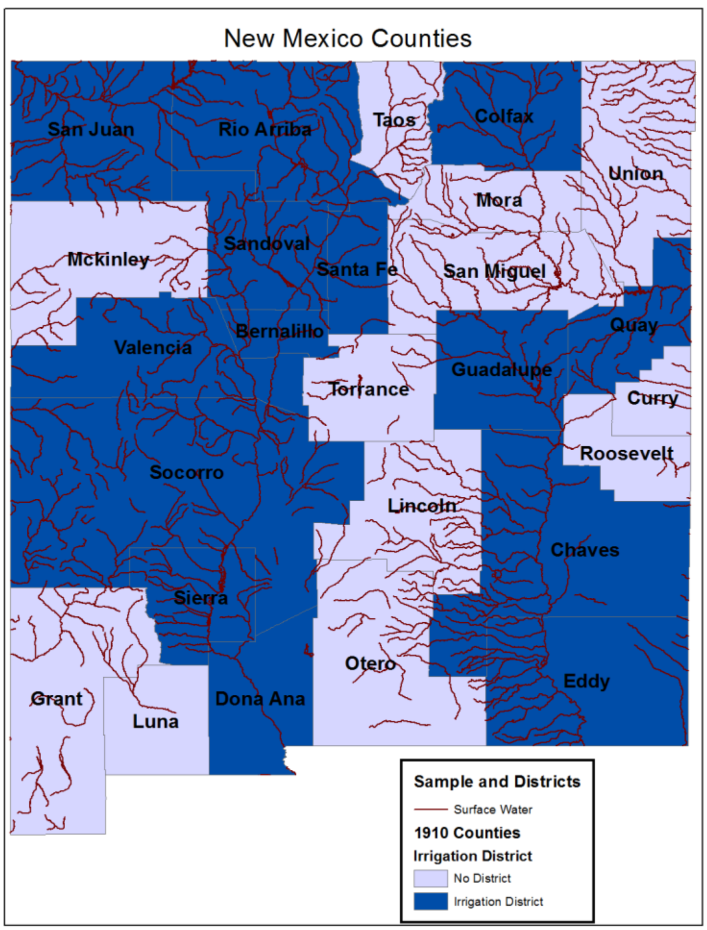
are also run allowing the denominator to vary based on specific year farm acreage (available upon request). As expected, all results remain, though are slightly reduced in magnitude. However, this alternative measure continues to utilize ID acres from 1987 as the numerator, leaving another source of bias that may or may not be worse than the chosen constant measure.

Conducting historic, county level analysis in the Western United States presents issues due to altering borders. In comparison to the East, the counties in the West are both larger and less consistent during this period. Today New Mexico boasts 33 counties, but as early as late as 1900, the same geographic area was divided into only 19 counties. Much of the dynamic process ended by 1925, but many IDs formed prior to this time.[19] Thus, there is a trade-off between the inclusion of ID counties and precise county level data. The main analysis is based on the 26 counties as drawn in 1910, shown in figure 3.1. As commonly done, the data from other years

Figure 3.1: 1910 NM Counties



[19] Los Alamos formed in 1949, but is quite small and has a miniscule agriculture sector. Cibola County formed from Valencia county in 1981.

are reweighted to reflect these borders (e.g. Hansen et al. 2009). In instances of a county being divided in two, this process is clearly valid. In instances of two counties forming three, the validity rests upon the assumption that the agricultural data is uniformly distributed geographically. This assumption is somewhat tenuous given the size of the counties and clumping of agriculture around streams, but this instance impacts only 3 counties. As robustness checks, I explore other variations of sample selection and data construction.

3.4.3 DiD Assumptions

In order for the above equation to have a causal interpretation, it is necessary to satisfy the assumptions that the two sets of counties, those with and those without districts, would have shared an overall trend absent the intervention. Inherently unknowable, often this assumption is validated through showing equal trends prior to intervention. In Table 3.6, I provide the coefficients for year fixed effects interacted with $District$ for the various outcomes. The regression includes all the other controls. An ID county is dropped from the sample once the ID is formed. Save the 1925 and 1930 year effects for agricultural production per acre, the district counties are not statistically different from the control group time dummies. Given the number of regressions, the 2 of 26 coefficients significant is not out of line with what one would expect to randomly find. With no distinguishable difference in pre-treatment trends, the different counties could be expected to continue to share a trend absent intervention.

Alternatively, levels—rather than trends—are often compared. Table 3.7 presents the mean values of variables in 1910, split by district and non-district counties. The counties included in districts do appear to have different levels in a number of categories, but few exhibit any statistical significance. Notably, the outcome variable means are not statistically different in 1910.

Table 3.6: Pre-treatment Trends

VARIABLES	(1) Land Value per Acre	(2) Total Value Crops Sold	(3) Value of Crops per Acre	(4) Value of Agric. Products	(5) Value of Agriculture Products per Acre	(6) Irrigation Cost per Acre	(7) Total Debt
1910 x District	-0.0605	0.217	-0.0809	0.315	0.0172	-0.0573	0.199
	(0.188)	(0.163)	(0.198)	(0.272)	(0.313)	(0.448)	(0.263)
1920 x District	0.00736	-0.0769	0.148	0.0794	0.304	-0.292	-0.321
	(0.213)	(0.184)	(0.224)	(0.308)	(0.354)	(0.503)	(0.295)
1925 x District	0.208	-0.0802	0.229	0.431	0.740**		
	(0.220)	(0.191)	(0.232)	(0.319)	(0.366)		
1930 x District	0.386	-0.336	0.256	0.428	1.021**	-0.126	-0.599
	(0.280)	(0.243)	(0.295)	(0.406)	(0.467)	(0.740)	(0.394)
Constant	3.068***	14.66***	2.126***	13.72***	1.193*	3.981***	14.48***
	(0.371)	(0.321)	(0.391)	(0.537)	(0.617)	(0.890)	(0.630)
Observations	83	83	83	83	83	54	62
R-squared	0.771	0.869	0.783	0.838	0.748	0.728	0.833

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3.7: Summary Statistics (1910)

	All Mean	Non-District Mean	District Mean	Difference
Variable of Interest				
Fraction Acres Irrigation District	0.01	0.00	0.02	-0.02*
Outcomes (logs)				
Log of Price per Acre	2.39	2.33	2.45	-0.12
Total Crop Value	12.51	12.28	12.71	-0.43
Crop Value per Acre	-0.11	-0.22	-0.01	-0.21
Value of Agricultural Good Sold	14.36	14.27	14.44	-0.17
Value of Agricultural Good Sold per acre	1.74	1.76	1.72	0.05
Irrigation Cost per Acre[a]	14.48	18.23	11.89	6.34
Total Debt	13.52	13.30	13.71	-0.41
Debt to Value Ratio (not Logged)	23.18	22.59	23.69	-1.10
Controls				
Number of Farms	1372.15	1,387.92	1,358.64	29.27
Number of Farm Acres	433462.30	400,290.60	461,895.30	-61,604.70
Fraction Irrigated Farms	0.45	0.29	0.59	-0.30**
Fraction Irrigated Acres	0.09	0.06	0.11	-0.05
Number of Creeks	5.62	6.08	5.21	0.87
Number of Dams	0.27	0.25	0.29	-0.04
Population	12,588.50	11,596.58	13,438.71	-1,842.13
Interstate Present	0.31	0.08	0.50	-0.42**
Railroad Present	0.81	0.92	0.71	0.20
Mean Elevation	87.31	79.68	93.84	-14.16
Mean Ruggedness	2126.19	1998.76	2235.43	-236.67
Latitude	-66041.35	-132244.00	-9296.18	-122947.90
Longitude	-819821.20	-644927.80	-969729.80	324802.00
Fraction Acres for Hay	0.0172	0.0206	0.0142	0.0064
Fraction Acres for Oats	0.0006	0.0006	0.0005	0.0001
Fraction Acres for Wheat	0.0006	0.0006	0.0006	0.0000
Fraction Acres for Corn	0.0016	0.0023	0.0011	0.0012
Fraction Acres for Beans	0.0004	0.0005	0.0003	0.0002

Table Continued Below.

Table 3.7: Summary Statistics (1910)--Continued

	All Mean	Non-District Mean	District Mean	Difference
Other Variables of Interest				
Irrigation Enterprises[a]	125.18	104.67	139.38	-34.72
Land per Enterprise[a]	382.16	287.12	447.95	-160.84
# of Main Ditches[a]	95.05	97.67	93.23	4.44
Ditch Length--miles[a]	265.59	195.56	314.08	-118.52
Acres capable of irrigating[a]	29189.82	16,121.89	38,236.85	-22,114.96**
Percent of irrigated capacity[a]	0.72	0.77	0.68	0.09
Acres Irrigated by Stream[a]	18115.45	12,788.11	21,803.62	-9015.504*
Reservoirs[a]	23.09	22.00	23.85	-1.85
Storage Capacity	1234.61	907.07	1,515.36	-608.28
Acequias (1987)	26.69	27.50	26.00	1.50
Total Acequias (Historic Count)	58.76	64.27	54.43	9.84
Fraction Acequias Lost	0.52	0.41	0.60	-0.20
# Farms Using Commercial Fertilizer	31.81	41.42	23.57	17.85
Fertilizer Expenses	975.81	772.92	1,149.71	-376.80
Hired Labor Expense	114839.50	104,106.80	124,038.90	-19,932.02
Fraction Tenants	0.07	0.06	0.08	-0.02
Observations	26	12	14	

Statistically different means
*** p<0.01, ** p<0.05, * p<0.1

[a] Irrigation data for Curry, Quay, Roosevelt, and Torrance Counties are not disaggregated in the 1910 census, resulting in 9 non-district and 13 district observations

Overall the evidence supports the utilization of non-district counties in New Mexico as a control group, especially as a good proxy for performance where *acequias* remain the main irrigation institution Below some evidence as to the exogeneity of the treatment is assessed from the communal irrigators' perspective.

3.4.3.1 Local Opposition

Acequia users tend to be opposed to being part of IDs, yet have been included in many places. Drawing on the five northern counties and their experience with formed districts and defeated districts, José Rivera (1998) reveals the concerns small *acequia* farmers have. In fending off a district in Taos County, Rivera says users fear that "not only would acequia self-government be circumvented by a superimposed board from the conservancy district, but the economic risks could bankrupt the irrigators individually" (p. 157). Ultimately these concerns defeated the formation of the Rancho del Rio Grande Conservancy District and *acequias* maintained local control of water decisions in Taos County. Many feared being forced into a market economy to financially keep up with ID alterations. The fear of being priced out and losing their communal roots, let alone the concern of losing control, turns out to be well founded based on the analysis below.

In many places *acequias* were unable to defend themselves and were subsumed by the larger governance structures. Of the six IDs operating in New Mexico in 1929, five had taken over irrigation systems already in place (Hutchins 1931). Using historical tabulations of *acequias* from Dos Rios Consultants (1996) and a State Engineer report of those still in existence in 1987 (Saavedra 1987), regressions on the percent of *acequias* no longer in existence find the formation of a district is the best and largest predictor. Results are reported in Table 3.8. While on average 31 percent have vanished, in counties with IDs, the rate is 63 percent, over twice the rate of loss.

Table 3.8: Lost Acequias (1987)

	(1) Fraction Lost
District	0.323** (0.144)
Constant	0.307*** (0.105)
Observations	28
R-squared	0.163

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

3.5 Results

3.5.1 Graphical Evidence

Prior to the statistical results, Figures 3.2, 3.3 and 3.4 provide a visualization of the trends for land value and value of all agriculture products, and irrigation costs per acre. These are all raw means of the district and non-district counties without any other controls. For Figure 3.2, the agriculture land values, the pre-trend of the two counties look similar. The ID adopters do appear to weather the depression era slightly better. The gap persists and even expands through 1960 before the non-districts begin to catch up. For agriculture products sold (Figures 3.3), the pretreatment trend looks very similar. The gains by the ID counties appear relatively later, sometime after 1940. This may partially be mechanical, driven by the various timing of ID adoption, with the positive impact of adoption being washed out by including counties not yet

Figure 3.2: Land Value overtime

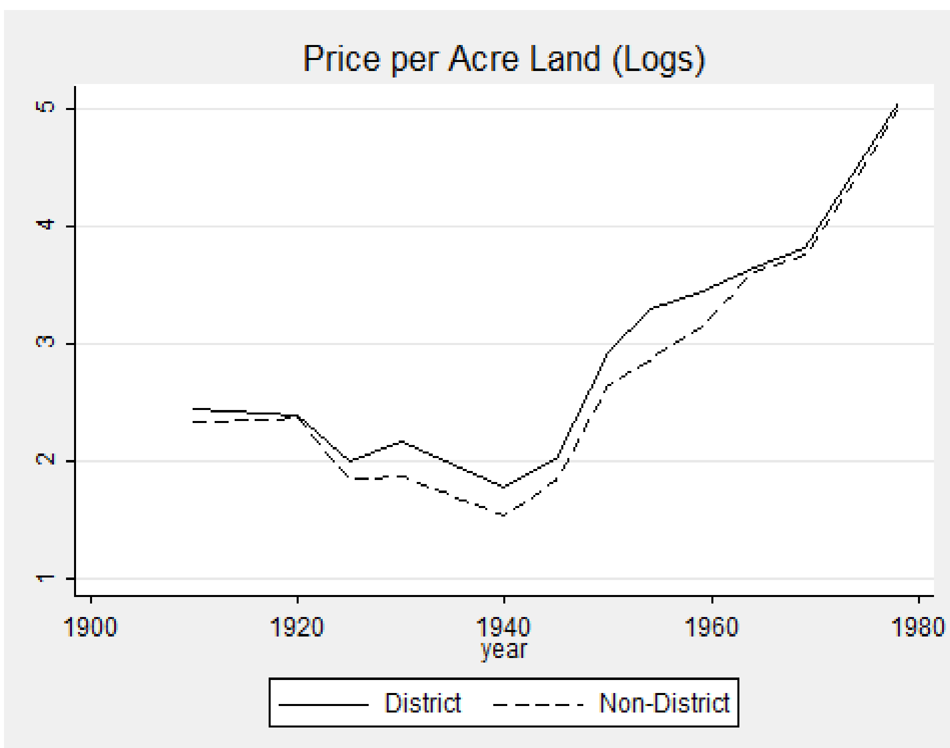


Figure 3.3: Agriculture Products Sold Overtime

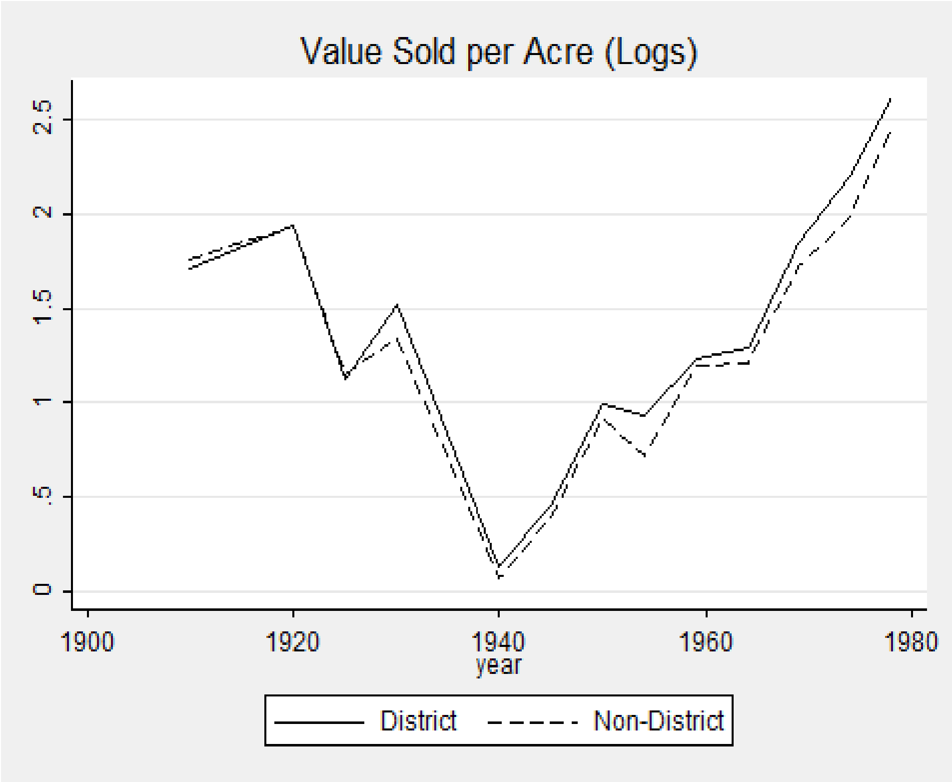
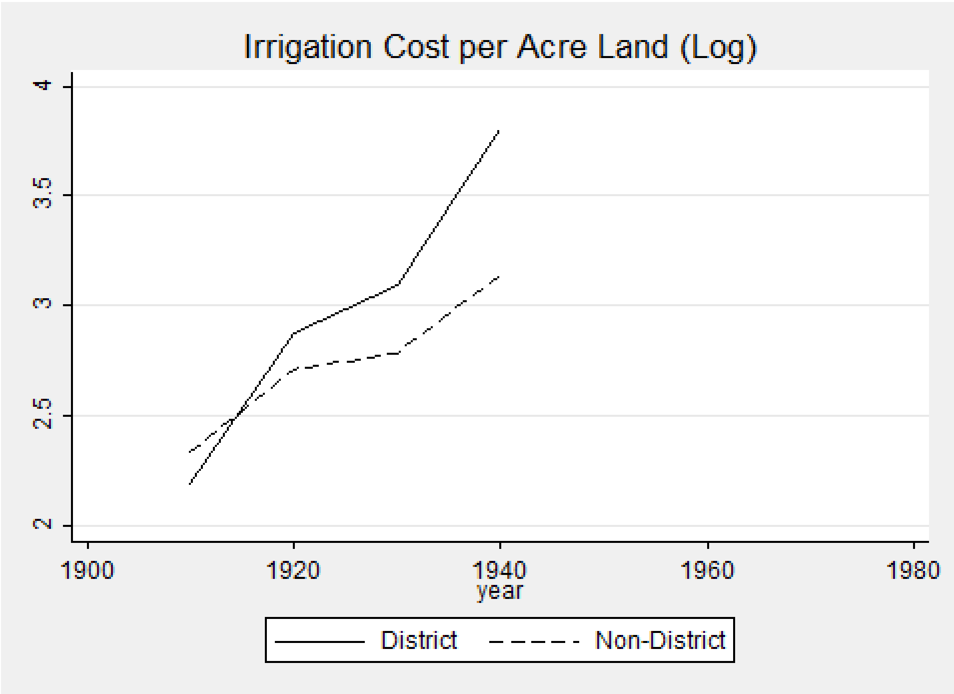


Figure 3.4: Irrigation Cost Overtime



choosing IDs in the mean. Alternatively, the delayed impact can be seen as the result of the lag between adoption and completion of physical infrastructure and implementation of new distribution rules. For instance, while the MRGCD formed in 1925, much of the infrastructure was not completed until 1934. In contrast, the price per acre would have incorporated the future benefit in the early periods.

3.5.2 Difference-in-Differences

In Table 3.9, I present the main results with the additional controls suppressed.[20] Column (1) summarizes the Hedonic outcome of land value, with 100 percent of county forming an ID leading to a 5.47 log point increase in price, an economic and statistical significant impact. Because the typical ID County is not fully covered by the ID, but rather around 2 percent of the land, the estimate needs adjusted. With this in mind, the average increase in price per acre is nearly 12 percent if we assume the gains are attributable only to the fraction of farm land in the ID. This rescaling of the main results can be found in Table 3.10. Because the change in log points remains large, I do calculate the corresponding percentages.

The largest gains are in the value of crops sold, increasing nearly 35 percent on average. This boon in production is somewhat tempered once all agriculture products are considered, though remains around 19 percent within IDs. The gains in production come at a cost, with ID counties having a 19 percent increase in irrigation costs per acre. And while not a cost per se, the ID counties do see an increase in the amount of debt by around 15 percent, substantiating some of the *acequia* irrigators concern of adopting an ID. Finally, it is noted that there is no significant increase in the debt-to-value ratio, and if anything, a decrease.

[20] Full tables are available from the author upon request.

Table 3.9: District Impact on Agriculture 1910-1978

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	Land Value per Acre	Total Value Crops Sold	Value of Crops per Acre	Value of Agric. Products	Value of Agriculture Products per Acre	Irrigation Cost per Acre	Total Debt	Debt-to-Value Ratio
Post District (Fraction of Acres)	5.469***	14.93***	14.86***	8.526***	8.496***	8.538***	7.060***	-13.05
	(1.216)	(3.343)	(3.303)	(1.657)	(1.677)	(2.048)	(1.656)	(13.46)
District	-0.126	-0.116	-0.266	-0.0643	-0.218	0.00939	0.0888	-0.288
	(0.0848)	(0.415)	(0.421)	(0.164)	(0.147)	(0.284)	(0.185)	(1.649)
County Fixed Effects	N	N	N	N	N	N	N	N
Census Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	338	329	329	338	338	95	104	104
R-squared	0.89	0.706	0.719	0.846	0.8	0.592	0.778	0.393
Post District (Fraction of Acres)	3.152**	10.96***	13.98***	8.638***	11.57***	8.667***	1.591	0.441
	(1.19)	(2.844)	(4.968)	(1.611)	(2.936)	(2.019)	(1.346)	(18.28)
County Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Census Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	338	329	329	338	338	95	104	104
R-squared	0.896	0.619	0.573	0.856	0.797	0.586	0.739	0.387
Number of id	26	26	26	26	26	25	26	26

Robust standard errors clustered at the county level in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Note: Sample consists of 1910 counties with data reweighted to reflect these borders. Additional controls include #farms, #farm acres, %farms irrigated, %acres irrigated, #creeks, #dams, population, interstate indicator, railroad indicator, elevation, ruggedness, latitude, longitude, %acreage for hay, wheat, corn, beans, and oats.

Table 3.10: Coefficient Interpretation (1910-1978)

	Mean	Observations	Coefficient	Log Points	Percent
Post District (Percent 1987)	0.02	14	n/a	n/a	n/a
Land Value per Acre	2.96	338	5.469	0.11	11.64
Total Value Crops Sold	13.60	329	14.93	0.30	35.07
Value of Crops per Acre	-0.32	329	14.86	0.30	34.88
Value of Agric. Products	15.26	338	8.526	0.17	18.73
Value of Agriculture Products per Acre	1.35	338	8.496	0.17	18.66
Irrigation Cost per Acre	2.90	95	8.538	0.17	18.76
Total Debt	14.23	104	7.06	0.14	15.28

Note: Coefficient comes from non-county fixed effect regression of 1910 county borders with the full set of controls.

These results are robust to the inclusion of county fixed-effects, as presented in the second panel of Table 3.9. The inclusion of the fixed effects does tend to slightly attenuate the valuation and crop production. The remaining results remain stable, though the impact on debt is smaller and no longer statistically significant at typical levels.

When analyzing an institution or organization, it is important to understand how they perform in a variety of economic and climactic conditions (Ciriacy-Wantrup 1967). Accordingly, I run the main regression with the price of farm land using 1910 as the pre-treatment year and each subsequent census as the post-treatment period, presented in Table 3.11.

Table 3.11: District Impact on Agricultural Value by Year

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre	Land Value per Acre
Post District (Fraction of Acres)	3.437	4.699***	6.996***	6.255***	4.708***	5.228**	13.40***	7.199***	1.856	4.482**	1.578	1.935
	(2.701)	(1.277)	(2.508)	(1.651)	(1.594)	(1.973)	(3.286)	(1.634)	(2.281)	(1.615)	(1.717)	(1.997)
District	-0.0724	0.137	0.114	-0.0133	0.00933	0.0354	-0.0802	-0.15	-0.185	0.0554	-0.0107	-0.0541
	(0.158)	(0.169)	(0.194)	(0.147)	(0.0928)	(0.121)	(0.138)	(0.131)	(0.197)	(0.199)	(0.219)	(0.21)
Year	1920	1925	1930	1940	1945	1950	1954	1959	1964	1969	1974	1978
Observations	52	52	52	52	52	52	52	52	52	52	52	52
R-squared	0.787	0.805	0.822	0.849	0.811	0.79	0.847	0.831	0.852	0.906	0.922	0.954

Robust standard errors clustered at the county level in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: Sample consists of 1910 counties with data reweighted to reflect these borders. Additional controls include #farms, #farm acres, %farms irrigated, %acres irrigated, #creeks, #dams, population, interstate indicator, railroad indicator, elevation, ruggedness, latitude, longitude, %acreage for hay, wheat, corn, beans, and oats.

Even with the limited observations (52), many of the individual periods have a statistical and economic significant gain. There is little gain in 1920, as could be expected with IDs forming only as early as 1918. Throughout the depression period (1925-1940 censuses), the IDs provided a significant positive value. This gain increased as conditions improved in the 1950s, accented by a 31 percent premium in 1954. Later periods do not exhibit the same advantages, with the magnitude and statistical precision of the estimates decreasing.

3.6 Robustness

3.6.1 Sample Selection

Utilizing the 1910 borders and reweighting the remaining observations is but one way to address the shifting county boundaries. Table 3.12 report three alternatives with attention to the main outcome variable of land value per acre. I reduce the sample to the 17 counties that existed in 1910 and were not subsequently divided. This smaller sample removes the need to reweight any data, but greatly reduces the observations to 10 ID counties and 7 non-ID counties (Column 1). Column (2) does the same thing for 1920 counties—including the 24 counties stable after 1920—but having adjusted 1910 data to the 1920 borders. The hybrid method reduces the reweighting, but permits the inclusion of the 5 counties forming an ID prior to 1920. Alternatively, I utilize the 1978 county borders, reweighting the prior periods based on the uniform geographic assumption to the 32 counties (Column 3). Notably, all three remain statistically significant. The 1978 county point estimate is the smallest, though this could be attributed to the implicit assumption of uniform distribution of agriculture statistics. Given the clumping of agriculture around streams, the assumption is unlikely met, leading to a noisier estimate as ID farms are attributed to non-ID counties and vice-a-versa.

Table 3.12: District Impact on Agricultural 1910-1978 (Alternate Samples)

VARIABLES	(1) Land Value per Acre	(2) Land Value per Acre	(3) Land Value per Acre
Post District (Fraction of Acres)	6.614***	4.270***	1.886**
	(1.425)	(1.037)	(0.693)
District	-0.0664	0.0265	-0.00973
	(0.122)	(0.0909)	(0.0745)
Sample	1910 Consistent	1920 Consistent	1978 Borders
County Fixed Effects	N	N	N
Census Fixed Effects	Y	Y	Y
Observations	202	293	410
R-squared	0.887	0.896	0.881

Robust standard errors clustered at the county level in parentheses: *** p<0.01, ** p<0.05, * p<0.1

Note: Additional controls include #farms, #farm acres, %farms irrigated, %acres irrigated, #creeks, #dams, population, interstate indicator, railroad indicator, elevation, ruggedness, latitude, longitude, %acreage for hay, wheat, corn, beans, and oats.

3.6.2 Non-Agriculture Outcomes

A threat to identifying causality, even with fixed effects, is the possibility of an excluded variable that is correlated ID district counties and altering property values or general production. To assess this possibility, Table 3.13 provides regression results from non-agriculture sectors, though do no perfectly parallel the main results above due to data limitations. Column (1) and (2) consider manufacturing output. According to recent work by Richard Hornbeck and Pinar Keskin (2012), agriculture gains are not expected to spill over to other sectors. Data for manufacturing production at the county level is not reported in 1910, though collected and published in 1900. Therefore the regression uses reweighted 1900 data to capture a pre-treatment period. The result is a noisy, negative estimate of IDs impact. This makes it very unlikely that the ID counties were simply attracting better capital and labor in general for an unrelated reason and becoming more productive overall.

Table 3.13: Non Agriculture Outcomes

VARIABLES	(1) Manufacturing Output	(2) Manufacturing Output	(3) Median Home Value	(4) Median Rent
Post District (Fraction of Acres)	-5.400	-4.856	-1.526	-1.157
	(4.661)	(5.769)	(1.862)	(0.971)
District	-0.227			
	(0.337)			
Observations	89	89	130	129
R-squared	0.565	0.486	0.924	0.927
Number of id		26		

Robust standard errors clustered at the county level in parentheses: *** p<0.01, ** p<0.05, * p<0.1
Note: Sample consists of 1910 counties with data reweighted to reflect these borders. Additional controls include #farms, #farm acres, %farms irrigated, %acres irrigated, #creeks, #dams, population, interstate indicator, railroad indicator, elevation, ruggedness, latitude, longitude, %acreage for hay, wheat, corn, beans, and oats.

Column (3) and (4) consider non-agriculture real estate values to assess whether the gains in agriculture property value are a product of a county wide gain. These data are not available until 1930, providing very little pre-treatment data. Accordingly, the district dummy is removed and the regressions do not follow the DiD structure, and instead only look at the difference between county types. There is no positive premium in home values or rent amounts in ID counties, though without the DiD structure, this does not preclude that ID counties gained more relative to non-ID counties. On net, the evidence supports the gains in agriculture land value stem from the formation of IDs.

3.7 Discussion

3.7.1 General Results

The formation of an ID improved the value of agriculture land. As discussed above, the gain could come through a number of channels, primarily the centralized management of distribution or the ability to overcome free-riding and construct shared infrastructure. The statistical results are not well positioned to distinguish between the two. Regardless, the results presented make some effort to remove gains from improved infrastructure. The additional controls do include fraction of land irrigated, capturing some expansion of supply, as well as the number of dams for irrigation use.[21] To this extent, the measured gains are excluding some infrastructure, though is not only the management effect. Indeed, regressions without the additional controls result in much larger gains, nearly twice as much in most cases.[22] On net, the IDs provide a substantial increase in land value, varying from 4 to 12 percent depending on the specification.

Most of the production gains are made at the intensive margin, delivering more irrigation water per acre. The aggregate increases of both crop and general agriculture products differs little from the per acre increases in production. Though unreported, there is very little increase in farm acreage in ID counties, while there are some gains in irrigated acres. However, controlling for irrigated acres their remains a premium in crop production, indicative of the greater water supplied from the 1950 census. The ID districts not only increase the irrigated acreage, but also appear to make the given irrigated acreage more productive.

It is worth noting that the gain in crop production of ID counties is far larger than the general measure of agriculture products (and the value of land per acre). Though further detail is not pursued here, these results are consistent with adjustments along other margins. That is, non-ID counties are choosing production in areas less dependent on irrigation. Accordingly, the main results should be treated as the treatment-on-treated effects, with gains from IDs being smaller in counties with less centralized water supplies. The gains were costly. Though the time-series is shorter, average irrigation cost per acre increased by $5.31 in district counties, nearly 20 percent

[21] The measure of dams do not account for gains to downstream counties, rather the raw number within the borders of the county.
[22] Additional results are available from the author upon request.

of the overall average. The evidence is consistent with the *acequia* irrigators concerns of IDs driving prices up and some farmers out. Economically, if growth in production was the goal, the IDs not only solved transaction costs but also yielded net benefits. From the local communal irrigators' perspective, they may still lose out if they are priced out of farm land market, possibly losing the land and forced to become tenants.

3.7.2 The Depression Era

Briefly, Siegfried von Ciriacy-Wantrup (1967) suggested that the measure of institutional rule efficiency should be performance in a variety of settings in contrast to profit maximizing in any one period. Overall, the 1920s and 1930s were a time of economic struggle for farms with high levels of farm foreclosures due to financial pressures (Alston 1983) and production shocks due to the dust bowl. Overall, production during this period declined in New Mexico, bottoming out in 1940 while irrigation costs and debt climbed, making the 1940 census of particular interest. Not only does this year exhibit a productive slump, the economic strain on farmers took a toll, more so in financed IDs. Frank Wozniak (1997) reports that 90 percent of the MRGCD lands were delinquent on payments and nearly a third of the irrigable land was confiscated by the state during the 1940s. Hutchins (1931) provides further national evidence that IDs suffered financially during this period through wide spread bond failures. Despite this, regressions looking only at 1910 as the pre-period and 1940 as the post-period yield evidence supporting the general findings above: Even in financial turmoil, the IDs softened the blow, making land relatively more productive and more valuable.

3.8 Conclusion

The evidence is supportive that the change of governance structure, from local communal irrigation organizations to larger centralized IDs, resulted in large production and value gains in

New Mexico. The institutional advantages given to IDs allowed for the expansion of irrigated land within the treated counties. The financial advantages of bonds and taxes allowed the irrigators to overcome free-riding and expand the water supply through infrastructure improvements, leading to more irrigated acreage. Though not conclusive, the econometric analysis indicate additional advantages of centralized management and reduction of transaction costs in making water allocation an internal, firm-like process. The centralization process did not extend too far, suggesting the IDs may have formed at the appropriate scale (Bretsen and Hill 2006), often reaching across county borders to manage hydrological basins as advocated by General Powell (Stegner 1954). Even with higher costs of irrigation, according to land value, the net benefit remains positive.

The economic impact should also be considered in light of ecological and cultural impact. For instance, while the land became more valuable and more productive, it is unclear the amount of displacement that occurred. The concerns of being priced out of farming by the original irrigators may represent a real cultural cost. The evidence certainly indicates an increase in farm prices as well as an (unreported) uptick in tenancy rates, though this is merely consistent with displacement, not conclusive. Fundamentally, the *acequias* also differ in that it is a cultural and ecological institution (Peña 1999; Rivera 1999; Rodríguez 2006), providing users with values beyond economic production (Brown and Rivera 2000). As Crossland (1990) puts it, *acequia* "people interacted with arid lands instead of dominating them technologically" (p. 278). Summary of Taos county in the 1890 Census of Irrigation echoes this notion, saying the irrigation "is of the most primitive character," but also, that they are not often short of water because the "have learned to adapt their acreage to the probable supply from the streams" (p. 201). This is to note that there is possible value beyond the direct economic output which is the metric considered here and increased production may be at odds with the sustainability of the environment. The large use of water for irrigation in the West, attributable largely to IDs and the Bureau of Reclamation (Libecap 2011) are not necessarily socially desirable.

Chapter four: Common or Private Property: The Relative Efficiency of Alternative Water Rights

4.1 Introduction

Arid regions are dependent on irrigation technology and institutions to be agriculturally productive. Because water is rival in consumption, while its mobility and non-distinctive marking makes exclusion difficult, efficient allocation is difficult. Stochastic supply of annual snowmelt requires a system to be flexible due to wide variation in temporal availability. In the Western United States, two distinct systems developed to cope with the issue. The first came through Spanish colonization, in which communal ditches called *acequias* developed decentralized agreements to share water more-or-less equally. The second developed during the American settlement of the region, assigning private property rights to various flows of water based on a seniority system widely referred to as the prior appropriation doctrine. In some instances, the new regime was superimposed over the Spanish practices of communal water management, though not always successfully.

These alienable water rights are exemplary of the private rights often advocated to address common-pool resource issues. In theory, the private rights can now utilize a market to achieve economic efficiency. However, there are often large transaction costs (both due to physical transportation and state regulation) and rarely does a well-functioning market develop. This aspect has led many to critique the efficiency of the prior appropriation doctrine (Anderson 1983; Burness and Quirk 1979; Howe et al. 1982; Richards 2008). In addition, the need for imposing private rights over the communal *acequia* system is not evident, as *acequias* are an example of common property right regimes and accompanying institutions capable of avoiding the tragedy of the commons (Cox 2014).

Given this, it is important to understand the relative merits of the alternative property rights in appropriating and dividing scarce irrigation water. To do so, I compare how use of private rights in water allocation for irrigation compares to the use of communal rights. This is done both theoretically and empirically. First, building on H. Stuart Burness and James Quirk's (1979), henceforth BQ, model of prior appropriation, I derive comparative results under a proportional sharing rule similar to that used among the Spanish irrigators. I also expand the model by altering some basic assumptions to better match reality. The BQ work has come under fire for ignoring heterogeneity and return flows (Howe et al. 1982). I choose to largely maintain these assumptions and instead question the assumption that marginal product of water is always decreasing.

The model uncovers some advantages of both systems, even when water markets in the priority system are effectively absent. Broadly, while distribution under the sharing regime is typically more efficient than under the priority system, this may not hold with heterogeneous irrigators or during lower water supply years. Second, I leverage a natural experiment to test both the assumptions and hypotheses developed through the model. Spanish irrigators developed Northern New Mexico with *acequias*, but a small subset were subsequently divided by a political subdivision when Colorado Territory was formed, resulting in an exogenous change in water law. The analysis considers the robustness of *acequias* under various stream conditions in Taos Valley, New Mexico, where sharing of water shortages is still permitted and practiced, to that of *acequias* in San Luis Valley, Colorado, the adjacent county to the north, where private water rights are enforced and sharing is difficult. Generally, the results support the model in that the marginal product of water is typically larger under communal sharing though not under drought conditions.

I begin by expanding on the description of the prior appropriation doctrine and the communal sharing practice of *acequias* in section two. In section three, I present the assumptions of the theoretical production model and some of the implications. Next, in section four, I provide the context of the natural experiment. In section five, I describe the data and methods of the empirical analysis as well as the links to the model to be tested. In section six, I present the results before discussing them more fully in section seven. Finally, I conclude with section eight.

4.2 Background

4.2.1 Prior Appropriation Doctrine

In the more arid regions of the United States, most states have adopted the prior appropriation doctrine. It is in contrast to the riparian doctrine which guides water law in wetter regions. In wet climates those owning land along the riparian zone have the right to utilize the water so long as it does not injure other riparian users. Prior appropriation is distinct in that water rights are severable from the adjacent land rights, creating a separate usufruct property right (the water itself is owned by the state). Described as "first in time, first in right," water rights to a certain flow or volume are established by first possession. In order to establish the right, you must divert water from its natural course and put it to beneficial use. Often this is defined as some consumptive use, but can extend beyond agriculture to manufacturing and domestic uses. The legal ownership of the right is defined by the original date of diversion, diversion location, use location, and approved beneficial use (Getches 2009). In times of water shortage, senior appropriators, those with the earlier diversion dates, are provided their water first. Only once their rights have been filled do more junior rights receive water. In situations where the senior diversion is further downstream, a call is placed on the river and all those junior upstream must close their diversions and allow the water to flow by.

With water rights separated from the land, the water can independently be bought and sold or even leased. In the arid region of water scarcity, the doctrine is supported by two economic arguments: 1) It provides incentive to invest in assets by guaranteeing the continued use of water (subject to seniority and flow); and 2) allowing water to migrate to higher valued uses through market mechanisms.

Subject to large transaction costs, these markets are typically thin, marked by sporadic large transfers (Howe and Goemans 2003). Accordingly, the efficiency is called into question. It is readily apparent that where homogenous farmers exist, the equi-marginal principle will not be satisfied when those farmers have heterogeneous amounts of water to use in production. Charles Howe et al. (1982) permits some weighting to increase flexibility of the model, but illustrates there are further complexities based on use and position on the stream. Elizabeth Richards (2008) expands this and illustrates how the priority system may lock water into lower value uses among heterogeneous users. As most senior priority dates are for ranching or agricultural purposes, it is the junior rights that provide more economic value today due to urban growth and industrial use of water. In addition, the prior appropriation system provides incentives counter to conservation (Brown and Rivera 2000; Heinmiller 2009).

4.2.2 Law of Indies

In contrast, settlers of *Nuevo México* began irrigating based on communal institutions, namely *acequias*. Water is not treated as individual property and shortages are shared based on norms and customs. Guided by the Law of Indies, division is guided by the principle that water is sacred and all living beings have a right of access—a sharp contrast to the commodification supported by the priority system. The *acequias* have persisted for centuries, with many in modern day New Mexico dating back to the 17th century and the bulk of them originating throughout the 19th century. The economic underpinning of the communal system is that the system will readily equate marginal value of water across irrigators. However, as an appropriative device, communal sharing incentives may induce excess entrance, putting more strain on any given flow of water.

4.3 The Formal Model

4.3.1 Assumptions

The base model to be used makes the same assumptions as BQ, but presents an alternative for how water delivery is determined. Rather than applying strict priority, I allow everyone to receive a proportion of flow based on diversion structures regardless of entry order. Borrowing BQ's notation for simplicity, the model assumptions are as follows:

1) x=acre-feet of streamflow which is a random variable with a known probability function, $f(x)$.
2) $f(x) \geq 0$ for $x \geq 0$ and $f(x) = 0$ for $x < 0$
3) The cumulative distribution function is defined $F(x) = \int_0^x f(c)dc$. I assume $F(0) = 0$ and $\lim_{x\to\infty} F(x) = 1$.
4) Letting a_i be the water available to appropriator i, and $\bar{a}_i$is the diversion capacity constructed by the ith appropriator, the profit function is dependent on these two elements: $\pi^i(a_i, \bar{a}_i)$ subject to the restriction that $a_i \leq \bar{a}_i$.
5) The derivatives of the profit function are as follows:
    a. $\pi_1^i \equiv \partial\pi^i/\partial a_i > 0$ for $0 \leq a_i \leq \bar{a}_i$ and $\pi_1^i = 0$ otherwise. This means the marginal profit from water is positive, but water beyond the diversion capacity offers no additional value.

b. $\pi_{11}^{i} \equiv \partial^2\pi^i/\partial a_i{}^2 < 0$. There are decreasing marginal profits to water as an input.

c. $\pi_{2}^{i} \equiv \partial\pi^i/\partial \bar{a}_i < 0$ for $\bar{a}_i \geq 0$. Marginal profit decreases as capacity increases due to the cost of construction and increased maintenance.

d. $\pi_{22}^{i} \equiv \partial^2\pi^i/\partial \bar{a}_i{}^2 < 0$ for $\bar{a}_i \geq \bar{a}_i{}^*$ and $\pi_{22}^{i} = \partial^2\pi^i/\partial \bar{a}_i{}^2 > 0$ for $\bar{a}_i < \bar{a}_i{}^*$ where $\bar{a}_i{}^*$ is the diversion capacity where problems of coordination overwhelm the economies of scale associated with diversion construction. Typically it is assumed that operation occurs in the $\bar{a}_i > \bar{a}_i{}^*$ so that the marginal cost of adding diversion is increasing.

e. We also assume that depreciation is due only to time, not due to use, so $\pi_{12}^{i} \equiv \partial\pi^i/\partial a_i \partial \bar{a}_i = 0$. This permits the profit function to be separable: $\pi^i(a_i, \bar{a}_i) = R^i(a_i) - C^i(\bar{a}_i)$ where R^i and C^i are the revenue and cost functions for the ith appropriator.

6) We further assume homogenous farmers in production capability. That is $\pi^i(a_i, \bar{a}_i) = \pi(a_i, \bar{a}_i)$.

7) As a matter of notation, let $A_i \equiv \sum_{j=1}^{i} \bar{a}_j$. In other words, A_i is the aggregate diversion capacity constructed by firms 1 through i. $A_0 = 0$. Under the priority system, it also represents the amount of water rights senior to firm $i + 1$.

4.3.2 Priority System:

Under the priority system, irrigators receive water sequentially. Specifically, I assume the water available to firm *i* is given as

8) $a_i = 0$ if $x < A_{i-1}$, $a_i = x - A_{i-1}$ if $A_{i-1} \leq x < A_i$, $a_i = \bar{a}_i$ if $x \geq A_i$

With this, I can write down the expected profit of firm i when choosing how much diversion capacity to build. Specifically,

$$E^{pa}\left(\pi^i\right) = F(A_{i-1})\pi(0, \bar{a}_i) + \int_{A_{i-1}}^{A_i} \pi(x - A_{i-1}, \bar{a}_i) f(x)dx + [1 - F(A_i)]\pi(\bar{a}_i, \bar{a}_i)$$

The pa refers to prior appropriation and is used to distinguish from communal sharing (cs) derived below.

4.3.3 Proportional Sharing

Rather than assuming a farmer receives water given priority, I assume they receive water proportional to their diversion structure. In particular, the amount of water available to farmer i is given as:

9) $a_i = \frac{\bar{a}_i}{A_N} x$ when $x < A_N$ and $a_i = \bar{a}_i$ when $x \geq A_N$.

In words, when the flow of the river is less than the aggregate capacity, then water available is in proportion based on i's proportion of diversion capacity of total capacity. If the flow is greater than this, all appropriators divert up to their capacity. Therefore, maintaining all assumptions but 5e from above, the expected profit function under proportional sharing is given as the following:[23]

$$E^{cs}(\pi^i) = \int_0^{A_N} \pi\left(\frac{\bar{a}_i}{A_N} x, \bar{a}_i\right) f(x) dx + [1 - F(A_N)]\pi(\bar{a}_i, \bar{a}_i)$$

For the sake of comparison, I keep the river the same in both cases, i.e. I use the same $f(x)$. The important differences between E^{pa} and E^{cs} are threefold. In communal sharing there is no longer the term for which receiving no water is an option. The middle term is now more complicated and includes a wider range of stream flow and is determined by the aggregate diversion built by all N appropriators. In this regard, expected profit can be altered by future diversion whereas in E^{pa} this is not possible. This immediately suggests there may be some inefficiency when this model is used at the outset as early firms may build too large of diversions

[23] Assumption 5e above can no longer hold by construction. While the spirit remains in the sense that maintenance is independent of use, constructed capacity now directly determines the amount of water received by irrigator i.

for the final allocation. Finally, the last term is similar in both cases, but the communal regime is influenced by future diversions. If we presume the ith appropriator assumes that no more diversion will occur after they enter, we can replace A_N with A_i when choosing their capacity.[24]

4.3.4 BQ Results Summary

The overarching result of the BQ analysis is that the priority system is not efficient when a market is lacking. The inefficiencies appear along at least two dimensions. First, more diversion capacity will be constructed than should be given the expected flow of the stream; however it will be below the maximum flow of the stream in the long run equilibrium. This suggests that if equal capacity is the efficient division of capacity, the appropriators under the priority system will build capacity beyond this. Second, and more apparent, is that allocative efficiency will not be achieved as the senior water right holder will receive all the water and the junior will receive none, in the most extreme case. BQ show that equal sharing is the efficient outcome. However, this counterfactual assumes diversion capacity is capable of being transferred between firms, highly unlikely given the fixed position of fields and diversion structures. Therefore, the equal sharing principle relies on the appropriate capacity being constructed. In actuality entrants do arrive sequentially, making it unlikely the first diverter builds the correct size diversion given the eventual number of appropriators.

[24] This myopic approach could be replaced by a sophisticated irrigator capable of backwards induction to determine the final diversion capacity, though this is also unrealistic and the truth likely lies somewhere in between.

4.3.5 Model Results[25]

Here I expand BQ's model to consider the alternative distribution rule which more closely mimics the practice of the Spanish irrigators. Initially, I maintain the assumptions used in BQ, but also consider a couple of extensions to consider other dimensions of inefficiency.

Proposition 1: *Given a particular amount of diversion already constructed, the next entrant under the communal sharing will build a larger diversion structure than one under prior appropriation. In other words:* $\bar{a}_i^{cs} \geq \bar{a}_i^{pa}$ *for a given* A_{i-1} *with strict inequality if i>1.*

Intuitively, the larger cost of construction nets more water (of any flow), justifying the extra construction. More diversion under prior appropriation nets more water for only a specific flow, decreasing the odds of enjoying the gain. It is easy to assume that this implies that communal sharing will then build even more diversion structure, making worse the over appropriation (excess capacity) found in BQ, but this proposition neither sufficient nor necessary. In these parallel worlds, the third appropriator does not face the same value of prior diversion in their constraint. Therefore this condition bears no impact on the capacity the second diverter will construct or the aggregate diversion following their entrance. Yet, once entrance is no longer expected to be profitable under the priority system, it remains so under the communal sharing system.

Proposition 2: *Total diversion capacity will be larger under the communal sharing regime than under prior appropriation.*

Since BQ suggested over capitalization under the priority system, the issue is exacerbated under the proportional sharing rule. The problem is made even worse because a new entrant

[25] Proofs of propositions are included in the appendix

reduces the water received by earlier irrigators under communal sharing, whereas they have no impact on earlier irrigators in the priority system. This underscores the merits of the priority system in curbing rent dissipation experienced in open access situations. Next I turn to the division of water.

As indicated by BQ, for a given aggregate capacity and number of irrigators, equal sharing of the available flow is more efficient. Let $\pi^{cs}(x)$ and $\pi^{pa}(x)$ be the aggregate profit for communal sharing and prior appropriation respectively.

Proposition 3: *For N>1 irrigators with equal diversion capacity,* $\pi^{cs}(x) > \pi^{pa}(x)$ *for all y.*

Corollary 1: *On average, marginal product of water is greater under communal sharing;* $E\{\pi_1^{cs}(x)\} > E\{\pi_1^{pa}(x)\}$

However, this corollary does not extend to $\pi_1^{cs}(x) > \pi_1^{pa}(x)$ for all *x*, only on average.

Proposition 4: $\pi_1^{cs}(x) > \pi_1^{pa}(x)$ *if* $x > a(i-1)\left(\frac{N}{N-1}\right)$ *for* $A_{i-1} \leq x < A_i$

Corollary 2: *Gains in production due to increased flows are uniformly distributed under communal sharing. Under prior appropriation, junior diverters are expected to do worse, yet more likely to accrue larger marginal gains.*

The marginal gain expected while $A_{i-1} \leq x < A_i$ will be higher under the seniority system if *i* is relatively large and *N* is relatively small. Another way to look at it is if $\frac{\text{Others' Water(pa)}}{\text{Others' Water Capicity}} < \frac{\text{i's water(pa)}}{\text{i's Capacity}}$, the gain under the communal sharing system will be larger. Notably, because the priority system's marginal gain is due only to the marginal irrigator, it is apparent that production should be expected to be non-uniform under the priority system.

4.3.6 Extensions

4.3.6.1 Fixed Water Needs.

The results thus far, assume decreasing marginal product of water for every irrigator when water is within their diversion capacity range. Instead, there is likely a threshold of water, say *w*, for which $\pi_{11}(a) \geq 0$ when $a \leq w$. The assumption being that first drop of water is not necessarily the most marginally productive because crops need sufficient amounts. For ease, consider the extreme case where $\pi_1(a) = 0$ if $a \leq w$. Beyond which the full amount of water is productive. For the priority system, the reduction in aggregate expected profit is:

$$\sum_{i=1}^{N} \int_{A_{i-1}}^{A_{i-1}+w} \pi(0, \bar{a}) f(x) dx = \sum_{i=1}^{N} [F(\bar{a} \times (i-1) + w) - F(\bar{a} \times (i-1))] \pi(0, \bar{a})$$

Whereas for the communal sharing, the expected reduction

$$\sum_{i=1}^{N} \int_{0}^{w \times N} \pi(0, \bar{a}) f(x) dx = N \times F(w \times N) \pi(0, \bar{a})$$

Which loss is relatively larger depends on the CDF, but what is clear is that complete disaster is more likely in the case of communal sharing. For $i = 1$, it is clear that $F(w \times N) > F(w)$. Furthermore, once $x > w$, the communal sharing still sees no production while the priority system does, yielding an advantage to the priority system despite the inefficiencies at higher levels of flow.

4.3.6.2 Various Skill Levels

Another big assumption above is that of identical profit functions. In reality, farmers are heterogeneous as is cropland.[26] To introduce some heterogeneity across irrigators, let $\pi^i(a_i, \bar{a}_i) = s_i \times \pi(a_i, \bar{a}_i)$, where s_i scales the relative productivity; perhaps capturing the farmer's skill or soil quality of the land. If we allow it to be soil quality, we may assume $s_i \geq s_{i+1}$, expecting that the earliest settlers chose the most productive land. It is readily apparent that equal sharing is no longer the efficient solution:

$$\pi_1^i\left(\frac{1}{N}x, \bar{a}\right) = \frac{s_i}{N} \times \pi_1\left(\frac{1}{N}x, \bar{a}\right) \geq \frac{s_{i+1}}{N} \times \pi_1\left(\frac{1}{N}x, \bar{a}\right) = \pi_1^{i+1}\left(\frac{1}{N}x, \bar{a}\right)$$

The earlier irrigators should receive more water if we keep capacity exogenously given. Fixing the diversion structure, the priority system may have more merits whenever $s_i \times \pi_1(x, \bar{a}) \geq s_{i+j} \times \pi_1(0, \bar{a})$

If instead we make the capacity choice once again endogenous, the solution is less clear. Under proportional sharing $\pi^i(x, \bar{a}_i) = s_i[R\left(\frac{\bar{a}_i}{A_N}x\right) - C(\bar{a}_i)]$. Now the marginal product is given by: $\pi_1^i(x, \bar{a}_i) = s_i \frac{\bar{a}_i}{A_N} R'\left(\frac{\bar{a}_i}{A_N}x\right)$. It is not clear that increasing diversion will decrease marginal profit of water:

$$\pi_{12}^i(x, \bar{a}_i) = s_i\left[\frac{x}{A_N} - \frac{\bar{a}_i}{{A_N}^2}x\right]R''\left(\frac{\bar{a}_i}{A_N}x\right) + s_i\left[\frac{1}{A_N} - \frac{\bar{a}_i}{{A_N}^2}\right]R'\left(\frac{\bar{a}_i}{A_N}x\right)$$

[26] In the empirical setting, *acequia* farmers use similar, simple technology using flood irrigation and natural fertilizers to grow mostly alfalfa and other hay/grass mixes, making the assumption of identical profit functions more tolerable. However, variation in soil quality or cost of diversion may still warrant consideration.

The sign of the expression depends on the flow as well as the revenue function. The intuition is that at some point, the savings of a smaller diversion structure can be justified by the increased productivity of the water available.

4.4 Empirical Setting

In order to test the model, I utilize a natural experiment. The two groups are the *acequia* irrigators in Taos County, New Mexico along the Rio Hondo stream and those on the Culebra stream in Costilla County, Colorado. Due to historic developments beyond the *acequias* control, the Hondo *acequias* practice communal sharing across *acequias* whereas the Culebra *acequias* employ the priority system. Here I explain the experiment first, then return to the hypotheses, data and model. The two regions can be found on the map in Figure 4.1.

4.4.1 New Mexico Water Law

New Mexico water code was at first defined by *acequia* customs and rules. The original U.S. water code of the region came from the Kearny Code proclaimed in 1846 following the United States' occupation of the area by Stephen Kearny. It states, "laws heretofore in force concerning water courses, stock marks, and brands, horses, enclosures, commons and arbitrations shall continue in force" (Victory 1897, p. 90). This protection was confirmed by the Treaty of Guadalupe Hidalgo in 1848 which officially granted the region U.S. Sovereignty from Mexico; "property of every kind now belonging to Mexicans now established there, shall be inviolably respected" (Victory 1897, p. 31). The *acequias* were provided further protection when the first territorial laws were passed in 1851 and 1852. The statutes, many still on the books, codified the customs and norms. With the arrival of the railroad in 1878, the region began to be transformed by the new Anglo arrivals. As they gained in number, they also gained representation in the

Figure 4.1:


Colorado and New Mexico Acequias
Conejos
Costilla
Las Animas
Taos
Rio Arriba
Colfax
Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
Map Overview
UTAH
COLORADO
KANSAS
NEW MEXICO
TEXAS
Legend
Culebra Acequias
Rio Hondo Acequias
0 4 8 16 Miles

territorial legislature. As such, water law began to transform water from a shared, life quenching resource, to a commodity and input into economic growth.

Spurred by the federal formation of Reclamation Service (todays Bureau of Reclamation) in 1903, the territorial legislature drafted and passed an expansive water code in 1905. The new water code had many implications, but two critical: 1) it adopted the prior appropriation doctrine as the guiding water code for the territory; and 2) created the Office of the Territorial Engineer (now the State Engineer) to centrally administer the private water rights. These both marked a departure from *acequia* tradition in creating private, rather than communal rights, while simultaneously moving water administration further from the local users. The new priority system came at odds with the historic practice of sharing shortages among all *acequias* on a single stream in many regions.

The process by which the new water code has been implemented has been long and drawn out. The adjudication process, that by which individual water rights are determined, is ongoing with many regions underway though many others have not even begun. The process Taos Valley began in 1968 with a hydrological survey was tentatively completed in 2013 to sort out the rights of the 51 independent *acequias* and the Pueblo village in the region. The complicated process of litigation, general opposition to the priority system, and distinctive history has presented New Mexico with unique solutions. Many basins have chosen to develop settlements among themselves rather than conducting adversarial litigation (Richards 2008). For *acequias* in Taos Valley, this has allowed them to agree on maintaining their century old sharing agreements and operate outside of the priority system. The agreement allows the region to maintain their customs and norms with the parties agreeing to refrain from priority calls

(Richards 2008).[27] According to Sylvia Rodríguez (2006), no *acequia* user interviewed in Taos recalls anyone ever placing a call, i.e. exercising their private right, on their water.

4.4.2 Colorado Water Law

Colorado also operates under the prior appropriation doctrine. Here, the principle initially came through court decisions instead of an explicit act by the legislature. Colorado committed to the system when the Colorado Supreme Court supported the doctrine in *Coffins v. Left Hand Ditch Co.* (1882), recognizing the right to divert water from its natural course and protecting that use from the interference of any new users.[28] The process of determining rights and administering the new priority system went much smoother in Colorado than it did in New Mexico. For one, the decision to adopt prior appropriation came earlier in Colorado, while much of the development came later. For instance, the oldest priority in Colorado is from 1852 while New Mexico is trying to sort out claims dating back to the 1600s and later in the case of Native American rights.

In Colorado, none of the water rights pre-dates U.S. sovereignty. Subsequently, all surface water rights in Colorado are subject to the priority system. This includes the *acequias* in Costilla County in the Culebra watershed. The oldest priority in Colorado hails from the Culebra, belonging to the San Luis Peoples Ditch with a diversion date in April of 1852, missing the protection of the Treaty of Guadalupe Hidalgo by four years. Accordingly, in Colorado the doctrine of prior appropriation is not merely *de jure*, but quite functional. This causes the *acequias* here to operate in a very different institutional context. Once water is within the

[27] In meeting Rio Grande Compact demands due to Texas, the priority system may come into play in determining curtailment of water.
[28] This decision also granted the ability to divert water across watersheds.

acequia, division to the individual irrigators is internally determined. Among *acequias*, in both New Mexico and Colorado, the process is typically based on sharing.[29]

There are 22 other ditches in the Culebra watershed that have senior right (all with priorities from 1852-1882) and another 45 or so *acequias* that have formed but have much more junior rights. Unlike their neighbors to the south, they are locked into the priority system. The mechanism is the risk of abandonment accompanied by state monitoring. Daily, the state determines the flow of water and then employs state commissioners to open and close head gates to ensure only those in priority receive water. Under the priority appropriation doctrine, rights can be lost due to non-use. Therefore, even if a senior ditch wishes to take only half their water in order to share some water with junior ditches, they may not due to the risk that the state would view this as non-use and put that portion of their right at risk to abandonment (in which case the right to use that portion of the water is loss).

While overtime the *acequias* here have adopted to the new system, overall their remains the cultural desire to share shortages. Gregory Hicks and Devon Peña (2003) recount a story of sharing during the 2002 drought. While they could not legally put water in the junior ditches, a senior right holder permitted some farmers with land on a junior *acequia* to sharecrop a portion of the senior's land. This permitted the shortage to be shared by circumventing the priority system. Illustrative of their frustration with their struggle to exercise their culture and norms, Costilla County, perhaps a bit tongue-in-cheek, suggested they leave Colorado and become part of New Mexico in 1973 (Simmons 1999). These anecdotal stories suggest they value their Spanish/Mexican heritage and still desire to allocate water similarly to their New Mexican

[29] Often the priority dates are the exact same as these are based on diversion and the acequia users share the initial diversion, precluding the use of internal priority. Newer mutual irrigation companies in Colorado may maintain seniority if the rights pre-date the formation of the company, but this is not the case for the *acequias* in question.

counterparts, but are much more constrained by the private property regime enforced in Colorado.[30] Both Taos County, NM and Costilla County, CO engage in similar agriculture production, using water to grow mostly forage. In Taos, 95% of the acres are for this purpose and 75% in Costilla (U.S. Department of Agriculture 2013).

4.4.3 Variation in Stream Flow

Besides the similarities beyond the water law variation, I chose the Culebra and Rio Hondo for their proximity and exogenous shocks of water supply. Not only do both regions exhibit wide variation year-to-year, they have come to expect less water on average—perhaps due to a dry-spell or a more permanent shift down driven by climate change. This pattern is displayed in Figure 4.2. Notably both the Rio Hondo and Culebra move much in tandem, and Figure 4.3 shows their empirical distribution of annual flow rate to be quite similar, though the Culebra almost always has a greater flow.

4.5 Methods and Data

4.5.1 Data

The primary data required are production values and water supply. The empirics builds on the analysis of Taos by Michael Cox (2014) in which the author utilizes satellite imagery to provide a measure of crop production in Taos Valley. Using Landsat Satellite imagery, values of Normalized Vegetation Difference Index (NDVI) are calculated. NDVI is an ecological metric capturing the extent of healthy vegetation present in an area. In arid regions, NDVI is a reliable measure of crop production. The measure itself is based on two wavelengths: NIR measure the extent that Near-infrared wavelengths are reflected back and RED measures the red wavelengths

[30] The different institutional settings could be framed as private rights in a functioning market (NM) versus those in a non-functioning market (CO). However, this would require the assumption that the Taos Valley Settlement agreement represents a market outcome. There is no evidence to support this assumption.

Figure 4.2: Average Stream Flow

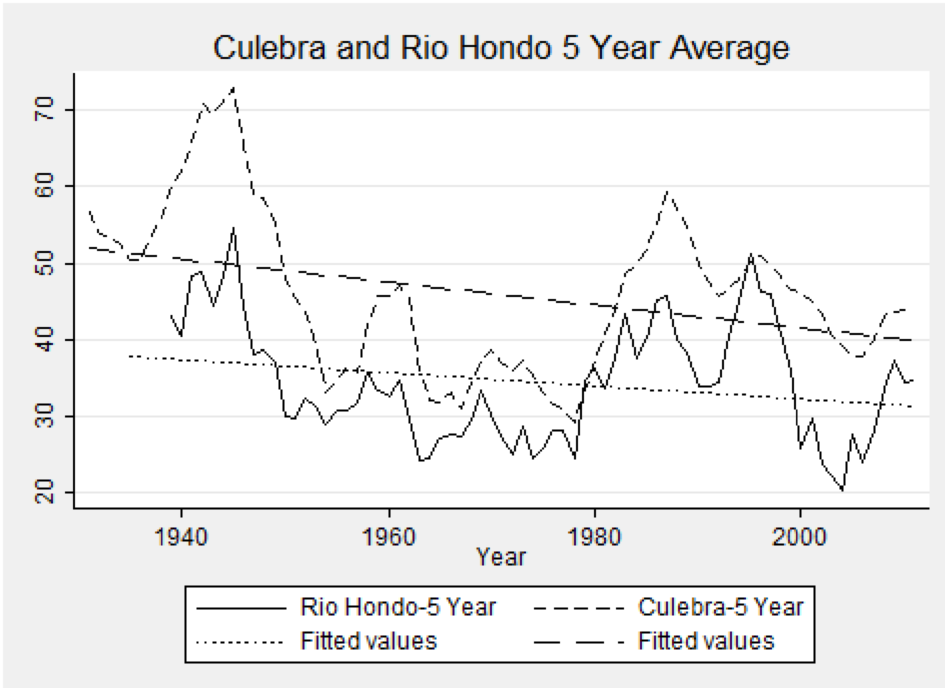
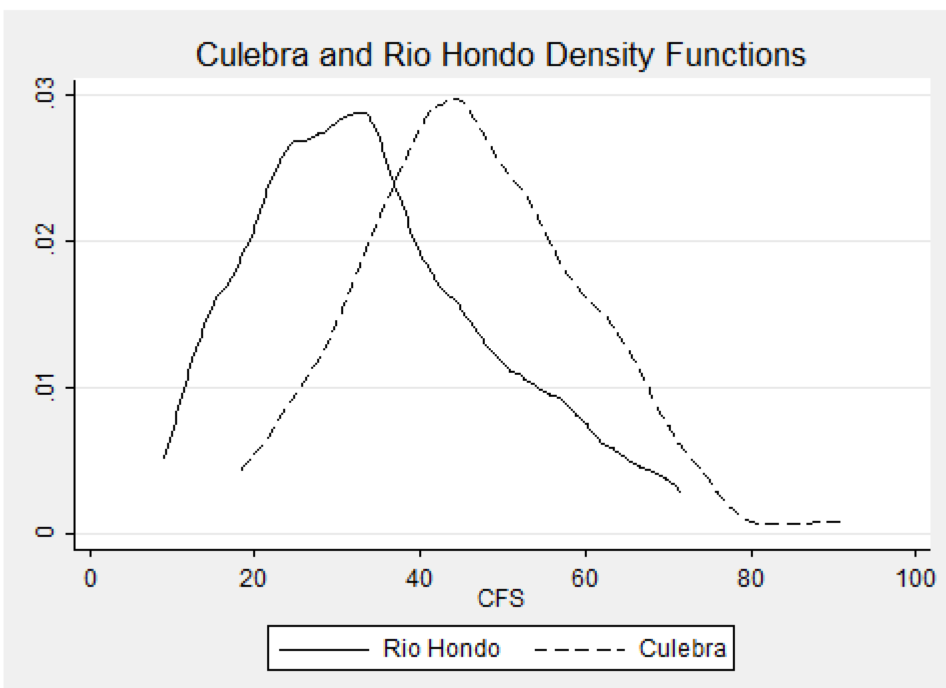


Figure 4.3: Empirical Flow Probability Distribution



in the electromagnetic spectrum reflected back. With healthy vegetation absorbing RED and reflecting NIR, NDVI is constructed such that values closer to 1 indicate abundant healthy vegetation and values closer to -1 indicate more barren ground.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

The raw data are gathered for each growing season from 1984-2011. Efforts are made to select images from the two regions as close together as possible. The resolution is 30x30 meters pixels, aggregated to various levels based on means and spatial standard deviations. Further detail on NDVI is provided in chapter five. Additional data are used to accurately connect *acequia* land to the images. Primarily, GIS information concerning the location and size of *acequias* are utilized from Colorado's and New Mexico's Office of the State Engineer (CDSS 2013; OSE 2013). Other data are considered to assign seniority rights based on dates of diversion.

For water supply I gather annual average flow rates from the United States Geological Survey (USGS 2013). The gauges gather daily readings, dating back to 1927 on the Culebra and 1934 on the Rio Hondo.[31] The annual average is calculated, delineated in Cubic Feet per Second (CFS), indicating how much volume of water passes a point during a second of time. Of note, water rights in Colorado are based on this flow, while New Mexico has adjudicated volumes of water per year, using Acre-Feet (AF), a measure of one acre of land covered by a foot of water. These measures can be linked by extrapolating the CFS over a year. An increase of 1 CFS of annual flow would yield 724 AF of more water over the year. In New Mexico, the stream measure is the most disaggregate level of flow data available; they do not measure intake by the *acequias* themselves.

[31] On the Culebra USGS Gauge 08250000 is used and USGS Gauge 08267500 for the Rio Hondo.

A summary of the data is provided in Table 4.1, divided by stream. Here the data are limited to the first 7 *acequias* on each stream. This aligns with those *acequias* with recorded priority dates and, in Colorado, with those considered to be the major irrigators and entering prior to 1882 (Peña 1999). Results below primarily maintain this division, but analysis with the full sample is quite similar.[32] The regions do exhibit a number of statistical differences. On average, Colorado is greener, both on *acequia* level and the stream level. This is likely related to Colorado receiving more water on average. The Colorado *acequias* are larger than those in New Mexico. This fact does not align with the theory above, as we expected those under the communal system to construct larger capacity on average. However, this may be explained by other factors, such as the later settlement of Colorado (nearly 50 years later) or the biophysical realities of the systems. But even after adjusting for the higher expected flow value, the Culebra irrigators remain larger. Notably, the Culebra watershed was established partially under New Mexico rule, meaning the incentives at initial development did not differ. Because the streams do not quite mirror one another, the emphasis will be on the marginal gain of another CFS. As Figure 4.3 shows, while the means are different, the historical distributions look rather similar in shape.

4.5.2 Method

In order to test the developed model, I run a number of simple time series regressions at the stream level as well as the *acequia* level. The main specification resembles the following:

$$NDVI_{sy} = \alpha_s + \beta_1 \times CFS_{sy} + \beta_2 \times CFS_{sy-1} + \beta_3 \times Year_{sy} + e_{sy} \qquad (4.1)$$

The dependent variable ($NDVI_{sy}$) is either the spatial mean or the spatial standard deviation. Subscript y refers to the year while s designates the stream. CFS_{sy} captures the annual average

[32] In New Mexico, only 1 *acequia* is removed whereas in Colorado this removes 11.

Table 4.1: Summary Statistics

	New Mexico (Rio Hondo)					Colorado (Culebra)					Difference
Variable	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max	
NDVI	196	0.44	0.11	0.15	0.68	196	0.51	0.09	0.27	0.66	-0.06***
NDVI Temp. Dev.	196	0.05	0.04	0	0.24	196	0.05	0.04	0	0.24	0
NDVI (Stream)	28	0.4	0.07	0.22	0.54	28	0.48	0.05	0.34	0.56	-0.08***
CFS	28	34.87	13.76	9.14	63.5	28	46.6	7.23	31.8	62.54	-11.74***
Acres	7	387.32	286.52	48.04	868.5	7	1345.3	1085.17	57.6	3158.22	-957.98*
Priority Year	7	1817.14	6	1808	1828	7	1862.57	12.2	1852	1882	-45.43***
Seniority	7	4	2.01	1	7	7	4	2.01	1	7	N/A

Data is based on the first 7 acequias in each region. Statistical different means are indicated in the final column: *** $p<0.01$, ** $p<0.05$, * $p<0.1$

flow for the year while $Year_{sy}$ adjusts for the downward trend present in both production and stream flow. While some specifications include a lagged dependent variable for robustness checks, overall autocorrelation tests do not warrant much concern. To test some hypothesis, the regression will be run on two different regions as separate samples. In order to assess if the impact is different in the two different regions, I run a fully interacted model with an indicator variable for Colorado.

Similar analysis is then performed at the *acequia* level. Because stream flow does not vary, the regressions based on equation (4.1) are quite similar and the parallel results are not reported here. However, *acequia* level analysis allows the testing of additional hypotheses by introducing controls for priority ranking. Equation (4.1) is estimated for each individual ditch, comparing how a ditch in New Mexico compares to the appropriate counterpart based on priority date in Colorado. In addition, I estimate the following:

$$NDVI_{iy} = \alpha_s + \beta_1 \times Priority_i + \beta_2 \times Year_{sy} + e_{iy} \qquad (4.2)$$

With $NDVI_{iy}$ as the *acequia* level mean. Alternatively, I run a specification where the dependent variable is the average deviation from the *acequias* average annual production (this is no longer a time-series).

4.5.3 Hypotheses

The model has produced a number of testable assumptions and predictions. First, the assumptions:

A1: More water increases aggregate production. (Assumption 5a)

A2: There are diminishing returns to water (Assumption 5b)

A3: Prior years' water has very little impact on production (Assumption 4)

A4: Earlier diverters are more skilled and/or selected better land (Extension 4.3.6.2)

Implications of model derived above give rise to following testable hypotheses:

H1: Earlier diverters build larger diversion capacity (Proposition 1)

H2: More diversion capacity is constructed in New Mexico (Proposition 2)

H3a: New Mexico has a higher average marginal product of stream flow (Corollary 1)

H3b: Colorado's marginal product is not well correlated with stream flow (Proposition 4)

H4a: Lower stream flow years will increase the spatial variance of NDVI by a greater amount in Colorado than in New Mexico. (Corollary 2)

H4b: Junior diverters in Colorado perform worse and have larger temporal variation than those in New Mexico (Corollary 2)

H5: Drought years reduce production, but more so in New Mexico (Extension 4.3.6.1)

4.6 Results:

4.6.1 Correlations

Correlations are provided in Table 4.2. For both regions, NDVI is positively correlated with stream flow (CFS) and notably stronger in New Mexico, lending some support to both A1 (more water, more production) and H3 (New Mexico has a higher marginal product of water). Of some surprise, Seniority is negatively related to production. A4 suggests that the better land is settled first, however, the opposite appears true. The relationship is weaker in Colorado, as one should expect given the water division rules with the earlier priorities securing a more reliable source of water. H1 appears to be true as seniority rank is strongly negatively correlated with acreage (capacity). While the relationship is slightly stronger in New Mexico, supporting H2, the difference appears to be quite slight (-0.77 compared to -0.74). Because larger systems are negatively related to production, this may partially explain the surprising negative relationship senior users have with production. Finally, it is worth noting that priority dates are

Table 4.2: Correlations

	Correlations--New Mexico (n=196)					Correlations--Colorado (n=196)				
	NDVI	NDVI Temp Dev.	CFS	Acres	Seniority	NDVI	NDVI Temp Dev.	CFS	Acres	Seniority
NDVI	1					1				
NDVI Temp. Dev.	-0.2068*	1				-0.3265*	1			
CFS	0.4271*	-0.1981*	1			0.1523*	0.0655*	1		
Acres	-0.5335*	0.1152*	0	1		-0.4010*	-0.1252*	0	1	
Seniority	0.5625*	-0.1193*	0	-0.7674*	1	0.2188*	0.0935*	0	-0.7366*	1

Data based on first 7 *acequias* in the region negatively related to temporal variation in New Mexico, but positively so in Colorado, as predicted in H4.

4.6.2 Regressions

In Table 4.3 I present the results from estimating equation (4.1) above. For both regions, the point estimate for this year's flow is positive, supporting the marginal product of water being positive (A1). Furthermore, generally the lagged term is insignificant, helping to justify the

Table 4.3: NDVI and Stream Flow

VARIABLES	(1) NDVI Mean	(2) NDVI Mean	(3) NDVI Mean	(4) NDVI Mean	(5) NDVI Mean	(6) NDVI Mean
Colorado					-5.796*	-6.310*
					(3.288)	(3.237)
CFS	0.00188	0.00187	0.00299***	0.00300***	0.00299***	0.00300***
	(0.00176)	(0.00180)	(0.000651)	(0.000665)	(0.000658)	(0.000671)
Lag CFS	0.00117	0.00114	0.000228	0.000456	0.000228	0.000456
	(0.00166)	(0.00171)	(0.000508)	(0.000773)	(0.000512)	(0.000780)
CFS x Colorado					-0.00111	-0.00112
					(0.00171)	(0.00175)
Lag CFS x Colorado					0.000937	0.000687
					(0.00180)	(0.00191)
Lag NDVI		0.0217		-0.0743		-0.0743
		(0.168)		(0.139)		(0.140)
Lag NDVI x Colorado						0.0960
						(0.239)
Year	-0.000669	-0.000677	-0.00360***	-0.00385***	-0.00360***	-0.00385***
	(0.00134)	(0.00138)	(0.00102)	(0.000938)	(0.00103)	(0.000947)
Year x Colorado					0.00293*	0.00317*
					(0.00163)	(0.00160)
Constant	1.679	1.687	7.474***	7.997***	7.474***	7.997***
	(2.722)	(2.795)	(2.059)	(1.893)	(2.079)	(1.911)
Sample	Colorado	Colorado	New Mexico	New Mexico	All	All
Observations	27	27	27	27	54	54
R-squared	0.278	0.279	0.719	0.721	0.736	0.736

Regressions based on first 7 *acequias* in each region. Robust standard errors clustered by year in parentheses

*** p<0.01, ** p<0.05, * p<0.1

discount of last year's water supply (A3). Stream flow in the current year serves as a good predictor of NDVI in New Mexico, increasing NDVI by 0.003 for each CFS. The impact in Colorado is smaller, though neither statistically distinguishable from zero nor the 0.003 found in New Mexico. The results are consistent with New Mexico having a higher marginal product of water (H3a). Notably, the R-squared for the Colorado region is quite low; substantiating the prediction that marginal product of water is highly variable in Colorado (H3b). The lumpiness can be visualized by comparing Figures 4.4 and 4.5, with the relationship between flow and production appearing much more consistent in New Mexico than in Colorado.

Figure 4.4: NDVI and CFS in Colorado

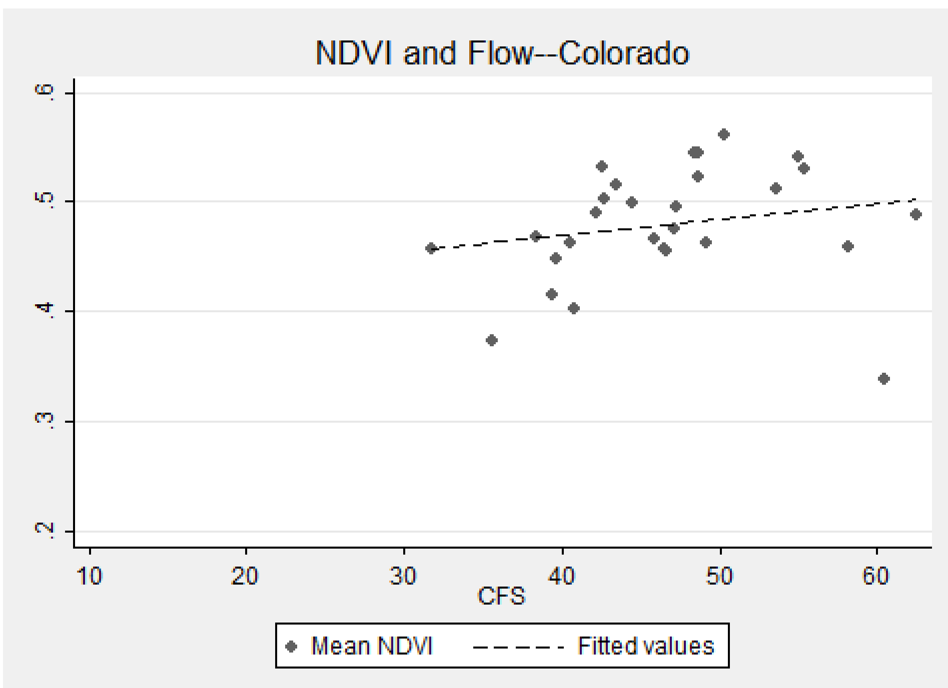


Figure 4.5: NDVI and CFS in New Mexico

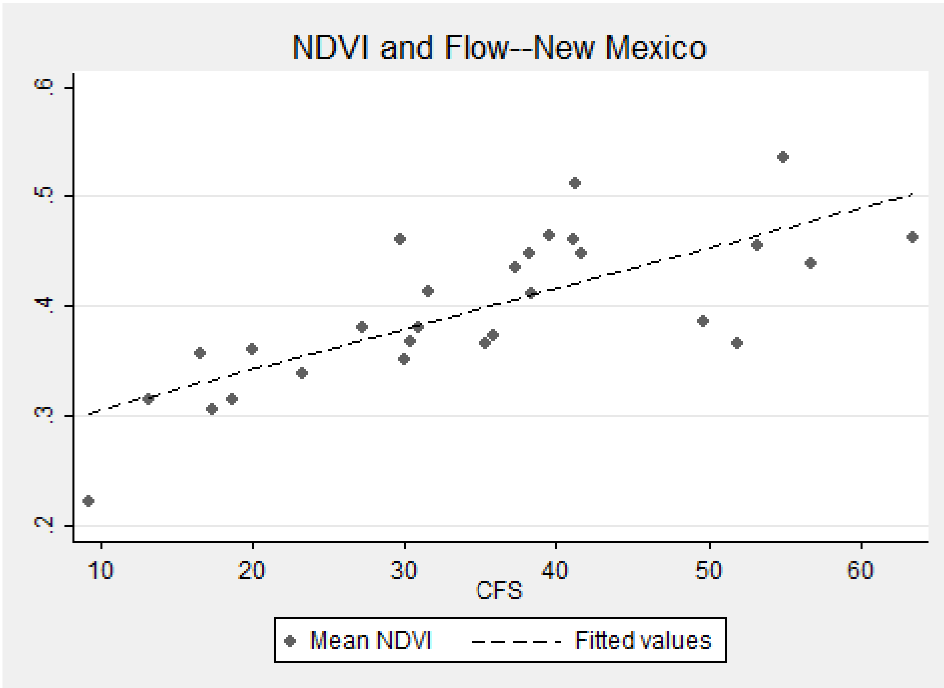


Table 4.4 allows CFS to enter Equation (4.1) in a non-linear fashion by including a second-degree polynomial of stream flow. Both Colorado and New Mexico indicate a diminishing returns relationship with water as modeled (A2). Table 4.5 provides an interpretation of marginal gains at various levels of stream flow. For comparison, the two regions are normalized by the mean flow to look at the marginal gains various distances from their mean. Notably the marginal gains are larger in Colorado when stream flows are low, but New Mexico has a larger marginal benefit as flows increase, suggestive that the impacts of droughts are greater in New Mexico (H5).

Table 4.4: NDVI and Polynomial of Stream Flow

	(1)	(2)	(3)
VARIABLES	NDVI Mean	NDVI Mean	NDVI Mean
Colorado			-4.145
			(3.146)
CFS	0.0296*	0.0101***	0.0101***
	(0.0154)	(0.00220)	(0.00222)
CFS^2	-0.000301*	-9.88e-05***	-9.88e-05***
	(0.000156)	(2.98e-05)	(3.01e-05)
Lag CFS	-0.00363	-0.000598	-0.000598
	(0.0107)	(0.00164)	(0.00166)
Lag CFS^2	5.38e-05	1.90e-05	1.90e-05
	(0.000110)	(2.20e-05)	(2.22e-05)
CFS x Colorado			0.0195
			(0.0152)
CFS^2 x Colorado			-0.000203
			(0.000156)
Lag CFS x Colorado			-0.00304
			(0.0110)
Lag CFS^2 x Colorado			3.47e-05
			(0.000111)
Year	-0.00128	-0.00318***	-0.00318***
	(0.00131)	(0.000924)	(0.000933)
Year x Colorado			0.00190
			(0.00156)
Constant	2.379	6.525***	6.525***
	(2.618)	(1.866)	(1.884)
Sample	Colorado	New Mexico	All
Observations	27	27	54
R-squared	0.425	0.810	0.804

Regressions based on first 7 *acequias* in each region. Robust standard errors clustered by year in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.5: Marginal Production of CFS

CFS	Colorado	New Mexico
-16	1.18	0.66
-15	1.12	0.64
-14	1.06	0.62
-13	1.00	0.60
-12	0.94	0.59
-11	0.88	0.57
-10	0.82	0.55
-9	0.76	0.53
-8	0.70	0.51
-7	0.64	0.49
-6	0.58	0.47
-5	0.52	0.45
-4	0.46	0.43
-3	0.40	0.41
-2	0.34	0.39
-1	0.28	0.37
Mean Flow (SLV=46 CFS; Taos=34)	0.22	0.35
+1	0.16	0.33
+2	0.10	0.31
+3	0.04	0.29
+4	-0.02	0.27
+5	-0.08	0.25
+6	-0.14	0.23
+7	-0.20	0.21
+8	-0.26	0.19
+9	-0.32	0.17
+10	-0.38	0.15
+11	-0.44	0.13
+12	-0.50	0.11
+13	-0.56	0.09
+14	-0.62	0.07
+15	-0.68	0.05
+16	-0.74	0.03

Estimates based on Stream level regression from Table 4.4

In Table 4.6 I consider the impact of a drought year categorically, using an indicator variable for years with flow from the lowest quartile of the empirical distribution. In both regions, those years see a reduction in NDVI mean (by 0.0637 in Colorado) with New Mexico decreasing by (0.0215) more (though not statistically distinguishable).

Table 4.6: NDVI and Drought Years

VARIABLES	(1) NDVI Mean	(2) NDVI Mean	(3) NDVI Mean
Colorado			-6.438**
			(2.991)
Drought Year	-0.0637***	-0.0852***	-0.0852***
	(0.0160)	(0.0207)	(0.0209)
Drought Year x Colorado			0.0215
			(0.0183)
Year	0.000130	-0.00313**	-0.00313**
	(0.00139)	(0.00114)	(0.00115)
Year x Colorado			0.00326**
			(0.00150)
Constant	0.236	6.674***	6.674***
	(2.777)	(2.283)	(2.304)
Sample	Colorado	New Mexico	All
Observations	28	28	56
R-squared	0.275	0.606	0.646

Regressions based on first 7 acequias in each region. Robust standard errors clustered by year in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

To look at H4a, in Table 4.7 I present regressions from equation (4.1) with spatial standard deviation of NDVI as the dependent variable. As predicted The CFS matters for Colorado, decreasing the variation while there is no consistent effect found in New Mexico. In addition, there is a residual effect of last year's flow in Colorado, increasing the variation.

Table 4.7: Spatial Standard Deviation and Stream Flow^

VARIABLES	(1) St. Dev.	(2) St. Dev.	(3) St. Dev.	(4) St. Dev.	(5) St. Dev.	(6) St. Dev.
Colorado					-1.398*	-0.0157
					(0.806)	(1.275)
CFS	-0.00122*	-0.00125*	0.000193	-0.000378	0.000193	-0.000378
	(0.000620)	(0.000652)	(0.000392)	(0.000257)	(0.000396)	(0.000260)
Lag CFS	0.00161***	0.00158**	0.000109	6.33e-05	0.000109	6.33e-05
	(0.000560)	(0.000582)	(0.000169)	(0.000182)	(0.000170)	(0.000184)
CFS x Colorado					-0.00141**	-0.000875
					(0.000681)	(0.000731)
Lag CFS x Colorado					0.00150***	0.00152**
					(0.000539)	(0.000552)
NDVI		0.0185		0.191		0.191
		(0.0733)		(0.143)		(0.144)
NDVI x Colorado						-0.172
						(0.144)
Year	0.000243	0.000254	-0.000457*	0.000222	-0.000457*	0.000222
	(0.000475)	(0.000490)	(0.000263)	(0.000597)	(0.000265)	(0.000603)
Year x Colorado					0.000700*	3.21e-05
					(0.000396)	(0.000617)
Constant	-0.343	-0.372	1.056*	-0.356	1.056*	-0.356
	(0.965)	(1.000)	(0.527)	(1.238)	(0.533)	(1.249)
Sample	Colorado	Colorado	New Mexico	New Mexico	All	All
Observations	27	27	27	27	54	54
R-squared	0.226	0.228	0.119	0.292	0.219	0.306

^ NDVI measure calculated based on all acequias. Standard errors clustered by year in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.8 considers the seniority of the ditch and how it performs (equation 4.2). To improve on the correlations reported above, acreage is included as another control. Notice for Colorado, seniority matters; junior ditches have lower average production. New Mexico has the opposite effect, with newer ditches performing better. These results offer support for H4b—greater risk borne by junior irrigators in Colorado—but undermine the assumption that earlier diverters settled the more productive land (A4). I give the New Mexico case greater detail in Figure 4.6 because the institutional water advantage/disadvantage of entry data is absent.

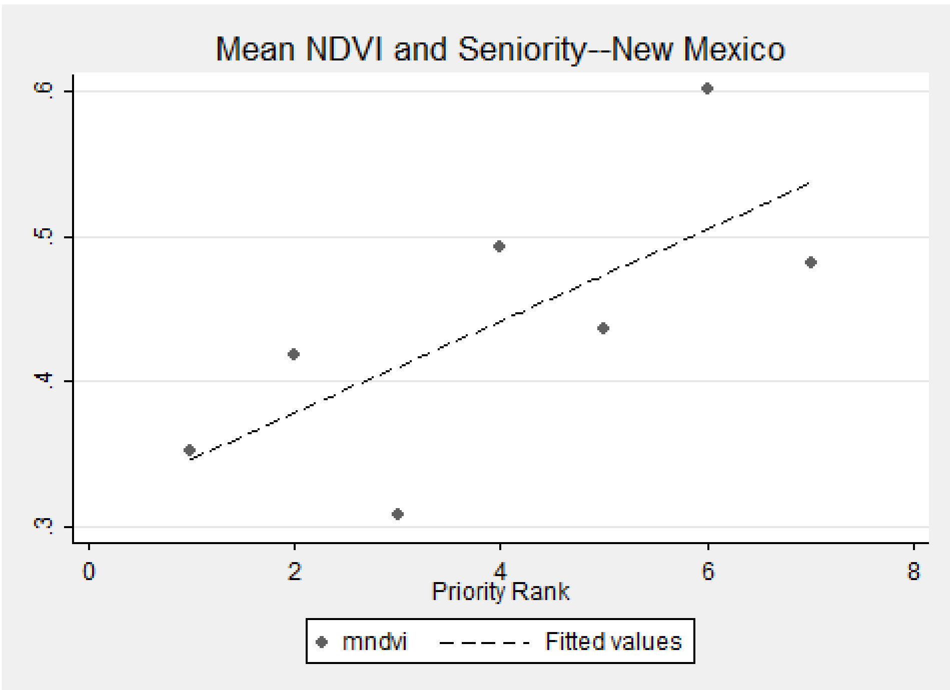
Table 4.8: NDVI and Priority Rank

VARIABLES	(1) NDVI Mean	(2) NDVI Mean	(3) NDVI Mean
Colorado			-6.157**
			(2.383)
Priority Rank	-0.00712***	0.0210***	0.0210***
	(0.00183)	(0.00142)	(0.00142)
Priority Rank x Colorado			-0.0281***
			(0.00214)
Acres	-4.12e-05***	-9.76e-05***	-9.76e-05***
	(3.76e-06)	(1.29e-05)	(1.29e-05)
Acres x Colorado			5.64e-05***
			(1.21e-05)
Year	-0.00114	-0.00432***	-0.00432***
	(0.00149)	(0.00119)	(0.00119)
Year x Colorado			0.00318**
			(0.00119)
Constant	2.870	9.028***	9.028***
	(2.983)	(2.371)	(2.374)
Sample	Colorado	New Mexico	All
Observations	196	196	392
R-squared	0.185	0.438	0.408

Regressions based on first 7 acequias in each region. Robust standard errors clustered by year in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figure 4.6: Average Performance and Priority



Clearly the would-be junior diverters perform better on average, not the seniors, questioning the assumption that the better suited land was actually settled first.

Digging into the risk profile of junior diverters, Figure 4.7 provides an illustration of deviations from mean production. The New Mexico line generally exhibits more variation with larger peaks and troughs. In Table 4.9 I provide estimates of equation (4.2) with temporal variation as the dependent variable. The dependent variable is the average absolute deviation from the *acequia* specific average mean, making it a cross-sectional analysis. Notably, there is less variation overall in Colorado, though variation increases as you move down the seniority ladder. This speaks to the stability overall of the seniority system, but also the increased variability for those with less secure flows. A visualization is provided in Figures 4.8 and 4.9. Notably, the first four in New Mexico are quite even, then priority five has an increase in variation while six and seven are quite low. Despite the outliers, there is not a clear relationship in New Mexico while Colorado is generally trending upwards.

Figure 4.7: NDVI Variation

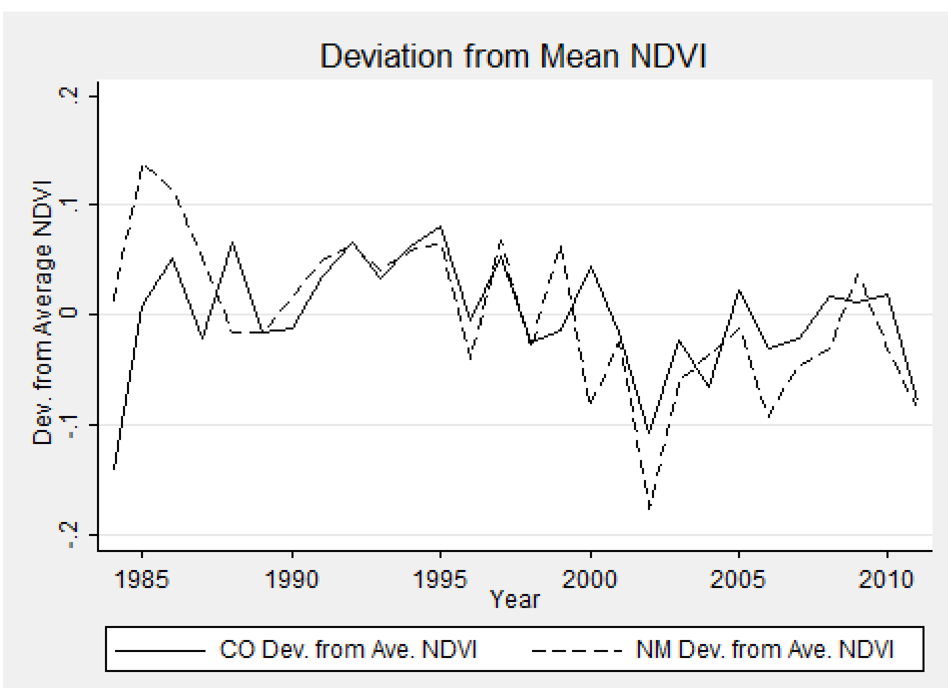


Table 4.9: Temporal Variability and Seniority

	(1)
VARIABLES	NDVI Temporal Dev.
Colorado	-0.0193*
	(0.00954)
Priority Rank	-0.00246***
	(0.000780)
Priority Rank x Colorado	0.00445***
	(0.00138)
Constant	0.0636***
	(0.00770)
Sample	All (1-7)
Observations	392
R-squared	0.012

Regressions based on first 7 acequias in each region.
Robust standard errors clustered by year in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 4.8: Variation and Priority in Colorado

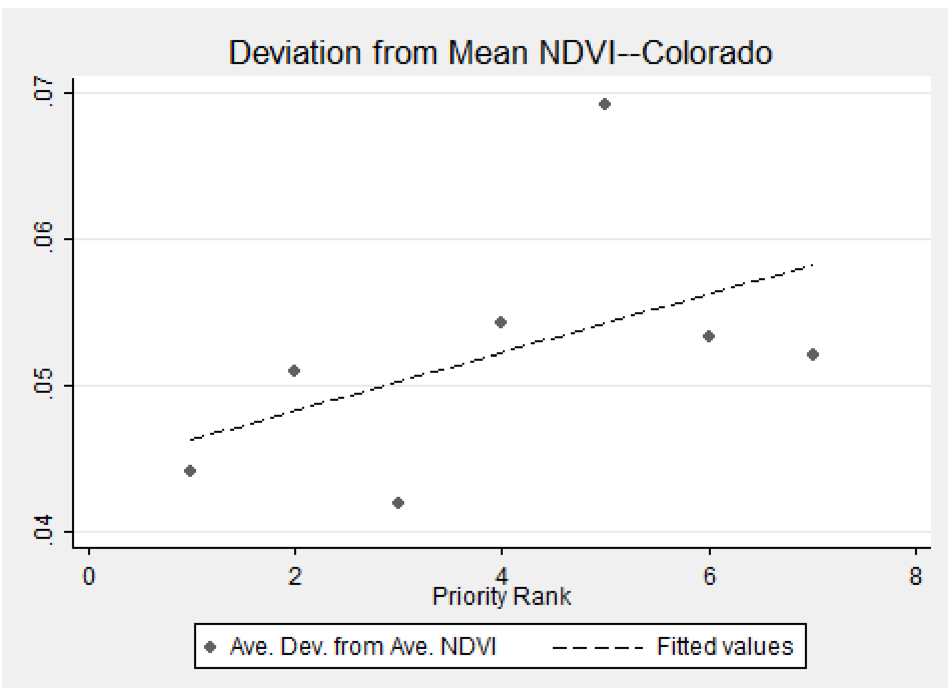
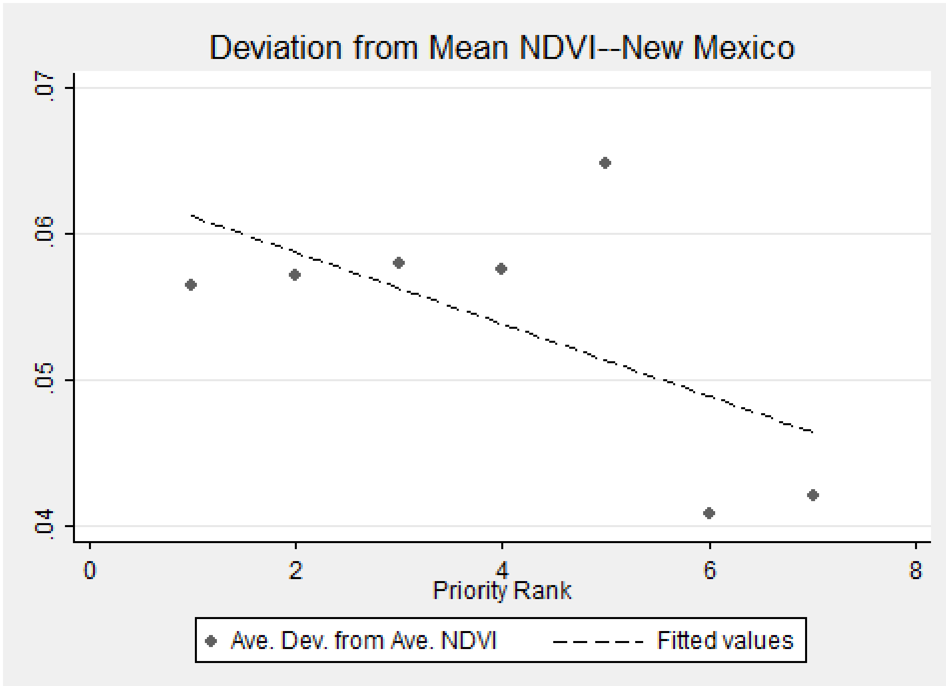


Figure 4.9: Variation and Priority in New Mexico



Finally, Table 4.10 reports results from a specification interacting indicators for seniority with stream flow including fixed effects. Notably, the R-squared for Colorado is quite low (0.069). In column (2), it is worth noting the stability of impact across all the *acequias*. The marginal gain is much more uniform, near 0.003, the same coefficient of the regional analysis. While only a few are statistically different from the impact in Colorado, five out of seven have a lower marginal gain than the New Mexican counterpart. On net, the results support H3a and H4b.

Table 4.10 NDVI and Stream Flow by Seniority

VARIABLES	(1) NDVI Mean	(2) NDVI Mean	(3) NDVI Mean
1 x CFS	0.000793	0.00315***	0.00315***
	(0.00187)	(0.000615)	(0.000794)
2 x CFS	0.00217	0.00302***	0.00302***
	(0.00187)	(0.000615)	(0.000794)
3 x CFS	-0.000797	0.00320***	0.00320***
	(0.00187)	(0.000615)	(0.000794)
4 x CFS	0.00443**	0.00326***	0.00326***
	(0.00187)	(0.000615)	(0.000794)
5 x CFS	2.21e-05	0.00365***	0.00365***
	(0.00187)	(0.000615)	(0.000794)
6 x CFS	0.00300	0.00230***	0.00230***
	(0.00187)	(0.000615)	(0.000794)
7 x CFS	0.00221	0.00240***	0.00240***
	(0.00187)	(0.000615)	(0.000794)
1 x CFS x Colorado			-0.00236
			(0.00177)
2 x CFS x Colorado			-0.000853
			(0.00177)
3 x CFS x Colorado			-0.00399**
			(0.00177)
4 x CFS x Colorado			0.00118
			(0.00177)
5 x CFS x Colorado			-0.00362**
			(0.00177)
6 x CFS x Colorado			0.000697
			(0.00177)
7 x CFS x Colorado			-0.000192
			(0.00177)
Year	-0.000143	-0.00270***	-0.00270***
	(0.000798)	(0.000413)	(0.000534)
Year x Colorado			0.00255***
			(0.000860)
Constant	0.712	5.722***	3.217***
	(1.622)	(0.829)	(0.869)
Acequia Fixed Effect	Y	Y	Y
Sample	Colorado	New Mexico	All
Observations	196	196	392
R-squared	0.069	0.605	0.338
Number of id	7	7	14

Regressions based on first 7 acequias in each region. Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.7 Discussion

In sum, all but A4 (better land settled first) and H2 (more diversion capacity in New Mexico) are supported by the data. Briefly, the non-support of H2 should not be surprising for two reasons given the empirical settings. For one, both regions initially developed under the communal sharing regime (though some of SLV's development did occur after the adoption of prior appropriation). Second, New Mexico did not develop as an open-access situation; instead the necessity of a land grant from the Spanish Crown (later Mexico) produced an alternative restraint to settlement and appropriation of the water resource.

The implication of the model and the empirics is that there are trade-offs of efficiency on various dimensions between the two systems. More water is always better, but the impact in Colorado is mediated to the marginal appropriator. That is, there is a general level of stability at the stream level, with those typically getting water getting it and those typically not, not. This is echoed by the spatial deviation, as more water does little for the senior users but allows junior users to irrigate, reducing the overall variation. While disparity in skill level is briefly discussed, the model does not endogenize this skill. The priority system can enhance its advantage in the presence of heterogeneous irrigators by providing secure water supply to senior appropriators, providing greater incentive to invest in new technology that will exacerbate the advantages they have in marginal production.

In New Mexico, their sharing system results in generally more efficient outcomes, with the marginal production gained from another CFS being higher. Table 9 exhibits this the most, showing how an additional unit of water is equally beneficial for irrigators, no matter their ranking based on entrance year. However, this efficiency advantage is greatly diminished in years of relatively low flow. Because the main model from BQ ignores the possibility of economies of scale on water usage, the possible advantages of the priority system are not made apparent. Once a minimum quantity of water is assumed to produce anything, the priority system provides some efficiency during droughts and the empirical results support the presence of this advantage. For one, the impact of a drought year is smaller in Colorado than in New Mexico. But more specifically, the marginal gains at the stream level are much larger in Colorado at low levels of water flow. The mechanism is that New Mexico is being forced to share the water and given the dearth of water, the unit is spread so thin it does anyone little good. In comparison, the additional units of water in Colorado are concentrated, overcoming the threshold needed to produce a profitable crop.

Overall, the study suggests a freely flowing market would likely provide the best of both worlds, though rights defined in proportions provide a better baseline. New Mexico, with proportional sharing, generally has greater gains during wet years, but fail to effectively concentrate water in a productive fashion during drought years. In contrast, Colorado's use of the seniority system increases relative performance during drought, but their inability to reallocate water to junior users in wetter years results in reduced gains.

4.8 Conclusion

In general, as indicated by BQ and others, the prior appropriation doctrine suffers allocative inefficiencies for irrigators due to unequal marginal production across irrigators. The most apparent solution is equal sharing, achievable through a market or alternative distribution rule. However, BQ failed to illuminate the advantages the priority system can have over a proportional or equal sharing regime. First, prior appropriation offers a mechanism to reduce open-access issues. Indeed, the imposition of externalities of late-comers on earlier diverters was the rationale for adopting the priority doctrine in Colorado (*Coffins v. Left Hand Ditch Co.*, 1882). Under the alternative distribution rule, more rents would be dissipated due to larger diversion construction and maintenance.

The model and empirics support the broad conclusion that communal sharing achieves greater efficiency for any aggregate diversion capacity. However, this overlooks the heterogeneity of land and irrigators. When the heterogeneity is so great that the efficient allocation begins to approach corner solutions, the communal sharing misallocates water to worse firms. Last, prior appropriation gains efficiency relative to communal sharing if production exhibits some economies of scale with respect to water at low amounts. The same sharing that equates marginal gains of water provides for mutual devastation during droughts, whereas the priority system ensures some production by concentrating the water during lower flow. Colorado takes advantage of this as indicated by the story in Hicks and Peña (2003) where the senior irrigator permitted share cropping on his land. Here Colorado concentrated the water to maximize production, but also shared the produce to maintain the spirit of sharing during droughts

Overall, the evidence supports the use of private rights and a functioning market. The ability to move water around would improve the shortcomings of division under both systems. In both cases, the root of inefficiency is unequal marginal production across irrigators, which a functioning market could address. Other research has indicated private rights delineated in shares rather than priority can lead to a better functioning market due to the homogenous units (Howe and Goemans 2003). While the priority system effectively solved the open access issue during initial appropriation, convincing senior appropriators to make the adjustment to proportional property rights is a tall order, suggesting the communal sharing can more readily address its issues during droughts.

Chapter five: Common Property Resources and New Entrants: Uncovering the Bias and Effects of New Users

5.1 Introduction

Sustainable management of common property resources (CPRs) requires continual cooperation. Once considered unattainable—the "tragedy of the commons" (Hardin 1968)—due to the disparity between individual incentives and group incentives (Gordon 1954), many advocated the need for private or state rights to address the externalities.[33] Other researchers, inspiring and inspired by Elinor Ostrom (1990), illustrated a number of exceptions. In successful cases the users in common utilize some combination of rules, trust, monitoring, and sanctioning to cooperate in managing and sharing CPRs. Several factors have been identified to alter the odds of successful collective action (Baland and Platteau 1996; Ostrom 1990), but are often implicitly treated as exogenous, particularly in empirical analysis due to data limitations. Specifically, user group characteristics are assumed fixed when they are at least partially determined endogenously and subject to disturbances. More valuable systems often attract new entrants (Alston et al. 2012). Most CPR analysis fails to account for the dynamic nature of the user group, suffers from omitted variable bias, and provides little identification of the role of repeated interactions in building trust.

Whether a user group undergoing turnover, replacing old users with new, can maintain high levels of success in managing the CPR remains largely unanswered. Stability of the population has been given credit in long-lived common arrangements (Ostrom 1990) while new entrants attracted by economic opportunity have been blamed for breaking down CPR management regimes (Libecap 1995). The mechanism—a break down in trust, increased

[33] I distinguish and prefer common property resource from common-pool resource. Common-pool resources may remain open-access with no exclusion; a situation truly prone to the tragedy of the commons.

transaction costs, or additional strain on the resource—is not clear nor whether new entrants inevitably perturb the cooperative equilibrium. Because there is a movement towards prescribing policies in environmental management such as decentralization (Agrawal and Ostrom 2001), it becomes more important to understand how a well-established common property management system responds to the introduction of new users—distinguishing the impact of being unfamiliar from that of being additional.

Often the difference between being new and being additional is overlooked; an additional user is inevitably new, but a transfer of access rights can introduce a new user without increasing the number of users. The new user introduces a number of unknowns into a system dependent partially on trust while the additional user drives up transaction costs—costs of negotiating, monitoring and enforcing agreements (Coase 1937; Williamson 1979)—and often increases demand of the resource. The role of trust has been explored empirically with measures of homogeneity serving as proxies. While legitimate and important, those measures do not account for the role of inter-personal trust built up overtime often emphasized in theory and likely significant in empirical settings.

To explore the relationship of entrants and cooperation, I build a unique data set based on communal irrigation systems known as *acequias* located in Taos Valley, New Mexico persisting from Spanish colonization. I combine remote sensing images, capturing performance, with property right records to form a panel of 50 irrigation systems over 28 years spanning from 1984-2011. Few panels exist on CPRs (Gjertsen 2005 and Kebede 2002 provide exceptions) because locally managed resources often lack centrally accessible data (Libecap 2013; Poteete et al. 2010) requiring costly field visits and surveys. In Taos, a mixture of private and common property of irrigation water and infrastructure creates a rich CPR data source lacking in many settings. In addition, state imposed limits on irrigated land bars any expansion in use—meaning additional users in this setting do not increase demand of the resource, and their impact is mediated wholly through the complexity of user interactions. This contrasts complications in other scenarios where more users result in larger aggregate harvests.

Repeated interactions are crucial to cooperation, allowing people to build trust, develop norms, and behave in a history dependent reciprocal nature. Its role is essential to moving beyond the prisoner's dilemma inevitable non-cooperative outcome but is difficult to measure and analyze in empirical settings (see Andersson (2004) for an example). Collection of panel data provides a straightforward way to address repeated interaction. The longitudinal component of the data results in correct inference of the statistical impact of disturbances within a given system and offers a solution to the omitted variable bias (OVB) that pervades empirical research. With so many factors influencing outcomes in a Social-Ecological System (SES), many interacting with one another, it is difficult or impossible to adequately control for everything in statistical analysis (Agrawal 2003). The analysis at hand serves as a diagnostic tool to assess the extent of OVB as it pertains to the user group. Cross-sectional treatments of the data are estimated to compare with fixed effect regressions in which unobserved time-invariant variables are implicitly controlled.

I find the existing *acequia* users and institutional rules mitigate the shock of a new user while additional users stress the system and reduce the level of success. Perhaps more importantly, the various specifications uncover a positive OVB in cross-sectional treatment. This result implies that while many studies have found cooperation to be inversely related to the number of users, empirical studies have likely understated the negative impact due to endogeneity issues: users are attracted to better functioning CPRs. The non-negative impact of new users is counter to predictions based on trust but also echoes the positive bias. Information gathered in surveys of a subset of *acequias* illuminates how the use of rules substitute for trust and indicate some positive selection on the part of new entrants. My findings make it important to learn what features of the SES provided resilience and to assess if similar impacts occur in other settings and with other resources.

Below I first explore some pertinent literature and theories concerning the impact of user group characteristics and the empirical shortcomings. Following a description of the empirical setting and background, I provide details on the data and methodology. After which I report the econometric results and robustness checks followed by a brief discussion of the implications for CPRs.

5.2. Background

5.2.1 Social-Ecological Systems

CPRs are well viewed through the larger framework of a social-ecological system or coupled human and natural systems. The hybrid systems combine natural elements, e.g. biodiversity, biomass, hydrology, soil, and wildlife with humanly devised elements, e.g. governance systems, harvesting, manipulation, relative prices, user group, and culture. A number of frameworks exist, each identifying a number of important components. For instance, a commonly utilized version put forth by Ostrom (2009) includes four core components—the resource units, resource system, governance structure, and the user group—each with ten or so second-level factors. The framework is not limited to CPRs, as the governance structure and property rights can vary. The resource units are most plausibly exogenous, as this serves to distinguish from forests, fisheries, oil, water and other resources. My study focuses on water, specifically snowmelt irrigation systems with no storage.

Arun Agrawal (2003) summarizes facilitating conditions of successful CPRs from a variety of researchers. Of primary concern here is that of the user group. User group characteristics making success more likely includes small size, defined social boundaries, shared norms, past success (social capital), appropriate leadership, interdependence, and homogeneity of resources, interests and views. Even if a user is replaced and the number remains the same, their identity matters; socio-economic composition, reliance on the resource, and shared norms may all be altered and there is a decidedly lack of history now between the new user and remaining users. On top of these alterations, the group size may increase when the new user is an additional user as well.

5.2.2 New Users and Game Theory

Like other situations where private outcomes are contingent on private decisions and strategies of others, game theory provides useful theoretical roots for the likelihood of cooperation. Though oversimplified, the tragedy of the commons is often given a prisoner's dilemma treatment.[34] In the simplest setting, two users must decide between cooperation and non-cooperation. The payoff structure takes a form like that given in Figure 5.1. While the social optimum is for both to cooperate, this strategy is strictly dominated by defection for both, producing the Nash equilibrium of non-cooperative behavior.

From a rational, theoretical standpoint, only once the game is repeated infinitely (or finitely with sufficient probability of another round) do cooperative outcomes become rational. Unfortunately, the application of the Folk Theorem is limited as it not only supports the always cooperate strategy as an equilibrium, but many other equilibria as well without offering

[34] Baland & Platteau (1996) provide other possible payout structures such as the assurance game and the hawk or chicken game.

Figure 5.1: Prisoner Dilemma Example

Player A		Player B	
		Cooperate	**Defect**
	Cooperate	5 (a),5 (b)	-1 (a),7 (b)
	Defect	7 (a),-1 (b)	0 (a),0 (b)

information on which result is more likely. That aside, the important point is that the repeated interaction permits strategies to be history dependent, allowing for the use of punishment (sanctions) but also the accumulation of trust, norms, and reciprocity, yielding a path dependent possibility of sustained cooperation (Seabright 1997).

Drew Fudenberg and Jean Tirole (1991, p. 169) provide a simple example incorporating the complexity of new users. With one player remaining and the other new each period, the typical Folk Theorem result is no longer applicable as the min-max threat that often sustains cooperation is not operational. Nonetheless, they show sustained cooperation is possible if the new user moves first and the old user chooses to behave as the new user does. Notably, this result still depends on knowledge of past decisions in order for the new player to observe the other users strategy.

Evolutionary game theory also incorporates players or payoffs changing overtime. In one apt treatment, Rajiv Sethi and Eswaran Somanathan (1996) address how the intensity of social interactions can impose social norms overtime, underscoring the role of repeated and frequent interaction. However, a curious result is that cooperative behavior has also been observed in one-shot games (Cox et al. 2009), shedding some concerns on the use of game theory.

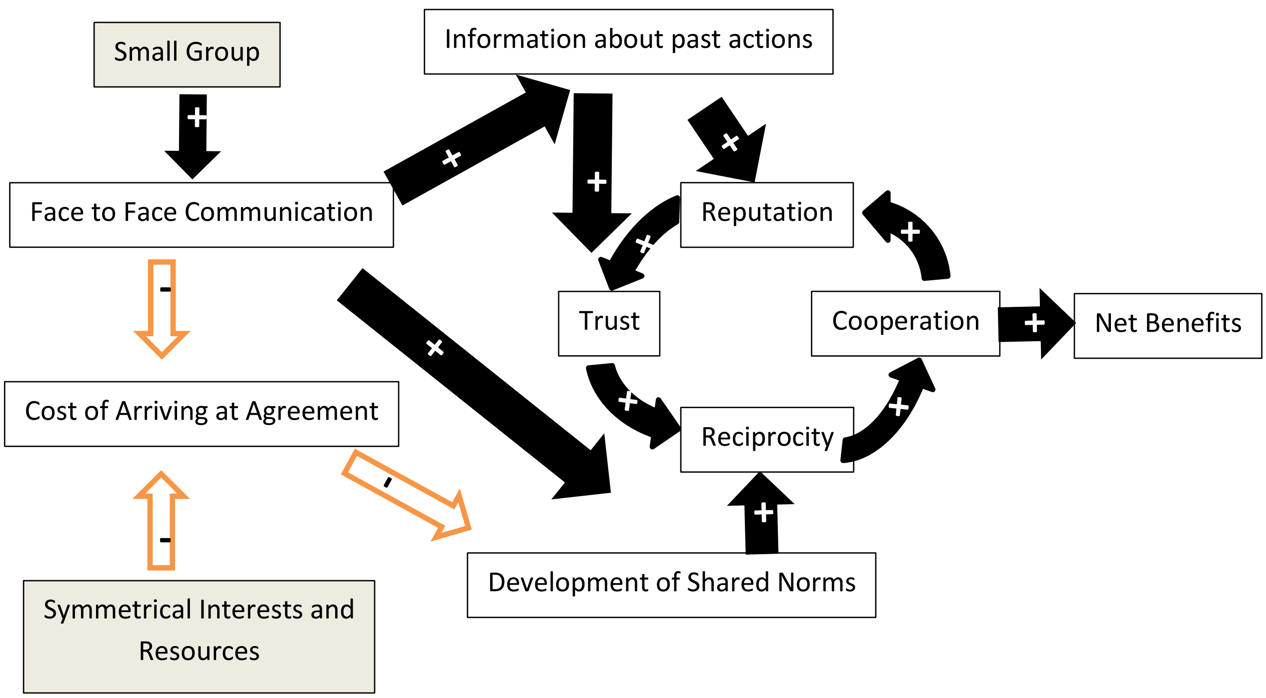
5.2.3 New Users and Trust

The failure of economic agents to behave rationally in one-shot games and other scenarios has led to efforts to create richer behavioral models for rational choice guided by information constraints and various motivations other than personal income maximization. Early on, Mancur Olson (1965) suggested that groups of users likely weigh the economic gains with the social costs of defecting. Ostrom (1998) provides a causal model of how user group characteristics interact with an internal positive feedback loop of trust, reciprocity, reputation and cooperation (recreated in Figure 5.2). This model relaxes the need for perfectly rational agents and allows for behavior based on personal interactions. New users will reduce the overall knowledge of past actions within the system; the lack of information is hypothesized to reduce trust levels and reputation. The implied outcome is a downward spiral due to the initial breakdown in trust. While helpful in illustrating the role of trust, the model lacks the intervention of endogenous institutions and rules.

Trust, prevalent in much of the literature, is often replaced by "social capital" when identifying factors related to successful management. While social capital and trust are similar, I find the concept of trust to be more appropriate. Both of which have been linked to one another and social networks and repeated interactions (Bordieu 1986; Grafton 2005; Paldam 2000). Often economists use social capital as the wording parallels other common forms of capital (human, physical, and natural), but Joel Sobel (2002) highlights a number of economists critical on its use suggesting that social capital does not require costly investment and often appreciates

Figure 5.2: Causal Model of Trust and Cooperation

*Adapted from Ostrom (1998)



with use. Social capital's lack of a firm definition provides no broadly accepted method of measuring it. Instead, often research falls into a circuitous argument in which social capital is assumed present where positive outcomes occur, resulting in positive outcomes (Portes and Landolt 2000; Sobel 2002).

Thus, while trust does not appear directly in either Ostrom's SES framework or Agrawal's synthesis of facilitating conditions, it is the more appropriate concept, particularly when the initial collective action has taken place the issue is continued cooperation. Sobel (2002) defines trust as the willingness to permit the decisions of other to impact your welfare.

This can be applied broadly to general levels of trust in others, though the application here is special trust; trust specific to social networks and specific individuals (Paldam 2000). Martin Paldam goes on to indicate that trust can be used in production in order reduce transaction costs. In this fashion, rules and sanctions can serve as a substitute to the use of trust and reduce its role in outcomes. On net, new users will reduce the extent of trust within the system, but institutional rules could mitigate the impact, making attention to the governance structure important.

5.2.4 Experiments and Trust

Experiments have been conducted to assess the role that trust plays in sustaining cooperation in the context of games. Cooperation can be achieved even in one-shot prisoner's dilemma when a mechanism to recognize the trustworthiness of the opponent exists (Janssen 2008). In repeated situations, the presence of face-to-face communication leads to more efficient outcomes (Castillo and Saysel 2005). While theory predicts that repeated interactions build trust and trust facilitates cooperation, conditional-trust may be exhibited from the start when there is possible profit in it and opportunity to build a reputation. Experiments with the trust game have shown that even without prior interactions the first mover will often exhibit trust in their mysterious partner by investing some money in to the group fund which then is left to the second mover to decide how to divide it among the two players (Cox et al. 2009). Therefore, experimental results indicate that trust is important but also that new users may exhibit a level of trust without past interactions.

5.2.5 Additional Users

Separate from being new, additional users alter the user group and incentives in its own way. Overall, the number of users has been posited to be negatively correlated to successful collective actions (Baland and Platteau 1996; Olson 1965; Ostrom 1990). The impact of the additional user may be mediated through trust but largely through increased transaction costs.

Mechanically, moving from the two player prisoner's dilemma game to a multi-player increases the complexity and reduces likelihood of selecting the cooperative equilibrium amongst the many combinations of strategies. Jean-Marie Baland and Jean-Philippe Platteau (1996) point out a number of reasons why smaller groups are more likely to choose the positive equilibrium: 1) players are more readily able to observe and condition on others' actions; 2) the free-rider incentives are reduced with fewer users; and 3) the smaller group will find it easier to communicate trustworthy intentions of playing the cooperative strategies.

In regards to the trust and norms avenue, the causal model indicates that greater number of users will find it more difficult to engage in face-to-face communication, reducing trust levels. Similarly, Sethi and Somanathan (1996) in their evolutionary game find that intensity of social interactions, crucial to imposing norms, reduces as population increases. Olson (1965) also indicates that larger group sizes would decrease the power of social sanctions, increasing the likelihood of more selfish behavior.

Not only do additional players reduce the ability to maintain high levels of trusts, they also make the substitute inputs of rules more difficult. A greater number of people increases the transaction costs of operating current rules and makes changing the rules more challenging. This phenomenon is common in the case of externalities (Coase 1960). In many resource settings, the additional user represents increased demand on the resource as well; a crucial component to possible breakdown often observed in CPRs upon new entrants, though not in the context analyzed below.

5.2.6 Heterogeneity

Though not the focus of the research at hand, heterogeneity of the users has received much attention from the literature as well (Baland and Platteau 1996; Bardhan and Dayton-Johnson 2002; Ostrom 1990) with much of the empirical work using heterogeneity as a proxy for trust or social capital. Both economic and cultural heterogeneity are commonly addressed. Cultural heterogeneity is seen as a hurdle to cooperation as factions are unlikely to share norms and have lower levels of trust for one another. Similarly, economic heterogeneity can incite low levels of trust across economic class. However, economic heterogeneity has been posited to have a U-shaped relationship due to the ability of a subset of well off individuals to provide the collective good based merely on their own private gains or key leadership positions. Because these factors are often altered with new users (Libecap 1995), it is important to consider them in order to not conflate the impact of new, additional, and different users with one another.

5.2.7 Empirical Work

Most empirical work on CPR institutions remains either single case studies (e.g. Trawick 2001) or cross-sectional analysis of a number of systems. Here I focus on the statistical analyses. Cross-sectional studies have been instrumental in understanding correlations but have failed to address the role of repeated interactions directly and the endogeneity of the user group characteristics. Moreover, some analysts attempt to infer temporal behavior from cross-sectional analyses, a practice fraught with methodological problems.

Considering the number of users, empirical work finds larger groups struggle more with allocation issues (Bardhan 2000; Cox and Ross 2011; Dayton-Johnson 2000), but sometimes aids in public good provision (Benin and Pender 2006; Dayton-Johnson 2000). Indeed, there is a tradeoff between increasing transactions costs and increasing division of labor as the user group grows, but CPRs with more users have been generally worse at management and performance.

Most empirical research use measures of heterogeneity as a proxy for trust. Eric Jones (2004) explicitly identifies trust as a mediating mechanism between homogeneity and cooperation in the cases of economic resources and Lore Ruttan (2006) in the case cultural identity, both in empirical field settings. Homogeneity is commonly captured by a Gini coefficient of some resource (e.g. land holdings) and a measure of cultural groups within a system. Pranab Bardhan and Jeff Dayton-Johnson (2002) survey empirical work on heterogeneity, concluding user groups with greater heterogeneity in any dimension, all else equal, achieve lower levels of cooperative measures. These results align with the behavioral model, but ignore trust built up over time.

Very little empirical work has been done concerning the role of trust and reciprocity derived from repeated interactions due to the difficulty of forming a longitudinal data set over a significant time period. There have been some attempts to capture the dynamic of turnover and social capital built up over time within a cross-sectional framework. Munyaradzi Mutenje et al. (2011) include a measure of the duration of the household and find households which have been around longer tend to degrade the communal forest less. Carina Cavalcanti et al. (2013) find that individuals with denser social networks cooperate more in a communal fishery scheme. Michael Cox and Justin Ross (2011) show irrigation systems with greater division of land overtime—signifying additional users—also produce less overtime. Addressing the role of repeated interactions and face-to-face communication directly, Krister Andersson (2004) reports that Bolivian forest users tend to communally manage the resource better when they have more meetings.

5.2.8 Omitted Variable Bias

The existing empirical research relies on single snapshots, simply comparing across various groups. This approach ignores the possibility that user group characteristics are endogenously determined. These analyses likely suffer from omitted variable bias as the SES structure includes many elements that interact with one another (Agrawal 2003) and are difficult to measure and collect data (Libecap 2013; Poteete et al. 2010). The problem arises when the excluded unobservable variables are correlated with the outcome and the other variables of interest.

For example, if success of an irrigation system varies based on the number of users and its position on the stream, failing to measure and include the position could yield biased estimates of the impact of the users if position on the stream also influences the size of the user group directly or indirectly. The direction of the bias depends on both the true coefficient of the omitted variable and the covariance with the omitted variable and the variable of interest. If upstream systems are more productive due to their ability to divert water first but are more populated because easy access to the mountains is desirable, the estimation (when omitting position) would yield a positive bias, understating the negative effect of additional users.[35] While an illustrative example, stream position is readily observable and included in the analysis

[35] Mathematically, omitting the position of the stream amounts to estimating the following equation:

$$y_i = \beta_0 + \beta_1 \times \#Users_i + \gamma_i$$

Where y_i is some measure of cooperation or success. However, the correct model would be:

$$y_i = \alpha_0 + \alpha_1 \times \#Users_i + \alpha_2 \times Upstream_i + \epsilon_i$$

Estimating the incorrect model introduces the following bias:

$$\beta_1 = \alpha_1 + \alpha_2 \times \frac{Cov(Upstream, \#Users)}{Var(\#Users)}$$

Therefore the direction of the bias depends on the product of $\alpha_2 \times Cov(Upstream, \#Users)$.

below. One could consider soil quality, water quality, or slope as the omitted variable. For the empirical setting below, the amount of water entering an *acequia* is not readily observable to the researcher, though this clearly impacts productivity, while for new entrants and users exiting the system, are likely observable (though perhaps imperfectly) and may impact the user group disturbances.

As an example, Cox and Ross (2011) provide an insightful exploration of disturbances and robustness of irrigation systems, but are ultimately limited by data availability. While they find a negative relationship between production and land fragmentation (their measure of entrants) as predicted by the behavioral model, the inference is complicated by the cross-sectional analysis. Causality is not clear with the 24 year temporal average dependent variable, as it could be those irrigation groups that struggled to grow healthy crops were those more likely to be broken up and sold rather than the fragmentation reducing the production. In addition to causal direction, the magnitude of impact could be misstated due to a third element which influences both the outcome and the user group characteristic, but is not included. For example, in Andersson (2004), communities that are geographically smaller could make holding meetings easier but also make it easier to monitor forest use—overstating the positive impact of holding the meetings.

While various approaches could address the OVB issue, the advantages of panel data create plausible causality and allow variation within systems rather than just across, measuring the impact of changing user groups directly.

5.3 Empirical Study Setting

To produce a panel data set on CPR systems, I utilize data on a number of irrigation ditches in Taos Valley of north central New Mexico, USA, highlighted in Figure 5.3. Farmers in

Figure 5.3: Study Region

*Source Cox (2010)

this area rely on common property irrigation ditches rooted in Spanish tradition called *acequias*. The ditches are simple unlined, earthen ditches whose flows are subject to supply, gravity, and simple head gates. The water comes from the snowpack in the Sangre de Cristo Mountains to the east as the water drains to the Rio Grande. With only 33 cm (13 inches) of annual rainfall on the high valley floor, the fertile soil would produce very little without supplemental irrigation water.

Taos Valley has fifty independent *acequias* that rely on surface snowmelt for irrigation. Many of the *acequias* were originally established during Spanish and Mexican colonization dating back to 1675. Of those with data on date of formation, all were established prior to 1881 (Dos Rios Consultants 1996). As the northern most outpost of *Nuevo México*, their isolation made subsistence agriculture a primary need and the communal *acequia* took priority over other projects such as the church (Rivera and Glick 2002). The *acequia* is designed to deliver water to water right holders, historically Hispanic farmers who harvest alfalfa, raise livestock on grass pasture, and grow smaller gardens. Throughout the study period, the total number of *parcientes* (*acequia* members) ranges from 2700-3600. The *acequias* are distributed around three main sources of water (though many draw from smaller tributaries). Two smaller regions include the Rio Hondo to the north (8 *acequias*) and the Rio Grande del Rancho to the south (14 *acequias*) and the third, large central region, draws from the Rio Pueblo de Taos (28 *acequias*).

The *acequia Madre*, or mother ditch carries the water from the stream and is property held in common. As these are often unlined earthen canals with simple head gates, each year all members must work together to clean and maintain the ditch so it delivers the water with minimal loss. The provision of this maintenance requires the group to avoid free-riding, often symptomatic of public goods. In practice, most *acequias* hold an annual cleaning during the spring just prior to irrigation season whereas seasonal maintenance may charge the individual land holders to maintain the portion through their property.

The water itself is no longer common property as it was under Spanish and Mexican law when the *acequias* were established. The doctrine of prior appropriation prevalent in the arid regions of the United States requires communities to allocate individuals with private water rights.[36] Due to the requirement to apply the water to beneficial use, the courts determined that *acequias* could not own the water rights because it is the individual who uses the water (*Snow v. Abalos* (1914) 140 P. 1044, 18 N.M. 681). In Taos Valley, the adjudication process, commonly

[36] Prior Appropriation, often called "first in time, first in right", is a seniority system allowing early diverters to obtain their full right of water before junior appropriators receive any. Most states beyond the 100th Meridian have adopted this over the Riparian rights common in the wetter more eastern regions.

referred to as the Abeyta case, began in 1969 and is not yet settled officially after 43 years.[37] The private rights are notably limited. Right of management is shared by the community with the *acequia* capable of denying conveyance of the water to the right holder. Transfer of water right outside of the *acequia* requires approval by the community.[38] More general transfers, accompanying the irrigated land, are not subject to communal approval.

While the water is *de jure* private, it is not treated that way. The State Engineer of New Mexico has attempted to adjudicate water rights to the individual level but will not interfere with delivery beyond the *acequia Madre.* Each *acequia* forms an autonomous political subdivision of the state ran by three commissioners (treasurer, secretary, and chairmen) in addition to the *mayordomo* elected annually by the *parcientes* from among themselves. Also, all users within an *acequia* share the same priority date. Furthermore, the reliance on the common property ditch for conveyance of the water restricts individuals rights with much of the management rights vested with the community.

Within an *acequia* water is commonly divided by time, providing one or two *parcientes* the full flow of water for some period. For some *acequias* this is done on a fixed schedule, while others use a first-come, first-serve schedule. In either case, those that are not using their "private" water right allow others to utilize that water and any surplus or scarcity is spread equally through the rotation. The rotation-system, often administered moving downstream, lowers the cost of monitoring and enforcement through easy self-monitoring; if an irrigator does not receive water at their allotted time, it is easy to detect and subsequently walk upstream to the adjacent irrigator, the likely culprit (Trawick 2001). Notably, the proximity of the irrigators

[37] All major parties signed an agreement late 2012 but the court will not accept it until all *parcientes* objections have been heard.

[38] If the Abeyta settlement is approved as currently written, *acequias* could not deny individual transfers to the Pueblo Indians in the area.

implies other interactions with one another, reducing incentives to disregard the rules at your neighbors' expense. The internal rotation is subject to the control of the *mayordomo*, an elected position charged with both the design, implementation, and monitoring of water division within the *acequia.* The position also provides the interface to other *acequias* to implement and enforce sharing agreements.

Across *acequias*, sharing water from the stream may be more contentious, but many have agreed to and practiced a proportional division of the water for decades (known as *repartimiento*). The Abeyta settlement has resulted in irrigators formally agreeing to forego the priority system and maintain their historic sharing agreements across *acequias* on a stream (Richards 2008).[39] [40] In advocating for the need of legal recognition of *repartimiento*, José Rivera (1998) notes that commissioners feared turnover, stating, "If land or water rights were to be sold anytime in the near future, they feared new owners might not continue the custom on their own, imperiling communities with junior rights" (p. 169).

On net, while water is *de jure* private, it remains *de facto* common property, with shortfalls shared in times of drought and surpluses shared in wet years. Instead, most users explain the system as built on need and cooperation; that when water is scarce, they all sacrifice to make sure everyone receives a portion of the scarce water.

The resulting division of water has eschewed the states desire to quantify flows. Unlike the neighboring *acequias* of Costilla County, Colorado, where the State Engineer monitors and adjusts *acequia* intake within a priority system, Taos *acequias* lack even simple measurement devices. As discussed below, there are four USGS gauges at a stream level, but the researcher

[39] The Treaty of Guadalupe Hidalgo provided the protection of all property rights including water rights pre-dating United States Annexation, providing legal standing to be free of the priority system. Additionally, the determination of dates has proved difficult without adequate historical records.

[40] The exception is for Rio Grande Compact requirements. If the Taos area is being curtailed, the priority system will determine the order in which the *acequias* are curtailed.

has no data on water flow into individual *acequias*. Beyond this, while irrigators have mostly continued to rely on surface flows rather than sinking wells, the region does have a valuable and variable groundwater system (Cox 2014). For many downstream irrigators, water seeps back into the streambed, though some more than others. This additional source of water is extremely difficult to quantify as an outside researcher, though local knowledge can likely categorically rank *acequias* in average water availability. This omission of information is just one, though likely important, of the possible omitted variables that can create a statistical bias.

The transfer of water rights, appurtenant to the land, remains a private decision. While transfers of water independent of land to use outside the *acequia* are subject to general non-injury to third party protection and specific *acequia* by-laws providing veto power, the same does not apply to transfers of water along with the irrigated land. In other words, the group lacks the ability to collectively screen and control the user group. In recent history, the *acequia* users have been changing while the institution and technology used remain constant, making Taos ideal to study the effect of new users on CPRs. Around 40 percent of the irrigated land in *acequias* has been sold since 1969, both on average and in total. From 1984-2011, 2.2 percent of the users in an *acequia* are new each year (the median is zero while the average disturbance when there is turnover is 4.5 percent). Many of the transfers also divide irrigated land into smaller segments, introducing additional users as well. The variation in turnover across time and location allows me to identify the impact of new and additional users on cooperation and production. Importantly, the technology employed remains rather stable with recent survey data confirming ditches remain unlined and irrigators still utilize flood techniques to irrigate, foregoing more modern sprinklers and drip systems.

The setting also provides an advantage by not confounding resource scarcity with the addition of new users. With irrigated lands determined and limited by state law, additional users do not expand the demand of the resource, as total irrigated land remains constant. With this, the impact of additional users is mediated through user interactions and not increased strain on the resource aside from any scale effects which are explicitly controlled in the analysis. Additionally, the reliance on snowmelt removes the complication of misaligned conservation incentives, as the supply of water is stochastic and beyond the control of the users. These dynamics contrast other situations such as fisheries, e.g. the Sri Lankan fishery case in Ostrom (1990, p. 149-157) in which additional users caused the system to collapse. In that instance, new users put more demand on the resource while struggling to divide the resource both across users and across time periods.

5.4 Data and Methods

5.4.1 Data

To assess the impact of user group disturbances in the field setting, I create panel data consisting of fifty *acequias* over a twenty-eight year period from 1984-2011 accounting for user group variables and a biological outcome tied to cooperation in maintenance and allocation. A panel of such length is extremely difficult to create through original field research. Instead, I create the data set through pre-existing records requiring compilation and analysis. The large-N sample of *acequias* comes primarily from two sources: 1) Satellite imaging provides the biophysical outcome variable; and 2) user group characteristics are derived from water right records. The two sources are linked by hydrographic maps from the New Mexico State Engineer's Office. Supplementary information is referenced from a survey conducted for 17 of the *acequias* following the initial data analysis.

5.4.2 Satellite data

Communal irrigation systems require solving issues of provision for infrastructure and division of water. In the Taos setting, use of surface water without storage facilities limits water allocation issues to spatial dimensions with little temporal concern for conservation (confirmed below).[41] With no direct measure, I utilize satellite data which captures the extent of healthy vegetation as a proxy that captures both issues of division and maintenance shortcomings that result in reduced water availability in the arid setting.

The measure utilized is the normalized difference vegetation index (NDVI). Influenced by a number of factors, NDVI is positively related to biomass (Lillesand et al. 2007). NDVI is calculated from satellite imagery that processes a variety of wavelengths. Isolating two in particular obtains a measure of healthy vegetation present. NIR is the reflectiveness of near-infrared wavelengths and RED is the reflectiveness of red wavelengths in the electromagnetic spectrum. The measures used to build the NDVI are the percentages of light reflected back in these particular spectrums. NIR is reflected back by healthy vegetation, while RED is not. NDVI is normalized to be between -1 and 1, with numbers closer to one representing more abundant, healthy vegetation.

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

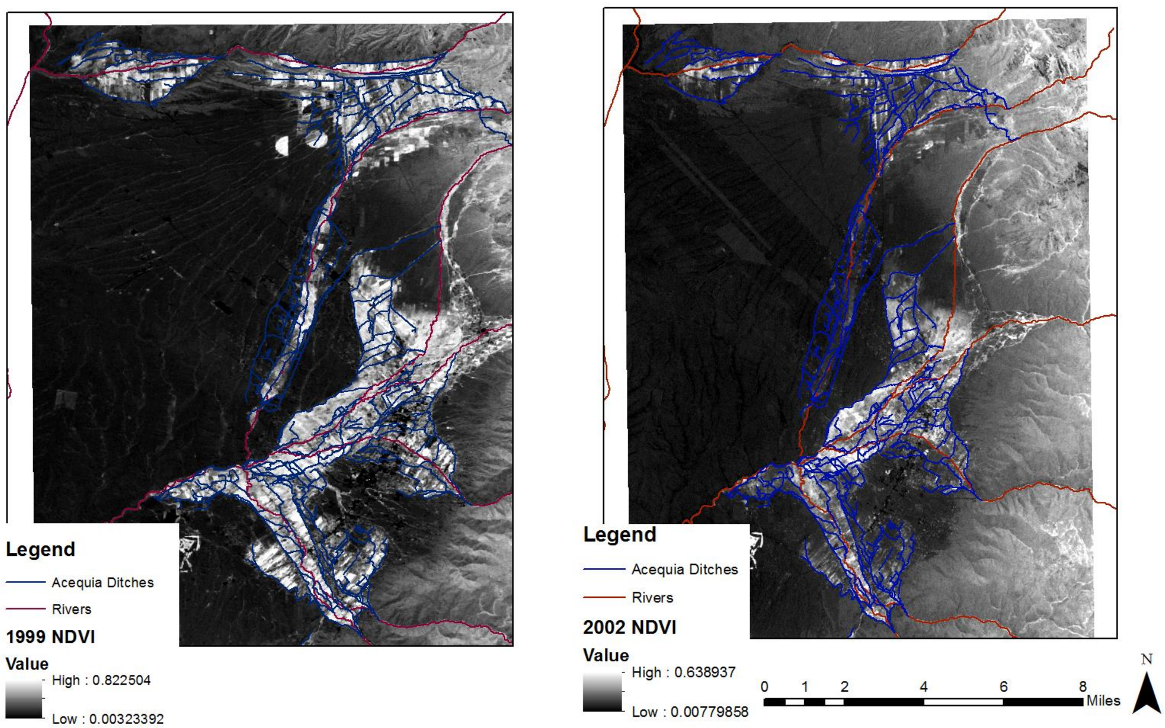
For analysis below, NDVI values are scaled to span -100 to 100.

Use of NDVI as a source of overtime data on land usage is no longer uncommon (Nagendra et al. 2005; Ostrom and Nagendra 2006; Honey-Roses et al. 2011). It is somewhat unique to utilize it as an indicator of water usage (see Cox and Ross 2011 for an example). Visuals of the data are provided in Figure 5.4, where higher NDVI values

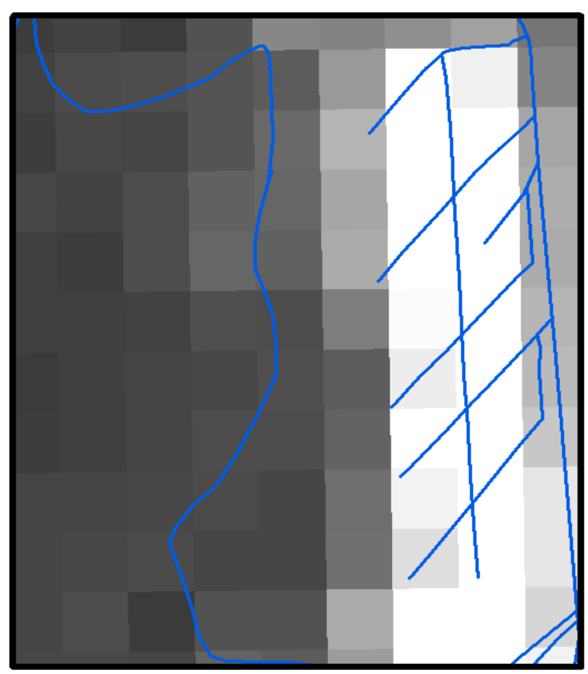
[41] The three reservoirs in the area serve only short-term storage functions, collecting water through the night to increase the supply during the day, avoiding the need to irrigate during the night.

Figure 5.4: NDVI Visualizations

Taos Valley Acequias and NDVI (1999 and 2002)



Aerial Photo



NDVI

agriculture. Like Cox & Ross, I utilize this biophysical outcome to measure the performance of the *acequias.* Given the arid locale in which water is often the limiting factor for agriculture, it indicates the level of success in delivering the water. In addition, while NDVI is a biophysical measure, given the simple irrigation technology, water delivery remains reliant on successful collective action and the measure can be reasonably expected to be correlated to the social outcome of cooperation. The measure has a number of favorable features for this research. First, it is objective. In most studies, cooperation or outcomes are measured by a survey question posed to a sample of users, introducing subjectivity (Bardhan 2000; Dayton-Johnson 2000; Ruttan 2006; Varughese and Ostrom 2001). Second, the satellite imagery is available retroactively; therefore it is unique in that I can create panel data dating back a number of years despite lacking surveys from that time period or relying on user recall.

Reliance on remote sensing does have limitations. Of primary concern in my application may be the impact of various crops and their impact on NDVI. However, the crop mix is rather stable in Taos with grass/hay/alfalfa mixes dominating the landscape. As of the 2007 U.S. Agricultural Census, Taos County had 11,842 of 12,452 (95%) of acres in production dedicated to forage. Looking further back to the 2002 and 1997 census, the measure remains above 95 percent.[42] The survey results of 17 *acequias* confirm forage's dominance with a small shift towards uncut pasture grass from the more labor intensive alfalfa or hay.

The original NDVI data comes from the Landsat Satellite, publicly available back to 1984. Collection and calculation of these values are due in large part to Cox (2010) generously sharing the data from his dissertation which also explored dynamics of irrigation in Taos Valley. Each year an image of the region is selected and overlaid with GIS data regarding which land is

[42] Comparable Data for 1992 and 1987 are withheld for Taos County to protect the confidentiality of the relative few farmers in Los Alamos County.

irrigated from each *acequia*. In all cases, the image selected comes from within the growing season with image dates spanning from June 9th to July 28th. The variation in timing is due in part by the timing of the orbit and in part by the need of cloudless images. The satellite images are calibrated and analyzed to calculate NDVI for each pixel. Once the 30x30 meter pixels are assigned to the appropriate *acequia*, a spatial average of NDVI is calculated for each *acequia* every year.

In relationship to cooperation, the broad assumption is that higher levels of mean NDVI are positively correlated to cooperation in delivering water. When considering infrastructure issues, this is straightforward and direct, as reductions in overall water availability should reduce the collective production of the community. In regards to equitable distribution of the water, the measure may not be as direct. When non-cooperative behavior takes the form of unequal distribution of water, there are winners and losers. The impact on the average production is less predictable. For this reason, in addition to the mean NDVI in the primary analysis, measures of distribution are utilized in other specifications, primarily the spatial standard deviation within the *acequias* and the average of only un-transferred lands.

In order to substantiate the dependence of NDVI on irrigation water, a brief valley-wide treatment is provided here. Figure 6 plots the annual average flow of water with the annual average NDVI value across *acequias*. The stream flow, in cubic feet per second, is the sum of the annual average of four streams in the region—the Rio Hondo, Rio Lucero, Rio Pueblo de Taos, and Rio Grande del Rancho—all monitored by USGS stream gages.[43] *Acequias* themselves do not measure intake, limiting the use of stream flow data. Regardless, the correlation of stream flow and NDVI is apparent in Figure 5.5. In Table 5.1 I provide the results

[43] The remaining smaller streams feeding some *acequias* do not have any stream gages.

from a simple regression of NDVI on the average annual flow of the streams including a lagged term for the flow with standard errors clustered by both year and *acequia* (Cameron et al. 2011).

Figure 5.5: Stream Flow and NDVI

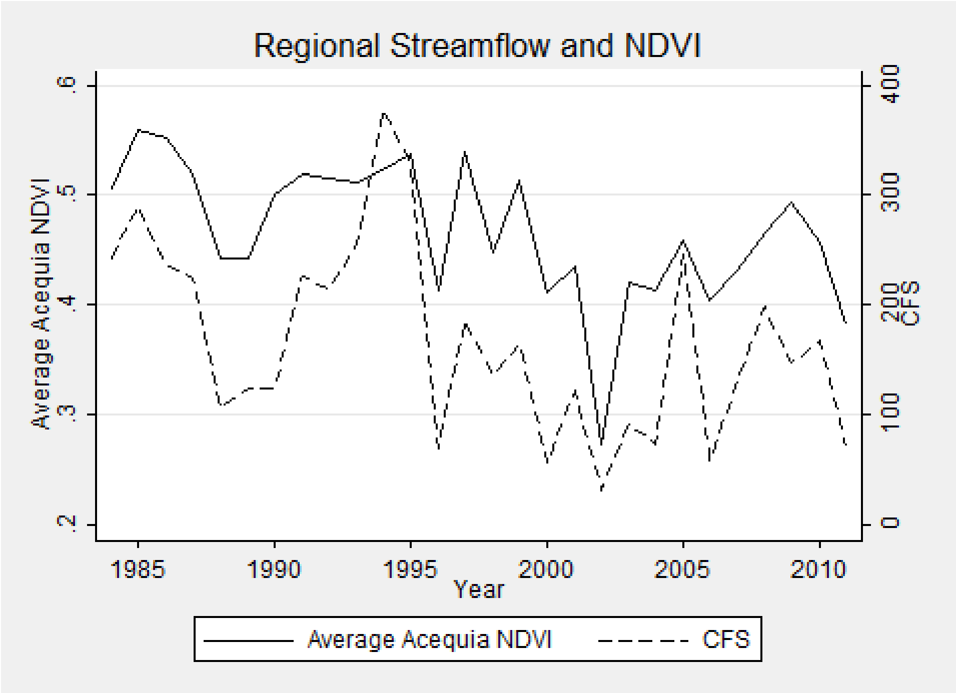


Table 5.1: NDVI and Stream Flow

VARIABLES	(1) NDVI	(2) NDVI
Annual Average CFS	0.0576***	0.296***
	(0.0117)	(0.0842)
Annual Average CFS (lag)	0.00190	-0.0614
	(0.00712)	(0.0413)
Constant	36.77***	41.71***
	(2.271)	(2.295)
Stream Flow	Total	Four Streams
Observations	1,350	1,066
R-squared	0.225	0.132

Robust standard errors in parentheses clustered by year and acequia
*** p<0.01, ** p<0.05, * p<0.1

The first column uses the additive measure of annual flow for the entire region. The second column uses the stream specific measures, limiting the analysis to only *acequias* from the four streams. In either case, there is a strong positive relationship with water availability in the concurrent year, but no statistical relationship to the prior year's flow. Using the total regional average, another CFS of flow increases NDVI by 0.0576 while the specific stream measure yields a stronger relationship of 0.296. The results serve to demonstrate the need for water to produce healthy vegetation in the region and to validate the discount of temporal conservation concerns.

5.4.3 Water right transfers

In addition to the NDVI, data are needed on ownership of parcels with water rights linked to the *acequias*. This collection is possible due to the *de jure* private, individual, water rights created in New Mexico. In order to put into action the prior appropriation doctrine enacted in the 1905 Water Code, the state of New Mexico created a series of comprehensive hydrological surveys of the irrigated lands to privatize and record water rights. The Taos Valley surveys, completed in 1968 and 1969, identify the irrigated parcels by which *acequia* they belong to, the name of the owner, as well as the acreage and which crop was planted at the time (OSE 2009).

In order to create a panel, I combine these records with water right transfers that are filed at the New Mexico Office of the State Engineer (OSE). The OSE records: 1) which irrigated parcel was transferred; 2) the acreage; 3) when it was transferred; and 4) the grantees and the grantors, as well as the amount of water rights which accompanies the land—a constant, technically determined 2.5 Acre-Feet/Acre in the Taos region. These records are not digitized in any form, requiring manual input from the physical copies maintained at the OSE in Santa Fe, NM. A total of 3638 transfers were recorded over the course of two weeks. These data, when combined, allow me to construct the user group in each year for each *acequia*. One should note that the documentation of the transfer is not legally necessary and the forms are filled out by the users themselves resulting in some measurement error.[44] The process and assumptions made to construct the user group are described in full in Appendix 1 while the extent of missing transfers is treated below.

In addition to capturing when a new user is present, the data represents the number of users and distribution of land amongst the users. The data has been collected for all Taos Valley *acequias*, dating back to 1969. I utilize a report based on the 1990 U.S. Census to establish which surnames most likely represent a Hispanic individual to calculate the cultural mix of the user groups as another control (Word and Perkins 1996). The panel data on the users is collapsed to the *acequia* level, maintaining the number of users, the distribution of land holdings, the Hispanic proportion, as well as variables measuring the extent of new users in each year. The *acequia* level analysis is an artifact of technical limitations in calculating NDVI at the plot level with both insufficient resolution for smaller plots and insufficient data on which portion of parcels are sold when broken up into smaller plots.

Other time-invariant controls are utilized in some specifications, many coming from Cox and Ross (2011), including social measures—water agreements, land fragmentation, and urban presence—and some biophysical measures—hydric soil and irrigation corridor. A statistical summary of the relevant variables are reported in Table 5.2.

[44] While legally required to fill out a transfer, the default is for the water rights remain attached to the land. Thus, a clean title of the land is sufficient to claim legal ownership of the water rights assuming the water has not been severed from the land—an act that does require paperwork.

Table 5.2: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Within St. Dev.	Min	Max
NDVI (Spatial Average)	1400	46.75	10.62	7.00	15.24	71.29
NDVI (Spatial Standard Deviation)	1400	11.63	2.69	1.92	2.40	19.25
No. Users	1400	64.00	81.91	6.93	4.00	398.00
Total Acres	50	260.72	305.97	N/A	7.70	1415.40
Cultural Homogeneity	1400	14.19	10.88	0.04	0.00	50.00
% Hispanic	1400	54.34	17.35	0.05	9.09	100.00
Average Acres	1400	4.79	4.00	0.50	0.59	25.12
Median Acres	1400	2.61	2.39	0.37	0.33	13.70
Land Gini Coefficient(x100)	1400	56.57	11.15	1.92	26.30	78.98
New Users	1400	1.39	2.66	3.26	0.00	39.00
New Acres	1400	5.06	14.16	0.40	0.00	181.98
% New User (per year)	1400	2.23	3.77	3.26	0.00	37.50
% New Acres (per year)	1400	2.19	6.01	4.38	0.00	57.28
% New Users 1969-2011	50	43.90	13.76	N/A	13.79	71.43
% New Acres 1969-2011	50	39.96	18.98	N/A	6.71	86.73
Average Annual Flow (CFS)	1107	24.57	13.31	11.68	2.92	63.50
Total Average Annual Flow (CFS)	28	167.86	86.38	N/A	31.11	377.40
Municipal Water Transfer	50	0.46	0.50	N/A	0.00	1.00
% Taos	50	16.01	32.31	N/A	0.00	100.00
Fragmentation	50	1.16	0.88	N/A	0.12	5.38
Sharing Agreement	50	0.48	0.50	N/A	0.00	1.00
Hydric Soil	50	40.19	25.58	N/A	0.00	91.86
Irrigation Corridor	50	48.31	41.13	N/A	0.00	100.00
Priority Date	32	1816.50	51.33	N/A	1675	1880

The *acequias* vary greatly in size spanning 4 to nearly 400 users and covering anywhere from 7.7 to 1415.4 acres. Greater detail is provided for number of users in Figures 5.6 and 5.7. Concern of the larger, more urban, *acequias* driving the results is addressed by excluding the outliers of 100 or more users seen in Figure 5.6. The correlation matrix of the main variables is reported in Table 5.3. Of note is the first column, particularly the number of users having a significant negative correlation with NDVI. Percent of users that are new also has a negative correlation with NDVI though much smaller.

Figure 5.6: Number of Users in 1984

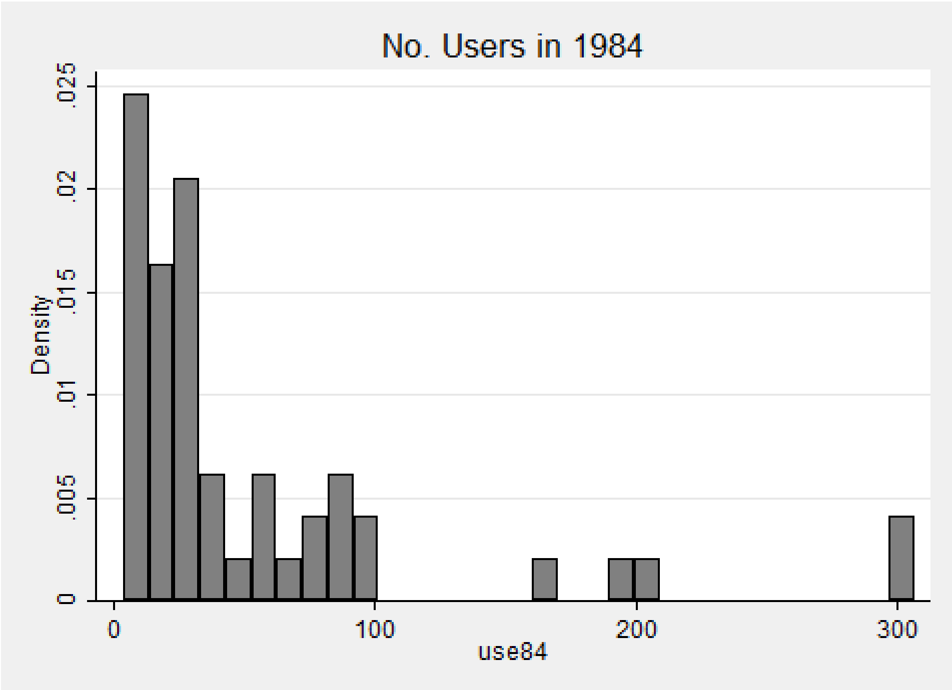


Figure 5.7: Change in the Number of Users

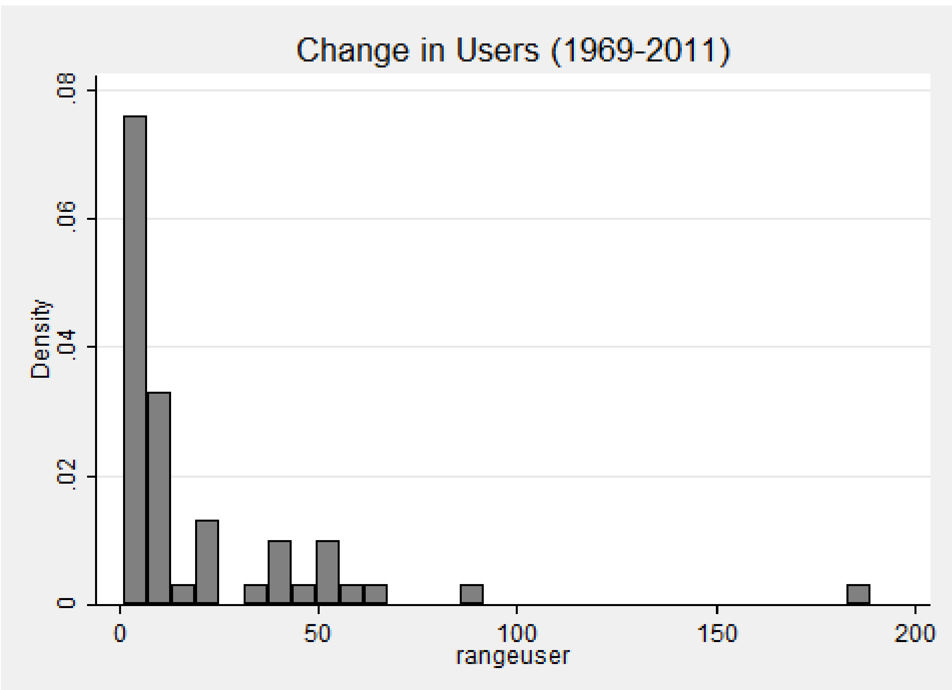


Table 5.3--Correlation Matrix

	NDVI	NDVI STD	No. Users	% New User	% Hispanic	Land Gini (x100)	Average Acres
NDVI	1						
NDVI STD	-0.01	1					
No. Users	-0.3622*	0.2753*	1				
% New User (per year)	-0.0286	-0.0153	-0.0124	1			
% Hispanic	0.2911*	0.0131	-0.0706*	-0.1664*	1		
Land Gini (x100)	-0.3635*	0.2930*	0.4961*	0.0019	-0.2159*	1	
Average Acres	0.1499*	0.0521	-0.1399*	0.0742*	-0.2216*	0.0626*	1
Year	-0.3226*	-0.0394	0.0802*	0.0564*	-0.2579*	-0.0234	-0.1095*

Finally, I conducted hour-long surveys with commissioners from seventeen *acequias* in Taos in September 2013. The sample was selected in order to ensure geographical representation, including ditches from the various streams but was ultimately determined by the needs of a larger project.[45] Looking at observables available for all *acequias*, the survey sample is representative, though slightly further upstream and incurring more turnover. Here, the survey data serve a supportive role providing qualitative data. However, it can also be used to measure the prevalence of missing transactions and the soundness of assumptions made in determining the user group. In order to assess the extent of the issue, 2011 user counts based on my algorithm are compared to commissioner reported values in 2013 for sixteen *acequias*. One *acequia* is removed from the analysis because the commissioner simply reported the number of users the original 1969 survey.[46] Reported in Table 5.4, the correlation between my count and the commissioner count is 0.97 while the OLS regression coefficient suggests that for every additional user I record there are 1.18 in actuality. The results confirm that my algorithm performs well despite the presence of some measurement error, some of which due to growth occurring after 2011.

I conjecture that the unreported transfers are most likely family inheritance that are treated with less rigor than outside transactions, though this cannot be confirmed. A statistical bias will emerge if these types of transfers are systematically more prevalent in certain types of *acequias.* If not, the simple measurement error will add noise to the estimation, attenuating the results. Concerning new users, bequeaths to children likely do little to interrupt the trust and

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[45] The NSF funded project compares snowmelt dependent systems in Taos, San Luis Valley in Colorado and two sites in Kenya.

[46] The survey corresponds to the outlier in Figure 5.7, gaining nearly 200 members.

norms developed due to their upbringing within the system. Therefore the missing transfers likely have little effect on the estimates.[47]

Table 5.4: Number of Users

VARIABLES	(1) Self-Reported (2013)	(2) Self-Reported (2013)
No. Users (2011)	0.975	1.181***
		(0.0844)
Constant		-5.873
		(5.687)
Statistic:	Correlation	Regression
Observations	16	16
R-squared	N/A	0.950

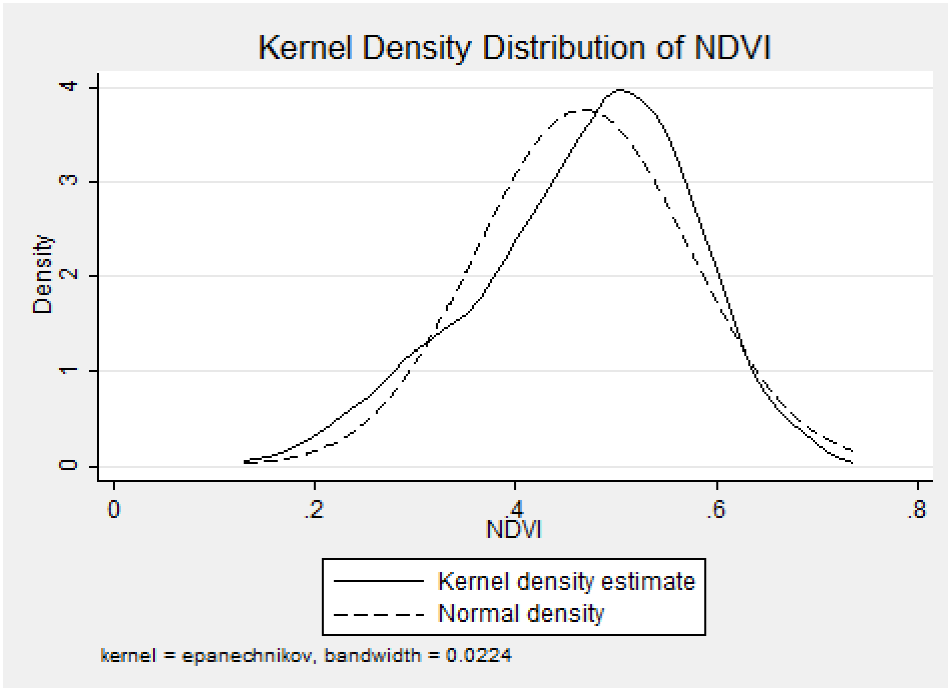
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.4.4 Methodology

Regressions are used not only to test the impact of changing user groups, but also as a diagnostic tool to assess the presence of OVB and ultimately correct for it. To do so, three main specifications are utilized—1) pooled OLS, 2) between-effects (BE), and 3) fixed-effects (FE). Ultimately the preferred the specification is the FE. The use of OLS estimation could be a concern with the dependent variable being a normalized, bounded measure. However, the NDVI values do not approach the bounds and the distribution appears normal. The kernel density estimation given in Figure 5.8, overlaid with a normal distribution.

[47] The exclusion of recorded familial transfers has no meaningful impact on the estimated impact of new users.

Figure 5.8: NDVI Empirical Distribution



Both pooled-OLS and the between-effects estimators are used to represent cross-sectional type analysis. For between effects, the specification is as follows:

$$\overline{NDVI}_i = \alpha_0 + \beta_1 * \overline{Users}_i + \beta_2 * \overline{New}_i + \beta_3 * \overline{Gini}_i + \beta_4 * \overline{Hisp}_i + \beta_5 * \overline{AveAcres}_i + \boldsymbol{X}_i + \epsilon_i \qquad (5.1)$$

The subscript i corresponds to the *acequia* and the bar refers to the average across time. $Users$ is the number of members; New is the percent of users that entered in a particular year; $Gini$ captures the Gini-coefficient based on distribution of acres owned by the users; $Hisp$ uses surnames to calculate the percent of the user group with Hispanic last names; and $AveAcres$ controls for economies of scale by dividing the total acres by the number of users. The BE specification calculates each *acequia's* temporal average over 28 years for each variable, regressing the means in a cross-sectional manner. $\boldsymbol{X}$ contains a variety of time-invariant measurements. In addition to those explored in Cox and Ross (2011), I include dummies for the three different regions and latitude and longitude coordinates. If performance of the *acequia* makes the system more or less attractive to new entrants, the error term will be correlated and fail to meet the independent mean zero assumption, resulting in biased estimates.

The pooled-OLS specification takes the following form:

$$NDVI_{it} = \alpha_0 + \beta_1 * Users_{it-1} + \beta_2 * New_{it-1} + \beta_3 * Gini_{it-1} + \beta_4 * Hisp_{it-1} + \beta_5 * AveAcres_{it-1} + \boldsymbol{X}_i + Y_t + \epsilon_{it} \quad (5.2)$$

This specification differs from the BE model in two distinct ways due owing to the addition of time with the subscript t referring to the year. First, this allows the introduction of Y_t, a series of dummy variables for each year, 1984-2011. Year fixed effects (Y_t) capture any general effect of the observation coming from a particular year. Most directly this addresses the timing of the satellite imagery timing. The year fixed effects capture more general elements impacting the entire region as well, namely snowpack and climactic conditions, but also economic and social conditions. Inclusion of the effects results in estimates relative to overall conditions at the regional level with fewer assumptions than imposing a time trend. Second, the time dimension allows me to lag the user group variables one year. This is done largely to ensure the transfers have occurred prior to annual meetings and the growing season being measured. In other words, the lagged variables preclude transfers that occur after the decisions influencing NDVI in a year are made. Leveraging time also aids in addressing the endogeneity issue; it is more difficult to conceptualize a situation in which next year's productivity influences this year's turnover. However, this does not alleviate all endogeneity stories, as there may remain an uncontrolled time-invariant variable that drives both today's user group alterations and productivity across all periods. In short, it continues to ignore the panel structure of the data with each observation treated as independent.

Finally, the preferred fixed-effect specification estimates the following:

$$NDVI_{it} = \alpha_0 + \beta_1 * Users_{it-1} + \beta_2 * New_{it-1} + \beta_3 * Gini_{it-1} + \beta_4 * Hisp_{it-1} + \beta_5 * AveAcres_{it-1} + A_i + Y_t + \epsilon_{it} \quad (5.3)$$

The FE specification leverages the panel data by utilizing *acequia* fixed effects. Also known as the within-estimator, the model is akin to estimating coefficients based on deviations from the group-means. Of note is that the time-invariant controls ($\boldsymbol{X}_i$) are no longer explicitly controlled for. Because they do not vary overtime, they are soaked up by the fixed effect term, A_i. The advantage is this term also controls for any other time-invariant attribute, even those for which I have no observable measure for. For example, due to the geographic position, hydrological features, soil quality, strong bylaws of an *acequia* it may be more or less productive on average. If any of these factors also influence the user group and are unobserved, estimates will exhibit OVB. Given the purpose of identifying the impacts of the user group shocks, the gain of controlling for more variables outweighs the loss of identifying the impact of time-invariant variables.

Utilizing within-estimators addresses endogeneity concerns of what *acequia* land is more likely to be sold and purchased. *A priori* it is unclear which way the bias will run due to the market nature of the transaction. Indeed, one can plausibly argue that poorly performing *acequias* have more transfers and fragmentation because users will be more likely to want to exit. However, it is equally plausible that the new entrants are attracted to the better performing areas, and given the higher value of this land, the previous owners more willing to sell at the higher prices. As a user group, they have no power of exclusion. It may also be that new users are attracted to an area for reasons besides production directly but is correlated with production nonetheless. So long as this unknown element is constant, perhaps the slope of the land, the fixed effect will capture it. While estimation of the fixed effects is not consistent, the remaining coefficients are consistently estimated.

4.4.5 Predictions

Prior empirical work and theory predict that as the number of users increases, cooperation becomes more difficult due to transaction costs and increased incentive to free ride. Though some literature suggests medium sized groups gain economies in scale of monitoring and provision of other public goods (Agrawal and Goyal 2001). On net, I expect a negative impact due to more users. Game theory fails to yield a clear prediction of the impact of new, different users. However, behavioral models lean towards a negative impact through declines in trust and reciprocity; these models, though, do not account for institutional design by which the systems may make themselves robust to such disturbances, nor do they consider the possibility of selection.

Given that the systems pre-date the analysis by a number of years, the advantages of economic heterogeneity on initial provision is assumed to be largely inapplicable and I expect the negative impacts on continued cooperation to be present. Cultural heterogeneity I expect to have a negative impact. Specifically, because *acequias* are central to the Hispanic culture in the region (Rivera 1998; Rodríguez 2006) and social norms often persist, I expect higher fractions of Hispanic users to yield greater levels of cooperation and production.

The scale of operation is important to agricultural production but difficult to predict the optimal size. There is some threshold of farm size that below, increases in size are helpful, but above, increases are harmful. Given the small size of parcels in Taos Valley (4.79 acres on average) a positive impact of growth could reasonably be expected.

5.5 Results

5.5.1 Primary Results

I present the main results in Table 5.5. The first four columns ignore the panel structure of the data, reporting the BE (equation 5.1) and the pooled-OLS regression results (equation 5.2). Even without fixed effects or time-invariant variables, the user group characteristics explain a large portion of the variation in greenness evident by large R-squared values. Without the use of other controls, an additional user reduces NDVI by 0.024. With the controls, the impact is negligible both statistically and economically. The standard deviation of mean NDVI is 10.62, meaning an increase in one standard deviation of the number of users (81.91) explains 10 percent of the variation in production. Because NDVI measures lack a firm economical interpretation, it is useful to keep in mind that an additional CFS increases NDVI by 0.0576. Each additional user is akin to reducing 0.5 CFS of annual stream flow.[48]

Somewhat surprisingly, *acequias* with new users perform better. When 2.23 percent of the users are new, the average disturbance, NDVI increases by 0.0015-0.065 depending on the model (1.5-60 percent of the NDVI variation). Production is negatively related to economic heterogeneity, reducing by around 0.20 for every 1/100 increase of inequality on the Gini scale. Meanwhile, the more Hispanic groups perform better, increasing NDVI by 0.10 with each additional percent. The results also confirm that small plots are inefficient; *acequias* with larger average plots perform better. Notably, while utilized as an example of potential OVB, the position of the *acequia* is observable, controlled for, and influential with average production

[48] An additional average CFS over the course of year results in 724.4 acre-feet of water. This is equivalent to 236,046,773.7 gallons of water.

Table 5.5: NDVI and User Group Characteristics Regressions

VARIABLES	(1) BE	(2) BE	(3) Pooled	(4) Pooled	(5) FE
Users	-0.0240*	-0.00444	-0.0243*	-0.00472	-0.0531***
	(0.0134)	(0.0145)	(0.0136)	(0.0141)	(0.0165)
Percent Users New	2.902**	0.939	0.131**	0.0678	0.0343
	(1.421)	(1.204)	(0.0572)	(0.0423)	(0.0282)
Percent Hispanic	0.219***	0.0415	0.123*	0.00577	-0.0695*
	(0.0741)	(0.0790)	(0.0617)	(0.0498)	(0.0363)
Land Gini	-0.210**	-0.113	-0.231**	-0.115	-0.110*
	(0.102)	(0.0927)	(0.0991)	(0.100)	(0.0547)
Average Acres	0.254	0.476**	0.401*	0.520***	0.259
	(0.255)	(0.216)	(0.218)	(0.100)	(0.426)
Percent Taos		-0.0644**		-0.0695***	
		(0.0303)		(0.0221)	
Fragmentation		-2.378**		-2.366***	
		(1.039)		(0.674)	
Water Agreement		-0.0281		-0.00958	
		(2.367)		(1.606)	
Hydric Soil		0.184***		0.193***	
		(0.0523)		(0.0361)	
Irrigation Corridor		0.0238		0.0240	
		(0.0279)		(0.0206)	
Taos		-4.265		-4.557	
		(3.776)		(2.888)	
Hondo		0.428		0.590	
		(6.295)		(6.709)	
Latitude		5.692		6.007	
		(30.56)		(33.40)	
Longitude		107.7***		115.5***	
		(37.87)		(30.42)	
Constant	40.33***	11,206**	45.32***	12,021***	50.61***
	(9.235)	(4,196)	(6.233)	(3,289)	(4.685)
Year Fixed Effect	N	N	Y	Y	Y
Acequia Fixed Effects	N	N	N	N	Y
Observations	1,350	1,350	1,350	1,350	1,350
R-squared	0.431	0.724	0.559	0.751	0.796
Number of id	50	50			50

Standard errors in parentheses clustered by *acequia* except for the BE specifications where it is not possible.
*** p<0.01, ** p<0.05, * p<0.1

higher for *acequias* further east, meaning further upstream.[49] In unreported regressions, user groups were also more likely to expand east, however the inclusion or exclusion of the coordinates has no discernible impact on the main results of the user group.

Column (5) reports estimates of the fixed effect regression (equation 5.3), leveraging the panel structure of the data. In this specification, the impact of additional users is statistically significant; within an *acequia*, adding members influences the outcome negatively with the point estimate 3-10 larger in magnitude than in the non-FE specifications. Furthermore, the percent new user coefficient is no longer significant and closer to zero. Both results are consistent with a positive OVB in the other specifications; underestimating the negative impact of additional users while overestimating a positive impact of new users.

Land inequality remains a significant predictor of production in the within *acequia* specification, with growing inequality reducing production on average while the percent Hispanic remains significant but switches signs, indicating a decrease in Hispanic farmers actually increases productivity within the *acequia.* This result is plausibly explained by self-selection in exit and discussed in greater detail below.

Since NDVI is not a common measure, nor does it have a clear, direct, consistent physical interpretation, it is helpful to put the impacts found into perspective in order to assess the economic significance. Drawing on the main FE specification results, Table 5.6 provides alternative methods of scaling the estimates. For illustration, the estimated impact of one additional user is -0.0531. Overtime, the average standard deviation of the number of users within *acequias* is 6.93; adding this one standard deviation of users reduces NDVI by 0.37. Column (5) scales this to a percentage of the mean within *acequia* temporal standard deviation of

[49] This measure captures only a portion of the physical location. Additional factors driven by proximity to unobserved elements may influence production and new entrance beyond position on the stream.

Table 5.6: Regression Coefficient Interpretations

	(1)	(2)	(3)	(4)	(5)	(6)
	Coefficient	With-in Standard Deviation	Impact of one S.D.	Percent of NDVI S.D.	Percent of NDVI S.D.(detrended)	CFS equivalence of a one unit
NDVI	N/A	7.00	N/A	N/A	N/A	N/A
No. of Users	-0.0531***	6.93	-0.3678	-5.25	-11.46	-0.92
Gini Coefficient	-0.11*	1.92	-0.2115	-3.02	-6.59	-1.91
Percent Hispanic	-0.0695*	5.22	-0.3626	-5.18	-11.30	-1.21
% Users New	0.0343	3.26	0.1119	1.60	3.49	0.60
Average Acres	0.259	0.50	0.1289	1.84	4.02	4.50
Acequia fixed effects	Yes					
Year fixed effects	Yes					
Observations	1,350					
Number of id	50					

Column (1) comes from the main fixed effect regression reported in Table 5; Column (2) is the with-in *acequia* standard deviation. Column (3) is calculated by multiplying Column (1) and Column (2); Column (4) scales Column (3) by the with-in standard deviation of NDVI, 0.07. Column (5) repeats this, but removes variation due to year from NDVI first. Column (6) is derived by dividing Column (1) by the estimated coefficient of CFS reported in Table (5.1), Column (1).

average production—5.25 percent in the case of the number of users. Column (6) recognizes that year-to-year variation is the largest source of variation due to stream flow variation. Adjusting for the year fixed-effects, the standard deviation of users explains 11.46 percent of the remaining NDVI temporal variation. Finally, in Column (7) I offer an alternative interpretation scaling the impact of a one unit increase to an equivalent increase of stream flow based on the regression result in Table 5.1. Adding one additional user has the same impact of reducing the annual average stream flow by 0.92 CFS. Extrapolating over the year, this is a reduction of around 700 acre-feet of water. This should be considered a back-of-envelope calculation but serves to indicate the effect of another user is not negligible. The impacts of the other user group variables are also included in in Table 5.6.

Because a variety of spatial distributions could yield similar means, Table 5.7 considers similar specifications (with the additional controls) but using the spatial standard deviation of NDVI within the *acequia* as the dependent variable.[50] On the whole, there are few significant predictors of the spatial standard deviation. Looking at the FE regression results, the coefficient on the number of users compresses the NDVI distribution while more Hispanics does the same. Notably, the point estimate for the percent of users new is positive. The decrease in variation due to additional users suggests the entire system becomes more difficult to operate while the positive point estimate on the new users could indicate some winners and losers within the system.

In order to untangle the variation a bit more, Table 5.8 reports the FE specification looking only at land that has not been sold, remaining whole and under the control of one owner for the entire period. In short, the NDVI mean is calculated based only on the unsold land by reducing the *acequia's* footprint to only that land, then calculating the average NDVI based only on the pixels within the unsold land. This exercise serves two purposes: 1) help to identify the winners and losers when a new entrant arrives; and 2) free the analysis from unobservable farming ability or effort of the new users by considering only the land for which farmers remain

[50] Similar regressions are ran including mean NDVI as an additional control. A lower mean is expected to compress the variation. While this is confirmed, the remaining estimates remain stable in size and direction. However, the specification without NDVI is preferred as the mean itself is being driven by the user group, thus the full impact is better identified without the mean.

Table 5.7: Standard Deviation and User Group Characteristics Regressions

VARIABLES	(1) BE	(2) Pooled	(3) FE
Users	0.00696	0.00593	-0.0238**
	(0.00461)	(0.00403)	(0.00969)
Percent Users New	-0.0704	0.0236	0.0224
	(0.384)	(0.0187)	(0.0142)
Percent Hispanic	0.0297	0.0239	-0.0550**
	(0.0252)	(0.0155)	(0.0212)
Land Gini	0.0356	0.0329	-0.00394
	(0.0296)	(0.0225)	(0.0266)
Average Acres	0.0472	0.0414	0.0578
	(0.0689)	(0.0323)	(0.247)
Percent Taos	0.00852	0.0102	
	(0.00967)	(0.0101)	
Fragmentation	0.0935	0.111	
	(0.332)	(0.248)	
Water Agreement	-0.589	-0.384	
	(0.756)	(0.545)	
Hydric Soil	-0.0174	-0.0177	
	(0.0167)	(0.0140)	
Irrigation Corridor	-0.00787	-0.00697	
	(0.00890)	(0.00624)	
Taos	0.791	0.521	
	(1.206)	(0.925)	
Hondo	1.387	1.039	
	(2.010)	(1.598)	
Latitude	-6.711	-5.670	
	(9.757)	(7.414)	
Longitude	-18.89	-19.03	
	(12.09)	(12.68)	
Constant	-1,743	-1,796	15.12***
	(1,340)	(1,373)	(2.174)
Year Fixed Effect	N	Y	Y
Acequia Fixed Effects	N	N	Y
Observations	1,350	1,350	1,350
R-squared	0.430	0.381	0.387
Number of id	50		50

Standard errors in parentheses clustered by *acequia* except for the BE specification
*** p<0.01, ** p<0.05, * p<0.1

Table 5.8: Unsold Land NDVI and User Group Characteristics Regressions

VARIABLES	(1) Unsold Land NDVI	(2) Unsold Land NDVI
Users	-0.0499***	-0.0464***
	(0.0174)	(0.0155)
Percent Users New (Forward 1)		0.0115
		(0.0222)
Percent Users New (no Lag)		0.000442
		(0.0301)
Percent Users New (1 Lag)	0.0771***	0.0613**
	(0.0253)	(0.0257)
Percent Users New (2 Lag)		-2.50e-05
		(0.0231)
Percent Hispanic	-0.0508	-0.0274
	(0.0406)	(0.0422)
Land Gini	-0.134**	-0.138**
	(0.0590)	(0.0636)
Average Acres	0.295	-0.122
	(0.395)	(0.404)
Constant	50.78***	68.21***
	(4.541)	(5.475)
Year Fixed Effect	Y	Y
Acequia Fixed Effects	Y	Y
Observations	1,350	1,350
R-squared	0.747	0.748
Number of id	50	50

Standard errors in parentheses clustered by acequia
*** p<0.01, ** p<0.05, * p<0.1

the same. The overall analysis (Table 5.5) may be driven by the fragmentation of land and the new entrants ability/effort of farming, reducing the production on their particularly parcels only while I attribute their impact to the entire system due to their impact on the average. The other advantage of considering only the unsold land is that there is no fragmentation, meaning any change in production is not systematically related to scales of production.

In comparison to the NDVI of the entire *acequia*, new users have a statistically significant positive impact while the remaining estimates are qualitatively similar. The positive impact of new users is ambiguous to the cooperation story as it is unclear whether the gain is at the expense of the new users or rather the new user are not engaged in farming, resulting in additional water for old users absent any breakdown in cooperation. If gains are made from new owners permanently retiring irrigated land the effect should persist into the future. However another regression, reported in Column (2), includes additional lags of percent users new that turn out to be insignificant and smaller in magnitude. The finding is inconsistent with the story that the new entrants are not farming. Inclusion of the future period turnover serves as a more general falsification test, as one would be concerned if future turnover predicted past production (this falsification, unreported, holds true for the original NDVI measure). The remaining estimates are consistent with the main analysis. Importantly, the impact of additional users remains negative and significant—indicating the overall results are not driven by the individual performance of the entrants nor based solely on the impact of dividing land into smaller parcels.

Given the negative relationship NDVI has with the number of users, I explore the possibilities of non-linear relationships in Table 5.9. Column (1) includes the number of users squared to allow for a slightly more flexible polynomial. While the squared term is not significant at typical levels ($p < 0.203$), the coefficient is positive, suggesting there are diminishing damages to additional users. Columns (3)-(4) perform the main FE specification, dividing the sample into terciles based on the number of users present in 1984. The estimates indicate the bulk of the decline is coming from medium sized groups, being considerably larger in magnitude and significance from the smaller and larger *acequias*. Returning to the equivalent water estimation, an additional user in the medium sized, those with 18 to 51 users in 1984, is akin to removing 136.4 acre-feet from the system over the year.

Table 5.9: NDVI and User Non-Linearity Regressions

VARIABLES	(1) NDVI	(2) NDVI	(3) NDVI	(4) NDVI
Users	-0.112*	-0.0509	-0.542***	-0.0254**
	(0.0568)	(0.186)	(0.181)	(0.0101)
Users Squared	0.000102			
	(7.93e-05)			
Percent Users New	0.0325	0.0287	0.115	0.0244
	(0.0283)	(0.0292)	(0.0763)	(0.0674)
Percent Hispanic	-0.0731*	-0.0550	-0.114	-0.0914
	(0.0370)	(0.0434)	(0.0933)	(0.0745)
Land Gini	-0.117**	-0.121*	-0.242	-0.127
	(0.0534)	(0.0650)	(0.163)	(0.107)
Average Acres	0.0199	0.969	-1.806**	0.123
	(0.577)	(0.570)	(0.685)	(0.268)
Constant	72.17***	60.88***	102.0***	71.16***
	(7.318)	(6.463)	(15.46)	(7.138)
Users in 1984	All	4 to 17	18 to 51	55 to 307
Year Fixed Effect	Y	Y	Y	Y
Acequia Fixed Effects	Y	Y	Y	Y
Observations	1,350	459	459	432
R-squared	0.797	0.767	0.786	0.887
Number of id	50	17	17	16

Standard errors in parentheses clustered by acequia.
*** p<0.01, ** p<0.05, * p<0.1

5.5.1 Robustness

Motivated by the findings above, I provide robustness checks concerning specification, sample, and variable selection. First, Table 5.10 reports two alternative panel data treatments of the data. Column (1) provides the first difference specification. The magnitudes are similar to the FE specification however the new user impact is statistically significant whereas the number of users is not. The model is less efficient than the deviation from mean FE model and implicitly assumes the impact of the additional user is felt only the year following entrance, which is unlikely. In Column (2) and (3) results from random-effects models are reported. An alternative to using fixed effects, the specification assumes that the individual *acequia* effects are random variables independent of the other regressors. This assumption is tenuous and a Hausman test rejects the consistency of the estimator (Chi2 [5] = 12.84, Prob=0.0249). The results are reported in Column (2) and (3) nonetheless for comparison and largely mimic the FE results while allowing the identification of time-invariant variables coefficients.

For Table 5.11 I increase the sample, including another *acequia* isolated in the southern end of the valley. Its previous exclusion is based on it being wholly reliant on a steady spring rather than snowmelt as well as being the only *acequia* developed originally by Anglos. Physically and statistically an outlier, the inclusion of the 7 member ditch yields similar results, but the impact of new users is never significant while the point estimate in the FE model is negative. Discussion with members of this *acequia* confirmed a large new landholder did not irrigate and others experimented with many others crops, both influencing the estimated impact on NDVI.

Table 5.12 and 5.13 report the main analysis but alter two of the variables. In Table 5.12 percentage of acres transferred serves as the measure new users. Preference is given to the measure based on users to focus on the social interaction and minimize any mechanical declines in NDVI related to idiosyncratic land use by new large landholders. The results are incredibly stable with regard to the other variables and the magnitude of percent new remains similar, though lacks the statistical significance. In Table 5.13 I use a cultural homogeneity measure rather than percent Hispanic. The alternative measure yields the same value for a group that is 80 percent Hispanic as it does for a group of only 20 percent Hispanic. Implicitly, this assumes only two cultural groups exist with non-Hispanic last names sharing cultural ties. The estimated coefficient is positive, as one would expect, but not statistically distinguishable from zero. As in prior robustness checks, the estimates of the other coefficients remain stable.

Table 5.10: NDVI and User Group Characteristics--
Alternative Panel Treatments

VARIABLES	(1) First Difference	(2) RE	(3) RE
Users	-0.0749	-0.0445***	-0.0360***
	(0.0741)	(0.0112)	(0.00879)
Percent Users New	3.673	0.0358	0.0389
	(2.586)	(0.0284)	(0.0287)
Percent Hispanic	-6.250	-0.0328	-0.0574*
	(7.875)	(0.0323)	(0.0309)
Land Gini	-16.36	-0.134***	-0.0958*
	(11.24)	(0.0453)	(0.0506)
Average Acres	-0.141	0.232	0.426*
	(0.550)	(0.269)	(0.228)
Percent Taos			-0.0582**
			(0.0234)
Fragmentation			-2.145**
			(0.945)
Water Agreement			3.323**
			(1.668)
Hydric Soil			0.162***
			(0.0369)
Irrigation Corridor			0.0349
			(0.0228)
Taos			-6.752**
			(2.760)
Hondo			-5.417
			(7.131)
Latitude			24.71
			(38.49)
Longitude			116.7***
			(33.21)
Constant	-7.726***	49.71***	11,471***
	(0.644)	(2.952)	(3,690)
Year Fixed Effects	Y	Y	Y
Observations	1,300	1,350	1,350
R-squared	0.740	0.483	0.726
Number of id		50	50

Standard errors in parentheses clustered by *acequia*
*** p<0.01, ** p<0.05, * p<0.1

Table 5.11: NDVI and User Group Characteristics--With Outlier

VARIABLES	(1) BE	(2) Pooled	(3) FE
Users	-0.00469	-0.00838	-0.0681***
	(0.0155)	(0.0134)	(0.0205)
Percent Users New	-0.478	-0.0227	-0.0199
	(1.140)	(0.0700)	(0.0499)
Percent Hispanic	0.0772	0.0821	-0.0848**
	(0.0833)	(0.0545)	(0.0364)
Land Gini	-0.114	-0.0935	-0.0318
	(0.0993)	(0.110)	(0.0871)
Average Acres	0.623***	0.572***	-0.264
	(0.223)	(0.105)	(0.477)
Percent Taos	-0.0700**	-0.0654***	
	(0.0324)	(0.0243)	
Fragmentation	-2.992***	-2.973***	
	(1.083)	(0.818)	
Water Agreement	-0.269	0.189	
	(2.535)	(1.570)	
Hydric Soil	0.145**	0.136***	
	(0.0535)	(0.0417)	
Irrigation Corridor	0.0305	0.0364	
	(0.0297)	(0.0223)	
Taos	-1.028	-1.345	
	(3.806)	(3.546)	
Hondo	0.258	-0.873	
	(6.746)	(6.665)	
Latitude	13.16	17.22	
	(32.60)	(33.55)	
Longitude	106.9**	104.3***	
	(40.58)	(32.30)	
Constant	10,855**	10,421***	50.06***
	(4,495)	(3,494)	(4.978)
Observations	1,377	1,377	1,377
R-squared	0.693	0.721	0.780
Number of id	51		51

Standard errors in parentheses clustered by *acequia*

*** p<0.01, ** p<0.05, * p<0.1

Table 5.12: NDVI and User Group Characteristics-New Acres

VARIABLES	(1) BE	(2) Pooled	(3) FE
Users	-0.00240	-0.00462	-0.0542***
	(0.0143)	(0.0142)	(0.0164)
Percent New Acres	0.594	0.0147	-0.00464
	(0.722)	(0.0253)	(0.0154)
Percent Hispanic	0.0490	0.00433	-0.0708*
	(0.0827)	(0.0496)	(0.0360)
Land Gini	-0.135	-0.116	-0.113**
	(0.0942)	(0.100)	(0.0555)
Average Acres	0.495**	0.522***	0.225
	(0.209)	(0.100)	(0.422)
Percent Taos	-0.0677**	-0.0699***	
	(0.0294)	(0.0221)	
Fragmentation	-2.219**	-2.361***	
	(1.059)	(0.675)	
Water Agreement	0.195	-0.00967	
	(2.407)	(1.611)	
Hydric Soil	0.182***	0.194***	
	(0.0528)	(0.0362)	
Irrigation Corridor	0.0215	0.0239	
	(0.0278)	(0.0207)	
Taos	-4.442	-4.568	
	(3.778)	(2.892)	
Hondo	0.202	0.608	
	(6.322)	(6.724)	
Latitude	8.484	6.048	
	(30.85)	(33.51)	
Longitude	105.7***	115.8***	
	(38.37)	(30.37)	
Constant	10,895**	12,052***	51.16***
	(4,286)	(3,284)	(4.712)
Year Fixed Effect	N	Y	Y
Acequia Fixed Effects	N	N	Y
Observations	1,350	1,350	1,350
R-squared	0.724	0.751	0.796
Number of id	50		50

Standard errors in parentheses clustered by *acequia*
*** p<0.01, ** p<0.05, * p<0.1

Table 5.13: NDVI and User Group Characteristics--Cultural Homogeneity

VARIABLES	(1) BE	(2) Pooled	(3) FE
Users	-6.87e-05	-0.00182	-0.0506***
	(0.0150)	(0.0134)	(0.0175)
Percent Users New	0.622	0.0644	0.0365
	(1.037)	(0.0439)	(0.0282)
Cultural Homogeneity	0.0808	0.0632	0.0302
	(0.0866)	(0.0611)	(0.0295)
Land Gini	-0.135	-0.128	-0.125***
	(0.0940)	(0.0965)	(0.0421)
Average Acres	0.519**	0.551***	0.257
	(0.219)	(0.102)	(0.439)
Percent Taos	-0.0611*	-0.0663***	
	(0.0303)	(0.0212)	
Fragmentation	-2.402**	-2.435***	
	(1.025)	(0.732)	
Water Agreement	0.116	-0.0231	
	(2.298)	(1.605)	
Hydric Soil	0.206***	0.202***	
	(0.0481)	(0.0341)	
Irrigation Corridor	0.0202	0.0198	
	(0.0280)	(0.0218)	
Taos	-4.933	-4.493	
	(3.239)	(2.819)	
Hondo	0.461	0.688	
	(6.229)	(6.715)	
Latitude	7.333	6.708	
	(30.20)	(33.07)	
Longitude	115.0***	117.5***	
	(35.94)	(28.33)	
Constant	11,924***	12,207***	47.55***
	(4,023)	(3,061)	(3.537)
Year Fixed Effect	N	Y	Y
Acequia Fixed Effects	N	N	Y
Observations	1,350	1,350	1,350
R-squared	0.728	0.754	0.795
Number of id	50		50

Standard errors in parentheses clustered by *acequia*

*** p<0.01, ** p<0.05, * p<0.1

5.6 Discussion

5.6.1 Statistics

In sum, the results illustrate the presence of omitted variable bias in cross-sectional treatments of the data, even with the inclusion of observable non-user group controls. In particular, users are attracted to irrigation systems that perform better, whether directly or indirectly, creating a positive bias for both the number of users and the percent of which are new. When including *acequia* fixed effects, the negative magnitude of the impact of additional users increases 2-12 times in magnitude and becomes statistically distinguishable from zero. This suggests that while other work in CPRs typically finds a negative impact of additional users on cooperation, the magnitude is likely understated due to some unobserved factor that increases productivity/cooperation and attracts more users. Furthermore, the impact is felt somewhat uniformly across users: The additional user compresses the spatial distribution of production and drives down the production of unsold land. Having dismissed other possible explanations, the additional user causes success to break down due to increased transaction and coordination costs.

Furthermore, the additional users exhibit something akin to diminishing returns. Estimation indicates while an additional user decreases performance, each additional user does less damage. Specifically, the results appear to be driven by the medium sized groups, falling in the 18 to 59 user range. The strength, statistically and in magnitude, is much stronger than smaller or larger groups. For extremely small groups, an additional user does not lead to a large increase in transaction costs because the group remains small. On the other extreme, the extremely large groups may have already developed appropriate rules for many users or reached the point of diminishing damages where the marginal user has very little impact on the aggregate. The medium sized groups, in contrast, are small enough that the additional user impacts their costs, but large enough that it is difficult to adjust.

A priori the direction of the bias was unclear due to the market nature of land transactions, but this case is dominated by entrants, as they prefer to enter the better performing *acequias*. The positive bias is expected to be found in other situations, particularly those with unclear property rights and low ability to exclude new entrants.

The positive bias is echoed by the results concerning new users. The cross-sectional results estimate the impact to be statistically positive. Based on the reduction in inter-personal relationships, I expected this result to be negative. While the result is not entirely inconsistent with all theory, it appears the result is partially driven by omitted variable bias. The coefficient in the FE specification is smaller in magnitude than in the BE and pooled-OLS specification and is not statistically significant. On net, the positive bias is consistent with the new, additional users being attracted to more productive systems.

The positive point estimate of new users could be consistent with non-cooperative behavior in a non-zero sum game, but also with strong institutional rules and positive self-selection of entrants and negative self-selection of sellers. As mentioned earlier, the mean does not perfectly capture un-cooperative behavior. While also insignificant, the point estimate of new users effect on spatial variation in production is positive, indicating some winners and losers. Evidence from the unsold parcels indicates original users are gaining at the new users' expense—but it remains unclear if it comes from a lack of cooperation or new users not farming. Given that the positive gains for unsold land lasts only one period, it is highly unlikely the new users are not farming permanently. However, it is not possible to distinguish between the old users bending the rules at the new users' expense or the new users taking a year to get things up and running. In either case, the *acequias* are remarkably robust to new entrants beyond the first year.

Concerning the other user group variables, economic heterogeneity consistently reduces production, whether within or across *acequias.* The fraction of Hispanic users is positively correlated with greenness across *acequias* but negatively within *acequias.* Though the data at hand cannot conclusively confirm so, the result can be substantiated by self-selection of buyers and sellers, with those performing poorly more likely to sell.

As stated above, there does appear to be a slight positive bias due to the position of the *acequias* with those further east doing better and attracting more users. However, the exclusion of this variable only has a small influence on the point estimates in the main regression. There remain unobservable elements that contribute to the bias and the panel data allows for those that are time-invariant to be controlled.

5.6.2 Context and Institutions

What is particularly useful about this case is that new users do not represent increased resource scarcity. That is, unlike the Sri Lankan case in which new fishing nets meant longer waits for access to the fish or where additional household may require more fuel from a communal forest, here the demand on the resource system remain relatively stable. With capped amounts of irrigable land and a fixed ratio of water to land, the impact of the additional users is felt wholly through cooperation. Therefore, in other settings the impact of the additional user will likely be larger due to the breakdown in cooperation and additional strain on the resource.

Subsequent to the statistical analysis, surveys of 17 *acequias* were conducted. Overall, the discussions confirmed the statistical findings. Additional users made scheduling and rotations increasingly difficult. In times of shortage, large tract holders received a set amount of water than had the power to apply it as they saw fit across all the land. Once the land was split into smaller portions, the *mayordomo* is now obligated to deliver some portion of water to each of the smaller tracts. In addition, the administration of the ditch—maintaining records, assessing fees, and unifying *parcientes* in their efforts—becomes more difficult as additional users increase the transaction costs. Substantiating the statistical bias found, a number of commissioners lamented the division of land in the "greenbelt" of Taos, indicating that entrants are attracted to the greener regions.

Very few *acequia* officers indicated issues with new users. While some specific individuals created disruptions, enthusiastic cooperation appears to be the norm. Commissioners cite to bylaws as an aid to smooth transitions, underscoring rules substitutability for trust. In addition, they consistently pointed to the annual cleaning as a mechanism to initiate new users into the system prior to the growing season. The positive bias (and non-result of the new user) was also confirmed as many explained that new users purposely move in to participate in farming and want to succeed—often more enthusiastic, more likely to show up to meetings and the annual cleaning than prior users. This can explain why they choose better performing systems and ultimately why the impact may even be positive, as prior owners were often there due to family inheritance and not direct choice. This sentiment can also explain percent Hispanic having an overall positive effect but switching to negative in the FE specification: the Hispanics that are exiting are those less interested in farming. The panel data can only correct for unobservables of the *acequia* and cannot concretely weigh in on the selection of new users. In other words, while the evidence suggests new users are positively selected, the data provides no way to confirm this as farming effort and ability of individuals are not measured.

It is important to keep in mind the context in which the new users have no impact. As trust can be used as a substitute for monitoring enforcement, trust is not as essential in this setting where they utilize a clear rotation system. In addition, the state has recognized the legitimacy of the *acequia* organization, providing them with state sanctioned recourse to non-payment (free-riding), reducing further the avenues through which break downs may occur. This greatly reduces the reliance on inter-personal trust and cooperation, relying more on organizational structure, ultimately making the *acequias* robust to disturbances of new users.

5.7 Conclusion

My research makes two important contributions to the growing literature on common property resources. First, this is one of the first large panel data analyses of CPR institutions. It is important for empirical research to follow in this direction; when the heart of the question is concerning sustainability in the face of disturbances, longitudinal data is needed to consider the robustness of a Social-Ecological Systems in response to disturbances within the system. Looking across systems can only provide so much information on the dynamic ability for a given system to sustain itself and likely suffers from omitted variable bias. In this setting, analysis that ignores the panel structure of the data results in positively biased estimates for both new and additional users. In other words, *acequias* that cooperate and perform better due to some other unobserved variable also attract more new entrants. By gathering panel data, research can continue to look at disturbances overtime as well as correcting for a significant amount of omitted variable bias.

The second contribution is identifying the impact of disturbances in the user group after correcting for the omitted variable bias. Despite some inclination to believe that repeated interaction and trust built overtime aided in cooperation, introducing new users has very little impact in this setting, perhaps even positive. This has important policy implications regarding the continuing use of common property management of resources when the user group appears poised for heavy turnover; if the institutions are strong enough, new users can transition into the system. However, additional users have a negative impact. While this finding is not uncommon, I find previous estimates are likely understating the impact due to the endogeneity of the number users. User groups tend to grow more rapidly in the systems that perform better. The impact is directly attributable to increased transaction costs in cooperating to administer the system rather than further strain and demand on the resource. On net, the implication is that the power to exclude additional users is crucial to sustaining communal management of a resource while transfers of access rights may need less regulation so long as the group size is maintained and local institutions are strong.

The impact of user group disturbances needs to be studied in other contexts to assess whether the results are consistent in other settings, particularly different resources. In the instance of snowmelt irrigation, there is no temporal dynamic in terms of conservation issues. Additionally, because trust is a substitute for monitoring, it is less important here where monitoring is eased by the rotational sharing of the water and strong institutions. Irrigation elsewhere, or even harvest of communal forests where monitoring and enforcement is more difficult, likely relies more on trust than developed institutions. Exploring the role of user group stability in these settings is important to understand the importance of repeated interactions.

Chapter Six: Conclusion

Water, like most natural resources, presents unique challenges for efficient allocation due to its physical attributes. The issues are particularly acute where water is scarce, like the arid Southwestern United States. Settlement and development of the region has been contingent on water usage for over 400 years. In my dissertation, I have taken advantage of varying irrigation institutions driven by the transition from the Hispanic institutions to the later Anglo-American institutions and corresponding demographic shocks to better understand the economics of irrigation.

Chapter two traced out the transition from Hispanic based communal *acequias* through legislative actions to the commodity and private property based system of the Anglo settlers. Chapter three continued to explore this transition and analyze how the larger irrigation districts were able to improve irrigation efficiency over the decentralized *acequias*, adding 12 percent of value to farms in New Mexico. Notably, this result ignores any possible cultural or environmental losses. Chapter four considered the ramifications of defining property rights as proportion of the total availability compared to the use of private rights to volume or flow based on seniority. The *acequias* forced to adopt the seniority system in Colorado perform worse than those in New Mexico on average. However, during drought Colorado suffered less loss. On net, both systems fall short due to missing markets, but the proportional sharing serves as a better baseline, providing a greater potential of a functioning market. Finally, in chapter five, I considered the role of trust and transaction costs in managing a common-property resource based on demographic shocks to *acequias* in Taos. The findings suggest trust is relatively unimportant, but transaction costs due to additional users erode economic performance. Notably, my use of panel data exposed omitted variable bias, with users selecting into better performing system, questioning the cross-sectional results throughout the literature. Overall, the *acequias* continue to exhibit high levels of resilience and ability to allocate the shared resource.

While *acequias* have maintained their practices for years, the new disturbance most feared is water transfers. With the adjudication process now complete, there is greater security of individual water rights and it is now possible that individuals will transfer those rights outside of the *acequia*. This has implications for the physical attributes of the stream flow and the resources available for maintenance. If new users enter, and instead of paying fees and not using water, essentially use the water by transferring it and no longer pays the fees, the entire system could collapse. Institutional adaptation is already underway as *acequias* seek to put in safeguards against such situations by requiring the *acequias* approval for transfer while creating a local water bank (they have opposed more central water banks) to make water reallocation more flexible. Economic efficiency may suggest this movement of water to higher valued uses is desired, but it will come at great cost to the local communities. It is of great interest how they will deal with this new potential disturbance.

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Appendix A: Chapter Four Proofs

Proof for diversion for a given amount of prior capacity (Proposition 1):

If the ith appropriator assumes they will be the final, then when deciding how much capacity to build they will choose ${\bar{a}_i}^{cs}$ to maximize expected profit given A_{i-1}.

$$\max_{{\bar{a}_i}^{cs}} E^{cs}(\pi^i) = \int_0^{{A_i}^{cs}} \pi\left(\frac{{\bar{a}_i}^{cs}}{{A_i}^{cs}}\, x, {\bar{a}_i}^{cs}\right) f(x)dx + [1 - F({A_i}^{cs})]\pi({\bar{a}_i}^{cs}, {\bar{a}_i}^{cs})$$

Taking the derivative we obtain the first order condition as follows:

$$[1 - F({A_i}^{cs})][\pi_1({\bar{a}_i}^{cs}, {\bar{a}_i}^{cs}) + \pi_2({\bar{a}_i}^{cs}, {\bar{a}_i}^{cs})] + \int_0^{{A_i}^{cs}} \left[\frac{x}{{A_i}^{cs}} - \frac{{\bar{a}_i}^{cs}}{({A_i}^{cs})^2}\, x\right] \pi_1\left(\frac{{\bar{a}_i}^{cs}}{{A_i}^{cs}}\, x, {\bar{a}_i}^{cs}\right) f(x)dx + \int_0^{{A_i}^{cs}} \pi_2\left(\frac{{\bar{a}_i}^{cs}}{{A_i}^{cs}}\, x, {\bar{a}_i}^{cs}\right) f(x)dx = 0$$

In the prior appropriation world, the appropriator is also maximizing their expected profit. BQ find the condition to be:

$$\pi_2({\bar{a}_i}^{pa}) + [1 - F({A_i}^{pa})]\pi_1({\bar{a}_i}^{pa}) = 0$$

Therefore, the two conditions are equal to one another because they are both set equal to zero. Furthermore, iff the profit function remained separable, $\pi_2(z, w) = \pi_2(w)$ and $\pi_2(w) = -C'(w)$, as pointed out by BQ for the pa world. Here, this cannot be done, but we can note that $\pi_2(z, w) = \frac{z}{{A_i}^{cs}} R'(z) - C'(w) > \pi_2(w)$. Therefore, we can write:

$$\pi_2({\bar{a}_i}^{cs}) + [1 - F({A_i}^{cs})]\pi_1({\bar{a}_i}^{cs}) + \int_0^{{A_i}^{cs}} \left[\frac{x}{{A_i}^{cs}} - \frac{{\bar{a}_i}^{cs}}{({A_i}^{cs})^2}\, x\right] \pi_1\left(\frac{{\bar{a}_i}^{cs}}{{A_i}^{cs}}\, x, {\bar{a}_i}^{cs}\right) f(x)dx < 0$$

Furthermore, because $\left[\frac{x}{{A_i}^{cs}} - \frac{{\bar{a}_i}^{cs}}{({A_i}^{cs})^2}\ x\right] > 0$

$$\left[\frac{x}{{A_i}^{cs}} - \frac{{\bar{a}_i}^{cs}}{({A_i}^{cs})^2}\ x\right] \int_0^{{A_i}^{cs}} \pi_1\left(\frac{{\bar{a}_i}^{cs}}{{A_i}^{cs}}\ x, {\bar{a}_i}^{cs}\right) f(x)dx > 0$$

It must be the case that

$$\pi_2({\bar{a}_i}^{cs}) + [1 - F({A_i}^{cs})]\pi_1({\bar{a}_i}^{cs}) < \pi_2({\bar{a}_i}^{pa}) + [1 - F({A_i}^{pa})]\pi_1({\bar{a}_i}^{pa})$$

Now assume that ${\bar{a}_i}^{cs} \leq {\bar{a}_i}^{pa}$. This implies two things: 1) ${A_i}^{cs} \leq {A_i}^{pa}$, meaning that $F({A_i}^{cs}) \leq F({A_i}^{pa})$ and $[1 - F({A_i}^{cs})] \geq [1 - F({A_i}^{pa})]$ and 2) $\pi_2({\bar{a}_i}^{cs}) \geq \pi_2({\bar{a}_i}^{pa})$ assuming we are choosing diversion capacity where $\bar{a}_i > {\bar{a}_i}^*$ such that marginal costs are increasing. From these two implications, in order for the above inequality to hold we have that:

$$\pi_1({\bar{a}_i}^{cs}) \leq \pi_1({\bar{a}_i}^{pa})$$

However, given that ${\bar{a}_i}^{cs} \leq {\bar{a}_i}^{pa}$, and that $\pi_{11}^i < 0$ due to decreasing marginal returns to water, we have that:

$$\pi_1({\bar{a}_i}^{cs}) > \pi_1({\bar{a}_i}^{pa})$$

Hence, we have found a contradiction, meaning our assumption cannot be true that ${\bar{a}_i}^{cs} \leq {\bar{a}_i}^{pa}$, meaning that instead, ${\bar{a}_i}^{cs} > {\bar{a}_i}^{pa}$. In other words, given the same amount of prior diversion structure constructed, the next entrant will construct larger capacity in a world where division is based on proportional sharing than where it is a strict prior appropriation system. Not only does this yield over capitalization for individual i, their construction also decreases the profits of everyone that entered before them, leading to greater inefficiency in aggregate diversions.

Proof for total diversion structure (Proposition 2):

An entrant will only enter if $E(\pi^i) > 0$. Assuming risk neutrality, we simply want to see if given a certain capacity of diversions already constructed, does it remain profitable to enter. To begin, assume contrary to the above proof and let $\bar{a}_i{}^{cs} = \bar{a}_i{}^{pa}$. Let us pick irrigator k such that under the priority system,

$$E^{pa}(\pi^k) = \int_0^{A_{k-1}} \pi(0, \bar{a}_k) f(x)dx + \int_{A_{k-1}}^{A_k} \pi(x - A_{k-1}, \bar{a}_k) f(x)dx + [1 - F(A_k)]\pi(\bar{a}_k, \bar{a}_k) + \varepsilon$$

$$= 0$$

Such that it is just non-profitable to enter, and we can see whether the same irrigator would have under the communal sharing system.

$$E^{cs}(\pi^k) = \int_0^{A_{k-1}} \pi\left(\frac{\bar{a}_k}{A_k} x, \bar{a}_k\right) f(x)dx + \int_{A_{k-1}}^{A_k} \pi\left(\frac{\bar{a}_k}{A_k} x, \bar{a}_k\right) f(x)dx + [1 - F(A_k)]\pi(\bar{a}_k, \bar{a}_k)$$

Now consider each term. The final term ($[1 - F(A_k)]\pi(\bar{a}_k, \bar{a}_k)$) is the same for each. Now consider the first term. When $a_k \leq \bar{a}_k$, $\pi_1^k > 0$ by assumption, meaning $\pi\left(\frac{\bar{a}_k}{A_k} x, \bar{a}_k\right) > \pi(0, \bar{a}_k)$ for $\forall x$. For the middle term, we begin with the fact that $x \leq A_k$ (or else we would be in the third term). This means $x(\bar{a}_k - A_k) \geq A_k(\bar{a}_k - A_k)$, implying that $x(\frac{\bar{a}_k}{A_k}) \geq (x + \bar{a}_k - A_k)$. Noting that $A_k = A_{k-1} + \bar{a}_k$, we have $x(\frac{\bar{a}_k}{A_k}) \geq (x + \bar{a}_k - A_{k-1} - \bar{a}_k)$, finally establishing that $x(\frac{\bar{a}_k}{A_k}) \geq (x - A_{k-1})$ for $\forall x$. Therefore the middle term is larger in the communal sharing world as well. On net,

$$E^{cs}(\pi^k) > E^{pa}(\pi^k)$$

Therefore, even when it is no longer profitable to enter under the priority system, someone under the communal sharing system would enter. This will result in greater overall diversion capacity constructed under communal sharing. Relaxing the assumption that $\bar{a}_k{}^{cs} = \bar{a}_k{}^{pa}$ maintains the result, as the more profitable decision is to pick $\bar{a}_k{}^{cs} > \bar{a}_k{}^{pa}$, which would only increase $E^{cs}(\pi^k)$.

Proof for Regional Profit (Proposition 3):

As is indicated by proposition 5 in BQ, the inefficient division of water in the priority system results in a lower expected profit at the regional level than with the communal sharing. To derive comparisons, we will assume a fixed capacity and equal diversions and focus only on the division rule. Let x be the stream flow available to the marginal irrigator under the priority scheme.

$$\pi^{pa}(y) = \sum_{i \leq y/\bar{a}} \pi(\bar{a}, \bar{a}) + \pi(x, \bar{a}) + \sum_{i > y/\bar{a}+1} \pi(0, \bar{a})$$

And

$$\pi^{cs}(y) = \sum_{i \leq y/\bar{a}} \pi\left(\frac{1}{N}y, \bar{a}\right) + \pi\left(\frac{1}{N}y, \bar{a}\right) + \sum_{i > y/\bar{a}+1} \pi\left(\frac{1}{N}y, \bar{a}\right) = N\pi\left(\frac{1}{N}y, \bar{a}\right)$$

Let k represent the marginal irrigator under the priority system, in other words, $(k-1)\bar{a} \leq y < k\bar{a}$. At this flow, $\pi^{cs}(y) = \pi^{pa}(y) + (k-1)\left[\pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right) - \pi(\bar{a}, \bar{a})\right] + \left[\pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right) - \pi(x, \bar{a})\right] + (N-k)\left[\pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right) - \pi(0, \bar{a})\right]$. Assume $k = 1$.

$$\left[\pi\left(\frac{1}{N}(x), \bar{a}\right) - \pi(x, \bar{a})\right] + (N-1)\left[\pi\left(\frac{1}{N}(x), \bar{a}\right) - \pi(0, \bar{a})\right] \geq 0$$

This implies that for $k = 1$, , $\pi^{cs}(y) \geq \pi^{pa}(y)$, with strict inequality so long as , $N > 1$.

When moving from k to $k+1$, the relative profit gains are:

$$\Delta\pi^{pa} = \pi(\bar{a}, \bar{a}) - \pi(0, \bar{a})$$

And

$$\Delta\pi^{cs} = N[\pi\left(\frac{1}{N}(x + k\bar{a}), \bar{a}\right) - \pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right)]$$

For profits under the priority system to raise above that under the communal sharing, the gain needs to be greater than the communal gain plus the gap already built. We would need to assume that

$\pi(\bar{a}, \bar{a}) - \pi(0, \bar{a}) > N[\pi\left(\frac{1}{N}(x + k\bar{a}), \bar{a}\right) - \pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right)] + (k-1)\left[\pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right) - \pi(\bar{a}, \bar{a})\right] + \left[\pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right) - \pi(x, \bar{a})\right] + (N-k)\left[\pi\left(\frac{1}{N}(x + (k-1)\bar{a}), \bar{a}\right) - \pi(0, \bar{a})\right]$.

If $k = 0$, meaning there is no water whatsoever and $\pi^{cs}(0) = \pi^{pa}(0)$. As shown above, when $k = 1$, $\pi^{cs}(y) > \pi^{pa}(y)$. That implies that that when $k = 0$, moving to $k = 1$,

$0 \le N\left[\pi\left(\frac{1}{N}(x + k\bar{a}), \bar{a}\right)\right] - (k)[\pi(\bar{a}, \bar{a})] - \pi(x, \bar{a}) - (N - (k+1)\pi(0, \bar{a})$.

Now assume this holds for k, and we need to show it holds for $k + 1$. Begin by assuming opposite:

$$\pi(\bar{a}, \bar{a}) - \pi(0, \bar{a}) > N\left[\pi\left(\frac{1}{N}(x + (k+1)\bar{a}), \bar{a}\right)\right] - (k)[\pi(\bar{a}, \bar{a})] - \pi(x, \bar{a}) - (N - (k+1))\pi(0, \bar{a})$$

Which becomes:

$$0 > N\left[\pi\left(\frac{1}{N}(x + (k+1)\bar{a}), \bar{a}\right)\right] - (k-1)[\pi(\bar{a}, \bar{a})] - \pi(x, \bar{a}) - (N - (k))\pi(0, \bar{a})$$

Which becomes:

$$0 > N\left[\pi\left(\frac{1}{N}(x+(k)\bar{a}),\bar{a}\right)\right] - (k)[\pi(\bar{a},\bar{a})] - \pi(x,\bar{a}) - \big(N-(k+1)\big)\pi(0,\bar{a})$$
$$+ N\left[\pi\left(\frac{1}{N}(x+(k+1)\bar{a}),\bar{a}\right) - \pi\left(\frac{1}{N}(x+(k)\bar{a}),\bar{a}\right)\right] + [\pi(\bar{a},\bar{a}) - \pi(0,\bar{a})]$$

From our assumption above, we know $0 \leq N\left[\pi\left(\frac{1}{N}(x+k\bar{a}),\bar{a}\right)\right] - (k)[\pi(\bar{a},\bar{a})] - \pi(x,\bar{a}) -$ $(N-(k+1)\pi(0,\bar{a})$. Furthermore, because $\pi_1 > 0$, $N\left[\pi\left(\frac{1}{N}(x+(k+1)\bar{a}),\bar{a}\right) -\right.$ $\left.\pi\left(\frac{1}{N}(x+(k)\bar{a}),\bar{a}\right)\right] > 0$ and $[\pi(\bar{a},\bar{a}) - \pi(0,\bar{a})] > 0$. This presents a contradiction, meaning

$$\pi(\bar{a},\bar{a}) - \pi(0,\bar{a})$$
$$\leq N\left[\pi\left(\frac{1}{N}(x+(k+1)\bar{a}),\bar{a}\right)\right] - (k)[\pi(\bar{a},\bar{a})] - \pi(x,\bar{a}) - (N-(k+1))\pi(0,\bar{a})$$

Therefore, $\pi^{cs}(y) \geq \pi^{pa}(y)$ for all y with strict inequality if $N > 1$.

Proof for Regional Marginal Profit (Proposition 4):

Begin with the profit functions:

$$\pi^{pa}(x) = \sum_{i \le x/\bar{a}} \pi(\bar{a}, \bar{a}) + \pi(x - i \times int(x/\bar{a}), \bar{a}) + \sum_{i > x/\bar{a}+1} \pi(0, \bar{a})$$

And

$$\pi^{cs}(x) = \sum_{i \le x/\bar{a}} \pi\left(\frac{1}{N}x, \bar{a}\right) + \pi\left(\frac{1}{N}x, \bar{a}\right) + \sum_{i > x/\bar{a}+1} \pi\left(\frac{1}{N}x, \bar{a}\right) = N\pi\left(\frac{1}{N}x, \bar{a}\right)$$

Therefore,

$$\frac{d\pi^{pa}}{dx} = \pi_1(x - A_{i-1}, \bar{a}), \text{for } A_{i-1} \le x < A_i$$

And

$$\frac{d\pi^{cs}}{dx} = \pi_1(\frac{1}{N}x, \bar{a})$$

At any moment, if $\frac{1}{N}x < x - A_{i-1}$, then $\frac{d\pi^{cs}}{dx} > \frac{d\pi^{pa}}{dx}$ because $\pi_2 < 0$. This condition holds while $A_{i-1} \le x < A_i$ if $x > a(i-1)\left(\frac{N}{N-1}\right)$. So in expected terms, if $F\left(\bar{a}(i-1)\left(\frac{N}{N-1}\right)\right) < 0.5$, $\frac{d\pi^{cs}}{dx} > \frac{d\pi^{pa}}{dx}$ for $\bar{a}(i-1) \le x < \bar{a}(i)$. Because $F(x)$ is non-decreasing, this implies the marginal gain under the priority system can be expected to be greater as i increases and N increases relative to the communal sharing system.

Appendix B: Chapter Five User Group Construction

Across New Mexico, steps are being taken to adjudicate water rights in compliance with the 1905 and 1907 water laws. In Taos Valley, the process began in 1969 with the state bringing suit against the water users (Abeyta Case). While a settlement has been signed by many of the major parties in 2012, the settlement remains outstanding awaiting any objection from the individual water users. Two steps are necessary to determine water rights under the priority system. The first step is to determine the user of the water. The second step, given the seniority system, is to determine the date of diversion for each water user. This latter portion is difficult and largely circumvented through the settlement process.

The state commenced with hydrological surveys in the region from 1968-1970. The resulting products include a listing of all water users, which acequia they divert from, the location and size of the plots they irrigate. In addition, maps were constructed, aiding greatly in the spatial component of the research. While not yet a confirmed a property right, following the initial determination in 1969-1970, those purchasing land with water rights were to file a change of ownership with the Office of the State Engineer of New Mexico. These forms list the grantor, the grantee, date of filing, the parcel, acreage and quantity of water. These records are kept in filing cabinets in the State Engineer's offices in Santa Fe, New Mexico. Over the course of two separate weeks (May 21-25, 2012 and February 18-22, 2013) I sorted through all the files and recorded all transfers in the Taos region, amounting to 3,638 records. With the original user groups from the survey and records of any transfer, it was possible to update the user group each year.

While simple in theory, some shortfalls in the data require applying some assumptions. Because the forms are filled out not by the state but by the purchasing party, inaccurate or incomplete forms are not uncommon. Three of the most common (impacting) errors are as follows:

1) Owner of record erroneously naming the original 1969 owner and not the most recent owner.

2) Listing total acreage of land purchased rather than the amount of irrigated land.

3) No parcel listed

Evidence of the first comes from records of complete parcel sales from the original owner following prior records of transfers. The second mistake was made obvious through a number of transfers claiming more land than the amount of irrigated land available. While easy to correct in simple instances (those that indicate the issue), assumptions had to be made in the more complicated cases arising after any partial transfer. Cases with no parcels were dropped.

To construct the acequia-year user groups, an algorithm within Stata was written and utilized to automate the process. Here I provide a description of the process, including the assumptions made to deal with unclear transfers. The main assumptions are summarized in Table A.A.1.

Beginning 1969 or 1970, any owner ever of an irrigated parcel is listed. If the owner entered after 1970, they are removed. The new entrants are then paired by parcel with the current record holder. At this point, Stata examines the last names to determine if it was a transfer outside of the family, coding that extra information. Parcels were than separated by whether or not a transfer occurred, ignoring those for which nothing transpired that year. The code then calls for treatment of the easy transfers, ignoring any that involve more than 3 parties. For cases with only two parties, if the acres transferred matches the total listed acreage, the previous owner is simply removed and replaced by the new owner. If the acreage listed exceeds the total listed acreage, the previous owner is removed and the new owner's acreage reduced to the previously listed acreage. Finally, if the transferred acreage is less than the total listed, than the new owner is added while the original owner has their acres reduced by the amount the transferred.

The next step looks at transfers from one original owner to two new owners. The transfer is treated similarly to above, but the new owners' acres are summed together. If their sum equals the previous listed acreage, the old owner is removed and the two new owners enter. If their summed acres are less, than all three are now listed with the original owners acreage reduced by that sum. Finally, if the sum exceeds the original acreage, the new owners have their acreage reduced proportionally to make their sum equal the original acreage. This is of course an assumption; alternatively, one could assume only one entrant made a mistake. This process is extended to one original owner and greater numbers of new users.

Further complications arise once multiple owners exist. Cases in which the new entrant clearly marks who the transfer occurs from are manually "tagged" before running the algorithm. In these cases, the algorithm approaches the transfer as above, ignoring the other parcel owners. When 2 possible sellers exist but the new purchaser does not indicate the seller, it is assessed whether it is only possible to purchase the acreage listed from one of the owners, if so it is assumed they are the seller. Again, this is an assumption, as it could have been the other owner with the acreage mistakenly inflated.

The other large assumption arises from large tract holders, though it is really just a broad application of the above case. Often, through a number a years a large tract would come to have a number of owners. When a new entrant could have feasibly purchased the acres from multiple current owners, if not specified, I assume that the sale is from the largest landholder. Those transfers which failed to record the parcel will simply dropped. This, along with the other assumptions, inevitably brings about some measurement error.

This process was repeated for every acequia in every year from 1969 to 2011. Once the owners of all the parcels were collected, the data is first collapsed to the individual-acequia-year level. Often irrigators own multiple parcels within a given acequia. At this juncture, the surnames were compared to the Words and Perkins (1996) report from the census which classified the most common Hispanic surnames. From here, the data was collapsed to the acequia-year level, maintaining the number of users, average acre per person, median acres per person, fraction of users which were new, fraction of acres owned by a new user, the gini-coefficient based on land holdings, the fraction of users which were Hispanic. In total, this data represents the user group.

Table A.A.1—Assumptions in constructing the user group characteristics

Issue	Assumption	Possible Alternative Assumption
1 grantee claims more acreage than grantor has	Land includes non-irrigated acres and grantee's acres are adjusted down	None
2 grantees claim in sum more than grantor has	Grantees land are reduced proportionally down to the grantors ownership	One grantee overstated their acres—must assume which one
2 or more grantors are possible	The grantor with more acreage is selected	Any other possible grantor, though no systematic way
2 or more grantors exist but grantee's acreage exceeds all but one	The acreage claimed is correct and comes from the only physically possible grantor	Grantee overstated irrigated acres and purchased from someone else with fewer acres