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The Relative Economic Merits of Alternative Water Rights

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Abstract:

The prior appropriation doctrine adopted by all 17 Western US States, in which water users are provided absolute, private rights to water allocated in order of first diversion, has been lauded for its incentive structure for initial development but critiqued for subsequent inequalities in water use. By contrast, Hispanic settlers of the region adopted proportional water rights. I compare the performance of proportional water rights to the more prevalent private rights (prior appropriation) using theory and empirical evidence. I test the theoretical predictions using a natural experiment where acequias (Hispanic-rooted irrigation ditches) developed in Territorial New Mexico are later divided by the formation of Colorado, exogenously forcing that subset to be subject to the priority system while those in New Mexico continue to practice proportional division today. With 1930 irrigation organization data, I first test the implications on infrastructure investment, finding that indeed more investment has been made in Colorado and increases in seniority of rights. Then, using annual satellite imagery from 1984-2011, I compare performance under various stream flow conditions, finding that the marginal product of water is generally larger under the proportional system. Finally, using survey data from 2013 I explore how governance form and concerns of these Hispanic organizations have distinctly evolved given the presence of, or lack thereof, the prior appropriation doctrine.

Keywords: irrigation, prior appropriation, *acequias*

JEL: Q15, Q25

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1 Introduction

Arid regions are dependent on irrigation technology and institutions to be agriculturally productive. Because water is rival in consumption, but 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 & 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; Smith, 2018).

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 Burness & 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 2. In section 3, I present the assumptions of the theoretical production model and some of the implications. Next, in section 4, I provide the context of the natural experiment. In section 5, I detail the data sets before providing methods and results in section 6. Section 7 explores the survey data before concluding with section 8.

2 Background

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). Often described as "first in time, first in right," water rights 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, and 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 & 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. 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. 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 & Rivera, 2000; Heinmiller, 2009).

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.

3 The Formal Model

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 $i + 1$.

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 $A_{i-1} \le x < A_i$, $a_i = \bar{a}_i$ if $x \ge A_i$

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.

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 $x \ge A_N$.

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:[1]

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

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 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.[2]

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,

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[1] 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.

[2] 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 inbetween.

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.

3.5 Model Results[3]

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 reduces the water received by earlier irrigators under communal sharing, whereas they have no impact on

[3] Proofs of propositions are included in Appendix A.

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 x.*

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* $F\left(\bar{a}(i-1)\left(\frac{N}{N-1}\right)\right) < 0.5$ *for* $A_{i-1} \leq x < A_i$ *on average.*

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 becomes apparent that production should be expected to be non-uniform under the priority system.

3.6 Extensions

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 $a \le w$. 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.

3.6.2 Various Skill Levels

Another big assumption above is that of identical profit functions. In reality, farmers are heterogeneous as is cropland.[4] 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 $s_i \ge s_{i+1}$, expecting that the earliest settlers chose the most productive land. It is readily apparent that equal sharing is no longer the efficient solution:

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

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 $s_i \times \pi_1(x, \bar{a}) \ge s_{i+j} \times \pi_1(0, \bar{a})$

[4] 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.

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:

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

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 Empirical Setting

In order to test the model, I draw upon a natural experiment with *acequias* in the southwest. One group of *acequias* is in Taos County, New Mexico and the other group is in the adjacent Costilla County, Colorado. The *acequias* are within 50 miles of one another and both regions are steeped with Hispanic roots, but due to historic developments beyond the *acequias'* control, the New Mexico *acequias* practice communal sharing across whereas the Colorado *acequias* are subject to the priority system. The two regions can be found on the map in Figure 1. Here I first explain the history and natural experiment, then tailor the model's propositions to testable hypotheses given the empirical setting.

4.1 New Mexico Settlement and Water Law

European settlement of what is now New Mexico began with the Spanish colonization of *La Provincia del Nuevo México* in 1598. After a brief expulsion by native populations, colonization resumed in full force in 1695 and on through Mexico's independence in 1821. The settlements were guided by the Laws of the Indies issued by the Spanish crown, stating access to water as essential for the formation of a community. Therefore, unlike most of the arid West, irrigation and water law was not lacking upon the United State's acquisition of the region. Instead, a unique set of water laws being employed by over 400 irrigation ditches (*acequias*) was inherited.

The Kearny Code, proclaimed in 1846 upon the United States' occupation stated, "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 passed the region to 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. The customary division of water follows *repartiemento,* by which water surpluses and shortages are shared across ditches in proportion (Rodríguez, 2006). 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 territorial legislature. As such, water law began to transform water from a shared, life quenching resource, to a commodity and input into economic growth (see Smith 2014 for more details).

Spurred by the federal formation of Reclamation Service (todays Bureau of Reclamation) in 1903, the New Mexico Territorial Legislature drafted and passed an expansive water code in 1905 (House Bill number 98 of the 36th Territorial Legislature). 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. 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 of implementing the new water code has been long and drawn out. The adjudication process, by which individual water rights are determined, is ongoing with many regions underway though many others have not even begun. The process in Taos began in 1968 with a hydrological survey and a partial decree was finally issued just in 2015. 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, 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).[5] According to Rodríguez (2006), no *acequia* user interviewed in Taos recalls anyone ever placing a call, i.e. exercising their private right, on their water. The decentralized water allocation mechanism appears to have worked just as well as more centralized allocation mechanisms that displaced *acequia* governance in portions of New Mexico (Smith, 2018).

4.2 Colorado Settlement and Water Law

Prior to the 1859 gold rush in Colorado, Hispanic settlement pushed north from Taos in 1852 to establish San Luis de la Culebra, the oldest town in Colorado. However, at the time and until 1861, the region was part of New Mexico Territory (Simmons, 1999), digging many irrigation ditches under the same codified customs as Taos *acequias.* Like New Mexico, Colorado moved towards the prior appropriation doctrine, but more quickly and smoothly. The doctrine was adopted in Colorado's initial constitution and they further 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.[6] The process of determining rights and administering the new priority system in Colorado suffered fewer complication than it did in New Mexico.

The San Luis People's Ditch, dug by the Hispanic settlers in 1852, hails the oldest water right in Colorado. Importantly, though, even this does not pre-date U.S. sovereignty, meaning the Treaty of Guadalupe Hidalgo carries no legal weight. Accordingly, in Colorado the doctrine of prior appropriation is not merely *de jure*, but quite functional. This causes the *acequias* in Colorado to operate in a very different institutional context, locked into the priority system.[7] The mechanism is the risk of abandonment accompanied by state monitoring. Daily, the State Engineer

[5] In meeting Rio Grande Compact demands due to Texas, the priority system may come into play in determining curtailment of water.

[6] This decision also granted the ability to divert water across watersheds.

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

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). Furthermore, unless the water is meant for the ditch next in priority, they have no legal mechanism to force the intermediate rights to refrain from extracting the water.

While overtime the *acequias* here have adapted to the new system, overall there remains the cultural desire to share shortages. Hicks & 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). Notably, Costilla county was never divided in squares by the Public Land Survey System due to its settlement under long lots. These anecdotal stories suggest they value their Spanish/Mexican heritage and still desire to allocate water similarly to their New Mexican counterparts, but are much more constrained by the private property regime enforced in Colorado.[8] Both Taos County and Costilla County 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 (USDA, 2013). Furthermore, in a more rigorous analysis based on extensive irrigation ditch surveys collected by the author in 2013, the *acequias* in Costilla county were found to be distinct in their organization and characteristics from other (Anglo) irrigation ditches in San Luis Valley and more similar to the *acequias* in Taos (Cody 2019). It is for this reason that they provide a compelling comparison for the investigation at hand.

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[8] 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.

4.3 Empirically Testable Hypotheses

Given the empirical setting and the predictions of the model, there are a number of testable hypotheses. Here is a summary:

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: Junior diverters in Colorado will perform relatively worse on average (Corollary 2)

H4b: Junior diverters in Colorado will experience relatively greater temporal variation in performance (Corollary 2)

5 Data

In order to test the hypotheses, I constructed two distinct data sets. The first, utilized to test predictions related to the irrigation investment predictions, is comprised of cross-sectional information hand-collected from the original 1930 irrigation census schedules held at the National Archives. The second, used to analyze the relationship between available water and production, is a panel data set comprised of USGS stream gauge data and values of "greenness" derived from satellite imagery.

5.1 1930 Census Data

As part of the 1930 Decennial Census effort, each irrigation enterprise in the 19 western states was requested to fill out a short questionnaire. The responses are tabulated at various levels and available as part of the report (US Bureau of the Census, 1932). But this analysis does not rely on county level averages. Instead, the original schedules have been preserved and are at the National Archives in Washington D.C. (Records of the Bureau of the Census, Record Group 29.8.3), providing a cross-section of the ditches themselves. In 2015, I collected the data for Taos and returned in 2016 to collect data for Costilla. An example form is provided in Appendix B. The sample keeps only the smaller systems, dropping larger irrigation districts and commercial enterprises (three from each county, all developed in the 20th century). For analysis, I extracted the variables that indicate investment or capacity.[9] These include capital investment, acreage, flow capacity, and length. The summary statistics, by county, are provided in Table 1.

These means provide some suggestive evidence that *acequias* in New Mexico did tend to be larger: acreage, capacity, and length all tend to be larger in New Mexico. However, Colorado tends to have invested more. But, it is also notable that Costilla *acequias* are on average 40 years later. Owing to the self-filled out forms, linking these directly to modern ditches (and data) has proven hazardous and, at best, incomplete. In order to create a "priority", I instead rank the ditches by their construction date. This is done both by county and by drainage basin. The latter is theoretical preferable on merits that priority is based on ditches sharing a water source, but practically dubious owing again to the self-filling out of the forms and lack of concrete definitions of a "stream", particular in New Mexico where ditches were not as well informed due to the lack of priority system. Both measures – overall ranking and within drainage basin ranking – provide similar results below.

5.2 Production and Water Data

In contrast to the census data, these data are limited to ditches along the Rio Culebra and Rio Costilla in Colorado and the Rio Hondo and Rio Lucero in New Mexico.[10] 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 measures the extent that Near-infrared wavelengths are reflected back and RED measures the red wavelengths 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.

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

[9] See the data appendix for an explanation of each variable.

[10] These are the primary streams in Colorado. Furthermore, stream gauge data (and priority date in New Mexico) are limited for the other streams.

To provide some physical context, NDVI values (coded such that whiter pixels are closer to 1 and black closer to -1) are contrasted to the greenness of a field in Figure 4. 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. 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). NDVI annual (spatial) averages are calculated by both the entire stream and individual ditches on the streams. For Colorado, ditches are given a priority based on formal state records. In New Mexico, where there is no priority system, I construct it based on construction dates from Dos Rio Consultants (1996).

For water supply, I utilize flow data from the United States Geological Survey (USGS, 2013).[11] The gauges gather daily readings throughout the year. Like many snowmelt systems, all four see considerable increases around April, peaking in June or July, before returning to low stable flows by October (see Figure CX in the Appendix). To create an annual measure, I first converted the daily cubic feet per second (CFS) to a volume of water delivered over the entire day, measured in Acre-Feet, the volume of water needed to cover one acre in one foot of water.[12] Dropping the winter months, I then sum up total annual water volume during the growing season on each stream. Figure 3 provides a rolling five-year average for the streams, revealing three patterns. First, the Culebra generally has the most water, followed by the Hondo, Lucero, and then the Costilla. Second, the streams are generally correlated with one another through time. And third, since 1983, all four streams have experienced a downward trend in annual water volume.

A summary of the panel data, separated by stream, is provided in Table 2. NDVI has been calculated for both the entire system of *acequias* on a stream and for individual *acequias* (note that the Rio Costilla *acequia* level is not yet completed). For much of the *acequia* level analysis, only the 7 most senior *acequias* on the Culebra while the Lucero and Hondo only include those

[11] The Gauges used are as follows: Culebra, USGS Gauge 08250000; Costilla, USGS Gauge 08261000; Hondo, USGS Gauge 08267500; Lucero, USGS Gauge 08271000 for the Rio Lucero. Flow is available as far back as 1913, though records are complete for all four streams from the 1960s.
[12] About 325,851 gallons of water.

with an available construction date to proxy for priority. For the Culebra system, these first seven are those considered to be the major irrigators and entering prior to 1882 (Peña, 1999). The analysis with the full sample is quite similar, but the later systems in Colorado have no direct comparison to ditches in New Mexico.[13] Across the stream level, NDVI tends to be slightly higher in New Mexico, while Colorado's *acequias* tend to be larger and slightly later.[14]

6 Empirical Analysis:

6.1 Settlement and Investment

Using the 1930 Census data, I test H1 (earlier diverters build larger systems) and H2 (more diversion is constructed in New Mexico). H2 is not directly testable since a number of factors may influence total capacity for which I am unable to account for. Instead, I test whether capacity decreases more slowly with arrival in New Mexico than in Colorado, which is the mechanism leading to the prediction of a larger aggregate capacity under the proportional system. I utilize the following equation to test these predictions:

$$Y_{ir} = \alpha_1 + \alpha_2 \times Col_r + \alpha_3 \times Priority_{ir} + \alpha_4 \times Priority_{ir} \times Col_r + \boldsymbol{v}_i' + e_{ir} \quad (1)$$

Here, Y_{ir} is one of the measures of investment or capacity for ditch *i* in region *r,* either Colorado or New Mexico. $Priority$ is simply the rank of the ditch based on its construction start within its drainage basin. Higher numbers indicate later arrival. This is interacted with an indicator for Colorado to allow for a differential effect. Finally, to account for the fact that a ditch built in 1710 is likely different in character than a ditch constructed in 1852 independent of its order of arrival, I include $\boldsymbol{v}_i'$, a vector of construction year indicator variables and their coefficients. There are insufficient observations for year fixed effects, so the indicators capture 25-year periods (e.g. 1701-1725). Therefore, the estimated effect uses variation within fixed time periods based on order of arrival.

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[13] In New Mexico, only 4 *acequias are* removed whereas in Colorado this removes 11. Stream wide regressions are stable with the inclusion of all *acequias* on both streams, but the data precludes including the additional Lucero *acequias* on analysis of seniority.

[14] If all the Culebra *acequias* are considered, the average size becomes smaller than in New Mexico.

Results are provided in Table 3. In New Mexico, there is no evidence that development or capacity is curtailed by later arrival and in fact, most point estimates are positive (though only statistically significant for acreage). This aligns with the model. In comparison, those that arrive later in Colorado do tend to build smaller: they invest less capital, develop fewer acres, and dig smaller and shorter irrigation ditches than their more senior counterparts. This bolsters the descriptive statistics suggestive evidence that ditches are, on average, larger in New Mexico by giving credence to the model's mechanism; later arrivals in New Mexico were not provided incentives to reduce their investment through the priority system. These results are robust to using priority rank across the county and excluding the time of construction fixed effects (see appendix table CX and CX).[15] Taken together, the evidence is supportive of H1 and H2.

6.2 Water Supply and Production

In this section, I test the hypotheses related to subsequent production. H3 has two parts. First, whether New Mexico has, on average, a higher marginal productivity of water. And second, whether that relationship is more readily recognizable in New Mexico. Before turning to the regression, the simple scatter plot of annual production is provided in Figure 4. Notably each stream does exhibit a positive correlation between stream flow and NDVI. Furthermore, the slope for both streams in New Mexico are steeper than those in Colorado. And last, the observations for two streams in New Mexico appear to stay closer to their fitted lines than those in Colorado.

In order to test these relationships more rigorously, I run the following regression:

$$NDVI_{sy} = \beta_1 + \beta_2 \times AF_{sy} + \beta_3 \times AF_{sy-1} + \beta_4 \times Year_{sy} + e_{sy} \qquad (2)$$

The dependent variable ($NDVI_{sy}$) is the spatial mean. Subscript y refers to the year while s designates the stream. AF_{sy} captures the annual acre-feet in the stream while $Year_{sy}$ adjusts for the downward trend present in stream flow and any trend present in production.

[15] The result on acreage was also validated by a similar regression using the GIS data underlying the panel-level data.

The estimates from running regressions on equation (2) for each stream separately are provided in Table 4.[16] Across all the streams, the coefficient on acre-feet is positive, but tends to be larger and more significant in New Mexico. Furthermore, last year's water supply has no predictive power for this year's production, consistent with the fact that the region has little in the way of storage and that production this year depends highly on the randomly available snowmelt. Somewhat related, it is worth noting that the Breusch-Godfrey test fails to reject that there is no auto-correlation in the error terms.[17] In column (5), a pooled regression is run with the coefficients interacted with Colorado, in addition to stream fixed effects. Here we see, in support of H3a, that New Mexico does have a statistically distinct and higher marginal productivity of water. However, it may not necessarily be higher because of the division; for instance, the Culebra receives more water on average, which might mean the marginal value of water is lower due to diminishing returns. Looking back at Figure 4, this concern is minimized to some extent since the Lucero and Costilla have similar amounts of water and the Hondo and Culebra also exhibit similar amounts. Depending on who is getting the water in the priority system, the marginal production of water at any given time in Colorado could be higher.

Underlying the model's prediction is that dividing the water equally across ditches means the equimarginal principle is being met and the water is being used efficiently, at least when water is the sole input to production. To better support the model, I consider the production across the various priorities within the streams. First, I regress a version of equation (2) at the *acequia* level and allow the marginal product of stream supply to vary by priority (and state). The coefficient estimates for the first 7 *acequias* are shown in Figure 5 (full results are provided in Table CX in the appendix; Table CX and Figure CX provide coefficients for all priorities). What stands out is that New Mexico exhibits very similar marginal productivity across all the *acequias* with rather tight confidence bands. In contrast, the Colorado point estimates vary and are noisy, only statistically significant for the 4th *acequia.* This lends more support to the model in that the

[16] Regression using acequia level NDVI are similar, as the independent variables are the same and the dependent variable are nearly the same, differing slightly as the stream level analysis essentially takes a weighted (by area) average of the acequias mean while the acequia level ignores the weighting.

[17] Robustness to specification is provided in Appendix Table BX for each stream. Results are not sensitive to the inclusion of the lagged water supply, year trend, lagged dependent variable, or the exclusion of 1984 – which has a notably lower NDVI in Colorado despite a higher water supply. Allowing water supply to enter the equation as a second order polynomial exhibits diminishing returns across all streams, statistically significant inclusive of the Colorado streams.

higher marginal productivity across the stream appears to stem, at least in part, due to the equimarginal principle being achieved.

Given the priority system's effect, it is suggestive that we should expect junior ditches in Colorado to be less productive (H4a) and subject to larger temporal variation (H4b). To test this, I use a regression framework similar to equation (1), but for the production data:

$$NDVI_{ir} = \gamma_1 + \gamma_2 \times Col_r + \gamma_3 \times Priority_{ir} + \gamma_4 \times Priority_{ir} \times Col_r + e_{iy} \quad (3)$$

First, using the temporal average for the outcome presented in Panel A of Table 5, there is little support that later *acequia* produce less on average. In fact, there is no detectable decline in Colorado and some evidence of increased production for later *acequias* in New Mexico. This could be driven by other factors not yet controlled for (topography, soil quality, etc.), but also indicative of other endogenous adjustments to variable water supply. However, the mean does appear to mask temporal variation. Presented in Panel B, the standard deviation for NDVI does increase significantly with lower priority in Colorado, providing support for H4b.

6.3 Empirical Summary

The evidence is generally supportive of the model predictions. Within a proportional sharing system, later arrivals are not incentivized to curtail development and capacity is generally larger in New Mexico. Water maintains a higher marginal production in the proportional system, seemingly from the equal division of the water. Thus, the priority system was effective in incentivizing and curtailing development, but the proportional system does achieve higher allocative efficiency. It should be emphasized that this true with water as the primary input and the empirical setting was suitable to this simplification. If greater water security (under the priority system) incentives investment in complementary inputs, than it is feasible that senior users, despite using more water, could have higher marginal products of water than junior irrigators, even to the extent that the priority system becomes more productive in aggregate with a given supply of water.

7 Survey Support

Under Construction

Manager level surveys were conducted for *acequias* in both Taos and the San Luis Valley in 2013. Questions are being identified to see if *acequias* in the two variant systems perceive distinct challenges and have changed in distinct ways.

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 & 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 may lead to a better functioning market due to the homogenous units (Howe & Goemans, 2003). Convincing senior appropriators to make this adjustment in property rights is a tall order, suggesting the communal sharing can more readily address the issues during drought.

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Figure 1: Map showing the location of the empirical setting.

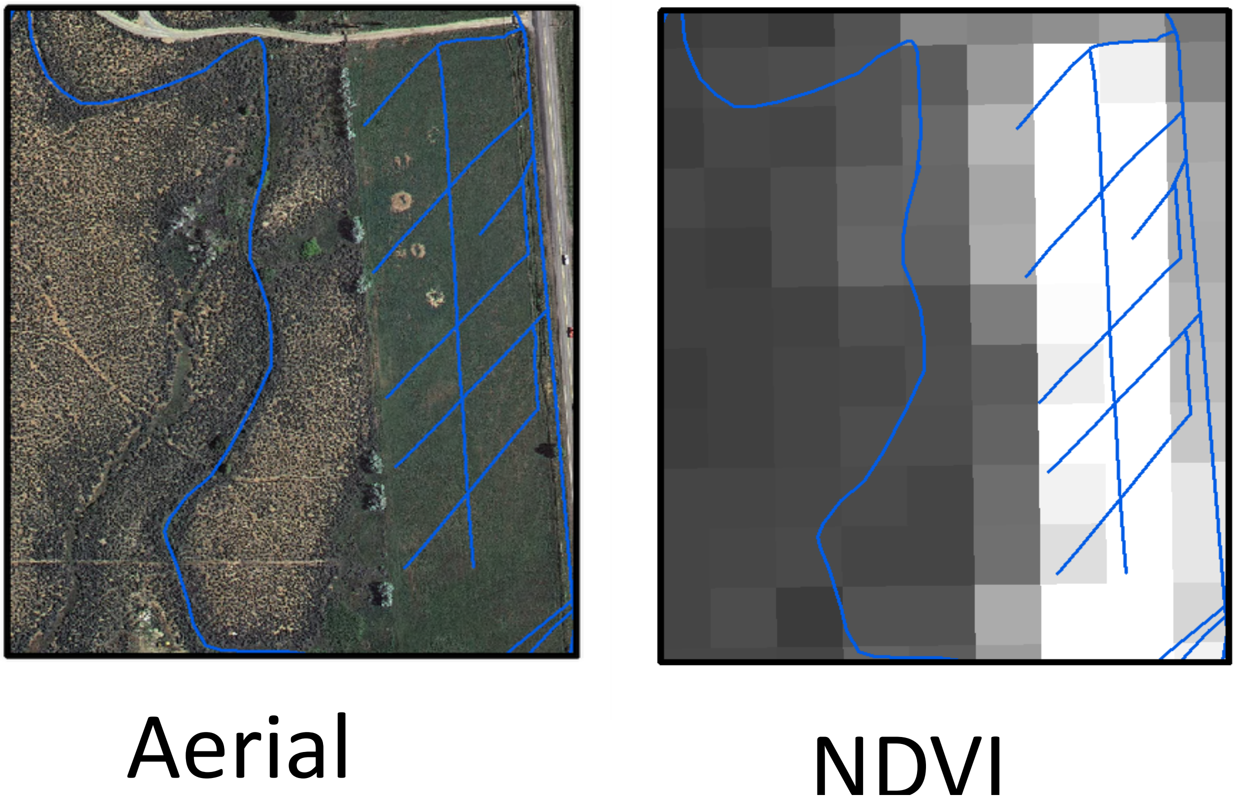

Figure 2: Illustration of the relationship between “greenness” and NDVI from New Mexico. NDVI pixels closer to 1 are more illustrated as being whiter.

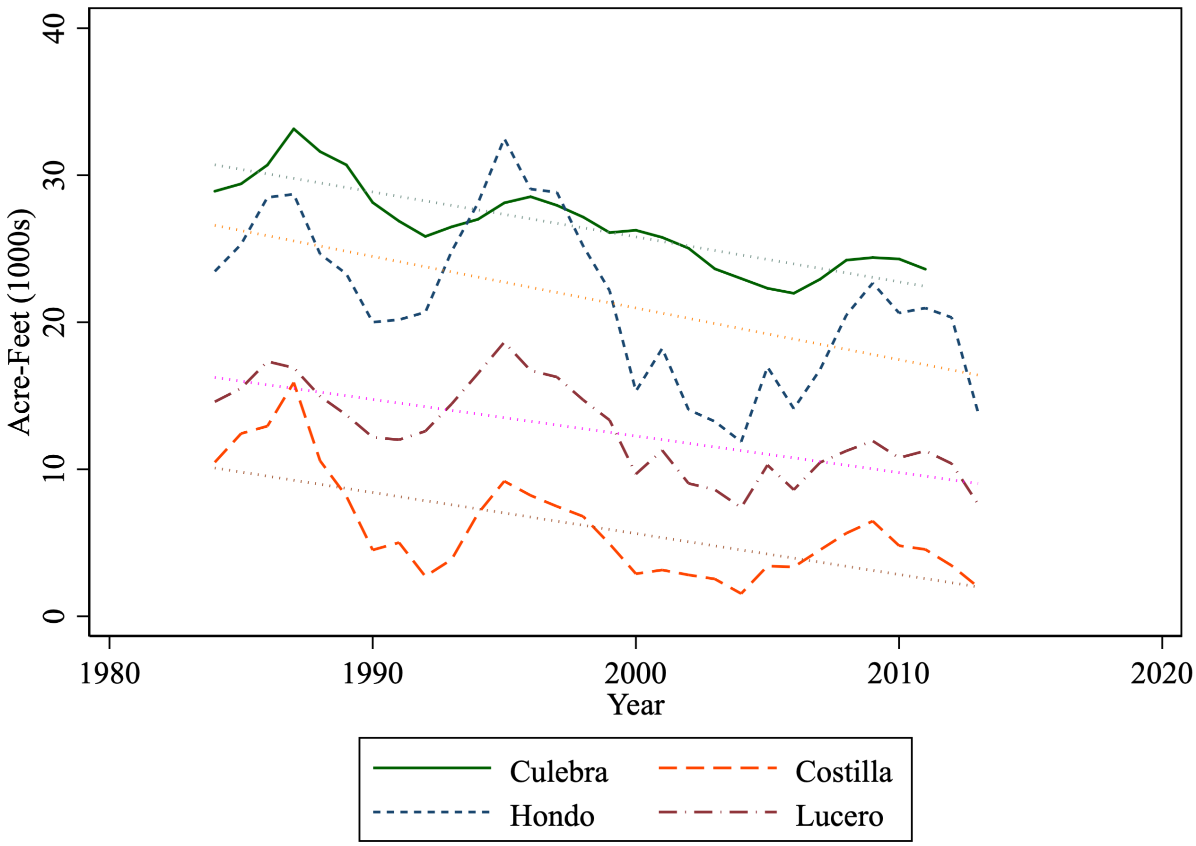

Figure 3: Plotting the 5-year rolling average of annual acre-feet supplied during the growing season (April-October) from 1983 to 2011. Overall trendlines are also provided for each stream.

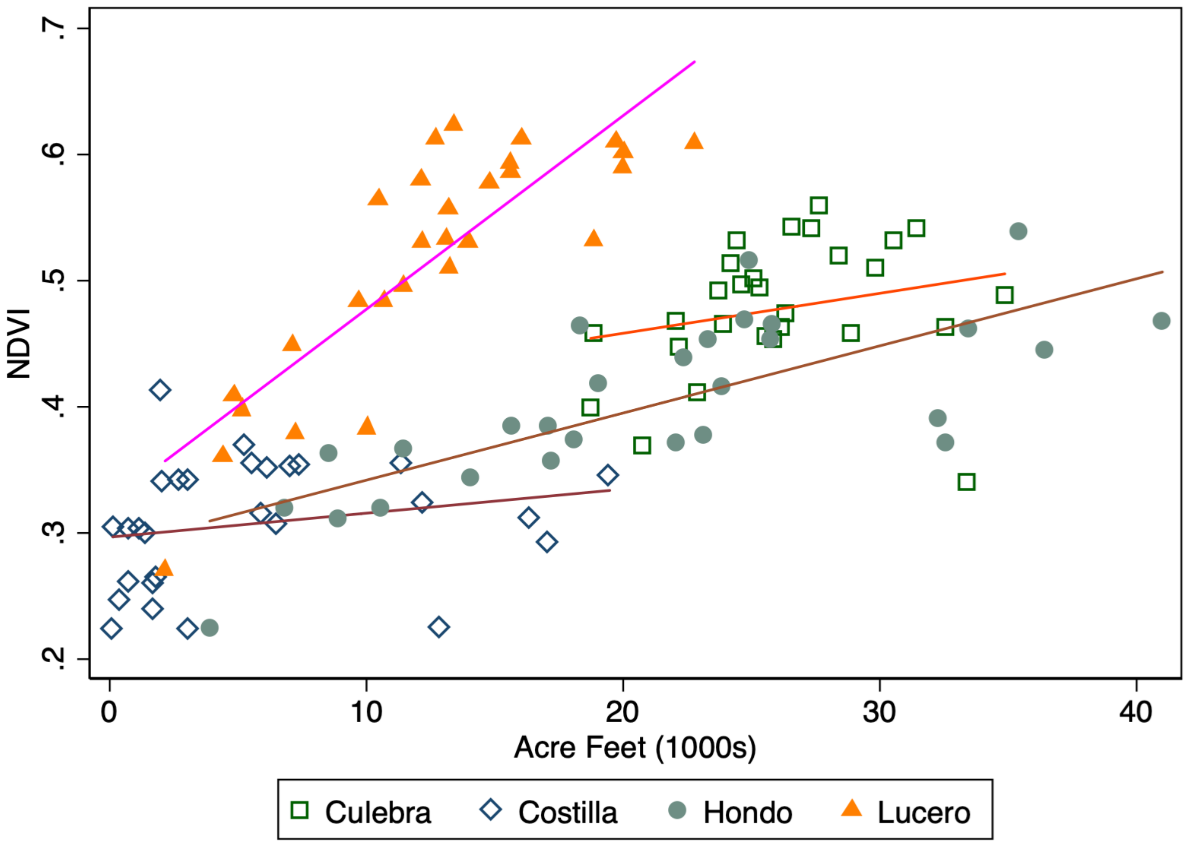

Figure 4: Scatter plot of stream-level annual NDVI and stream flow. Linear fit lines are provided.

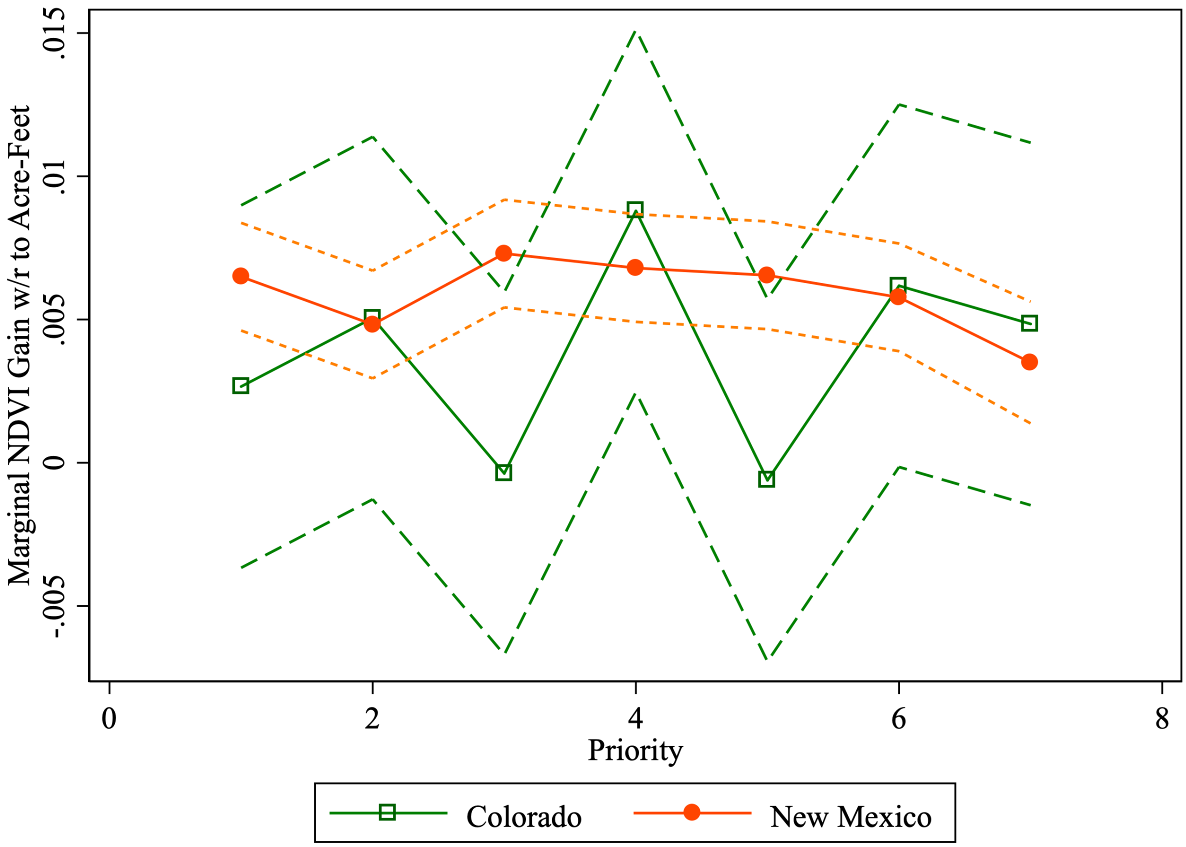

Figure 5: Coefficient estimates of the increase in NDVI due to another (1000) acre-feet of water supplied in the entire stream. Coefficients are plotted for *acequias* of each priority rank, with larger numbers indicating more junior systems. Dashed lines provide the 95th confidence interval.

Table 1

1930 Analysis Summary Statistics

	Taos (New Mexico)			Costilla (Colorado)			Difference
Variable	Obs	Mean	Std. Dev.	Obs	Mean	Std. Dev.	
Capital ($)	75	1299.13	3159.65	85	1800.06	6316.48	-500.93
Capital per Acre ($)	75	4.21	5.06	85	3.99	4.48	0.21
Maintenance Costs ($)	69	246.36	373.37	39	134.03	242.72	112.34
Original Acres	75	517.31	881.28	85	256.66	376.06	260.65
Capacity (CFS)	71	10.70	11.66	39	10.30	15.86	0.41
Length (Miles)	71	2.72	2.39	39	1.95	1.20	0.77
Construction Start Year	75	1845.31	45.79	85	1884.98	15.01	-39.67
County Priority	75	44.96	23.18	85	43.00	24.59	1.96
Drainage Basin Priority	75	4.87	3.83	85	14.86	8.41	-9.99

Note: Descriptive Statistics for irrigation enterprises from the 1930 census by county. See Data Appendix for a full description of the variables.

Table 2

1984-2011 Analysis Summary Statistics

VARIABLES	Observation Type	No. Obs	Mean	Std. Dev.	Min	Max
Panel A: Culebra						
NDVI	Stream-Year	28	0.478	0.053	0.339	0.559
Acre Feet (1000s)	Stream-Year	29	26.449	4.286	18.736	34.866
NDVI	Acequia-Year	196	0.507	0.085	0.266	0.658
Temporal S.D. NDVI	Acequia	7	0.068	0.011	0.056	0.085
Priority Year	Acequia	7	1862.571	13.138	1852.000	1882.000
Acres	Acequia	7	1345.296	1169.125	57.600	3158.224
Panel B: Costilla						
NDVI	Stream-Year	28	0.307	0.050	0.223	0.412
Acre Feet (1000s)	Stream-Year	29	6.341	6.798	0.118	27.344
NDVI	Acequia-Year					
Temporal S.D. NDVI	Acequia					
Priority Year	Acequia					
Acres	Acequia					
Panel C: Hondo						
NDVI	Stream-Year	28	0.402	0.068	0.224	0.539
Acre Feet (1000s)	Stream-Year	29	21.825	9.790	3.896	41.002
NDVI	Acequia-Year	196	0.442	0.113	0.153	0.684
Temporal S.D. NDVI	Acequia	7	0.069	0.008	0.057	0.078
Priority Year	Acequia	7	1817.143	6.466	1808.000	1828.000
Acres	Acequia	7	387.316	308.690	48.037	868.451
Panel D: Lucero						
NDVI	Stream-Year	28	0.516	0.094	0.270	0.623
Acre Feet (1000s)	Stream-Year	29	12.799	5.267	2.156	22.775
NDVI	Acequia-Year	168	0.447	0.122	0.153	0.637
Temporal S.D. NDVI	Acequia	6	0.089	0.018	0.057	0.110
Priority Year	Acequia	6	1827.333	45.320	1747.000	1865.000
Acres	Acequia	6	653.173	432.384	261.314	1375.955

Note: Summary statistics. Acequia level statistics are for the first 7 acequias and not yet calculated for Costilla

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

Table 3

1930 Irrigation Enterprise Census Regressions

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Capital ($)	Capital per Acre ($)	Maintenance Costs ($)	Original Acres	Capacity (CFS)	Length (Miles)
Priority	58.18	-0.157	4.916	40.44*	0.547	0.0974
	(100.9)	(0.206)	(12.04)	(22.51)	(0.400)	(0.0658)
Priority x Colorado	-364.2**	-0.0983	-17.63	-65.86**	-1.198**	-0.147*
	(182.4)	(0.211)	(13.10)	(31.15)	(0.597)	(0.0758)
Colorado	5,721**	1.581	151.4	562.5***	14.40**	1.000*
	(2,659)	(2.147)	(136.2)	(189.7)	(6.650)	(0.595)
Constant	254.5	1.392**	87.71***	298.9**	13.63***	3.756***
	(287.4)	(0.544)	(30.59)	(130.8)	(4.473)	(1.398)
Observations	160	160	108	160	110	110
R-squared	0.149	0.145	0.171	0.212	0.175	0.305

Note: Regression results for various measures (see data section) of irrigation investment and priority for ditches in Costilla and Taos counties. Fixed effects for construction start by 25 year intervals are included in all regressions. Robust standard errors in parentheses

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

Table 4

Stream Level NDVI

VARIABLES	(1) Mean NDVI	(2) Mean NDVI	(3) Mean NDVI	(4) Mean NDVI	(5) Mean NDVI
Acre Feet (1000s)	0.00298	0.00265*	0.00443***	0.0140***	0.00642***
	(0.00335)	(0.00138)	(0.000924)	(0.00221)	(0.00115)
Acre Feet (1000s) = L,	0.000540	-0.000920	0.000206	-0.000516	-9.03e-05
	(0.00405)	(0.00168)	(0.000748)	(0.00235)	(0.000938)
Year	0.000134	0.000832	-0.00330***	-0.00234	-0.00339***
	(0.00143)	(0.00111)	(0.00101)	(0.00144)	(0.00102)
Colorado Interactions					
Acre Feet (1000s)					-0.00347**
					(0.00165)
Acre Feet (1000s) = L,					-0.000600
					(0.00201)
Year					0.00373***
					(0.00120)
Observations	28	28	28	28	112
R-squared	0.061	0.088	0.704	0.741	0.772
Breush-Godfrey p-value	0.959	0.826	0.686	0.354	
Stream	Culebra	Costilla	Hondo	Lucero	All
State	Colorado		New Mexico		Both

Note: Average NDVI is the dependent variable. Acre Feet is the total volume of water on the stream from April to October. Each Column presents a separate regression for the stream indicated. The final column pools the observations, includes stream fixed effects, and allows the coefficients to vary across states. Robust standard errors in parantheses.

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

Table 5

Acequia Cross-Sectional Regressions

VARIABLES	(1)	(2)	(3)	(4)
Panel A: Temporal Average NDVI				
Priority	0.00931	0.0317**	0.00234	0.0199*
	(0.00740)	(0.0111)	(0.0165)	(0.00989)
Priority x Colorado				-0.0105
				(0.0121)
Colorado				0.100
				(0.0591)
Constant	0.469***	0.315***	0.439***	0.369***
	(0.0377)	(0.0439)	(0.0664)	(0.0470)
Observations	7	7	6	20
R-squared	0.129	0.496	0.002	0.285
Stream	Culebra	Hondo	Lucero	All
Panel B: Temporal Standard Deviation NDVI				
Priority	0.00378***	-0.00215*	0.00315	-0.000820
	(0.000852)	(0.00110)	(0.00305)	(0.00238)
Priority x Colorado				0.00460*
				(0.00252)
Colorado				-0.0283**
				(0.00997)
Constant	0.0528***	0.0771***	0.0780***	0.0811***
	(0.00297)	(0.00390)	(0.0164)	(0.00956)
Observations	7	7	6	20
R-squared	0.602	0.322	0.108	0.199
Stream	Culebra	Hondo	Lucero	All

Robust standard errors in parentheses

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

Appendix A:

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:

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

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 $k = 1$,

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

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 $\pi_1 > 0$, $N\left[\pi\left(\frac{1}{N}(x + (k + 1)\bar{a}), \bar{a}\right) - \pi\left(\frac{1}{N}(x + (k)\bar{a}), \bar{a}\right)\right] > 0$ 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: Data Appendix

Under construction.

1. Raw Data Sources

NDVI

United States Geological Survey (USGS). Global Visualization Viewer. Landsat Satellite Images. 2013 https://glovis.usgs.gov (accessed June 15, 2013)

Cox, Michael, Justin M. Ross. 2011 "Robustness and vulnerability of community acequia systems: The case of the Taos valley acequias. *Journal of Environmental and Economic Management.* Vol 61: 254-266

Flow

United States Geological Survey (USGS). Streamgage data. 2013 [cited 7/12 2013]. Available from http://waterdata.usgs.gov/nwis/nwisman; (accessed May 13, 2013).

Survey

Andersson, Krister, Michael E. Cox, Steven M. Smith, and Kelsey C. Cody. 2013. "Manager Questionnaire: Snowmelt dependent systems in the Unites States and Kenya." Collected Summer 2013.

Census Schedules

United States Bureau of the Census. 1930. "Irrigation Schedules". Available at the National Archives, Washington D.C.: Records of the Bureau of the Census, Record Group 29.8.3 "Miscellaneous nonpopulation schedules and supplementary records." Collected May 2016.

New 5-983

CONFIDENTIAL.—The information given in this report is *strictly confidential* and will not be used as a basis of taxation nor communicated to any tax official

Form 15-230
DEPARTMENT OF COMMERCE—BUREAU OF THE CENSUS
WASHINGTON

FIFTEENTH CENSUS OF THE UNITED STATES: 1930

IRRIGATION–1

98

ENUMERATOR'S RECORD

State Colorado County Castilla

Supervisor's District No. 9th Enumeration District No. ....

Enumerated by me on July 3rd, 1930.

Simon T. Parsons, Enumerator.

This schedule is to be used ONLY for irrigation enterprises serving LESS than FIVE farms, in the following States:

Arizona	Kansas	New Mexico	Texas
Arkansas	Louisiana	North Dakota	Utah
California	Montana	Oklahoma	Washington
Colorado	Nebraska	Oregon	Wyoming
Idaho	Nevada	South Dakota	

I.—MANAGEMENT AND LOCATION OF ENTERPRISE

1. Name of canal or enterprise Alban Sanchez Ditch

2. Individual, partnership, or company controlling enterprise:
(If supplying more than one farm, give name of each farmer. If two or more ditches are used for a single farm, state that fact and give names of ditches.)

Name (or names) Alban Sanchez, Jose P. Sanchez, Celestino Atencio, Manuel Esquibel.

Post-office address: San Pablo, Colo.

3. Location of enterprise: State Colorado. County Costilla

4. Location of head of canal, well, spring, or reservoir:

Section 6 Township 2 Range 71
(If located on unsurveyed land, describe by direction and distance from some near-by town or place)

Culebra Creek.

5. Person furnishing information:

Name Manuel Esquibel

Title ....

Address San Pablo, Colo.

II.—SOURCE OF WATER SUPPLY

6. Indicate class by X: (If more than one class, mark each)

Stream	X X	Spring	
Pumped well		Stored storm water	
Flowing well		City water	
Lake		Sewage	

7. Name of stream or other source........

8. Drainage basin........
(Give name of river system which drains the region where enterprise is located)

III.—WATER RIGHTS

9. Indicate class by X: (If more than one class, mark each)

Notice filed and posted		Riparian right	X X
Right adjudicated by court		Certificate or license from State	
Permit from State		Appropriation and use	X

10. Dates and amounts of rights June 20, 1889 1 24/40 cu. ft.

IV.—CLASS OF ENTERPRISE

11. Indicate class of enterprise at the present time by X:
Individual or partnership X Cooperative ....

EXPLANATIONS AND INSTRUCTIONS

Legal requirement.—A report of every irrigation enterprise in the United States is required by the Decennial Census Act of the Congress, approved June 18, 1929.

Definition of an irrigation enterprise.—An irrigation enterprise, for the purpose of the census, is a canal or a canal system, pumping plant, or reservoir supplying water for irrigation, or any combination of these operated under a single management by either an individual, a partnership, a company, or other organization.

Land should be classed as irrigated which has water supplied to it for agricultural purposes by artificial means or by seepage from canals, reservoirs, or irrigated lands, but land which has natural ground-water sufficiently near the surface to support plant life should not be classed as irrigated. Land which is flooded during high-water periods should be classed as irrigated if water is caused to flow over it by dams, canals, or otherwise, but should not be classed as irrigated if the overflow is due to natural causes alone.

This schedule is to be used by enumerators to report irrigation enterprises serving less than five farms.—Reports for larger enterprises will be secured by enumerators only when they are specifically instructed by their supervisors to do so, and enumerators will then use schedule Irrigation-2. However, enumerators are cautioned to *return reports for all pumping plants, wells, canals, or reservoirs operated by individuals or small groups of farmers* who also obtain water from enterprises serving more than four farms.

If the General Farm Schedule (Questions 122 to 125) shows that the farm was irrigated, the enumerator should ask whether the irrigation enterprise reported under Question 125 serves less than five farms in all; if the answer is "Yes," he should obtain the names of all the farmers involved, and from one of them (or other reliable source), obtain the information needed to fill out this Irrigation Schedule, unless, upon further inquiry, he is told that an Irrigation Schedule has already been received from the Census Bureau. If such a schedule has been received, he should ask whether it has been filled out and returned. If the answer to this question is "Yes," the enumerator should make an entry to that effect on his daily report. The enumerator should satisfy himself, however, that it was actually a United States Census Irrigation Schedule, and not some other form of schedule, which was received and filled out, and that the irrigation enterprise it described was none other than the one about which he is inquiring.

If the enterprise has received an Irrigation Schedule by mail and has not filled it out, or has filled it out but has not returned it, the enumerator should obtain it. *Only a few schedules will have been received by mail by enterprises serving less than five farms, these being individuals or partnerships in isolated sections, or enterprises whose size was not definitely known by the Bureau of the Census.*

All questions are to be answered.—If exact information is not available, get the best estimate possible and write "Est." beside the answer. Use the margin of the schedule or a separate sheet when additional space is necessary to make the answers clear, definite, and complete.

Section I.—If a farm is supplied with water by more than one canal, and these canals supply water to ***not more than three*** other farms, a schedule should be made out for each canal; but if a farm is supplied with water by more than one canal and these canals supply no other farm or farms, all such canals should be included on a single schedule, the names, if the canals are named, being written on the blank lines under Question 2.

Section II.—If water is secured from more than one source, each should be marked and the principal source indicated by underscoring. If water is secured from two or more streams or other sources, the names of each should be given.

"Stored storm water" refers to reservoirs filled by storing storm water from channels that carry water only during storms and are not classed as streams. When water is obtained from a reservoir filled from a stream, the stream should be given as the source.

Under "Drainage basin" the name of the smallest stream that is well known and which is shown on ordinary maps should be given. This inquiry should be answered, even if water is not obtained from a stream.

Section III.—These questions relate to the rights of the enterprise to take water from the stream or other source from which it is obtained. Some enterprises have several rights, each of which should be shown; and many rights will fall in more than one of the classes named. In each instance the right should be reported in the class in which it stands at the time of the enumeration.

Section IV.—***"Individual or partnership"*** enterprises are those belonging to individual farmers or groups of farmers associated without formal organization. ***"Cooperative"*** enterprises are controlled by the water users combined in some organized form of cooperation under State laws, the most common form being the stock company, the stock of which is owned by the water users.

(OVER)

c11—10120

THIS SPACE FOR OFFICE USE ONLY	SCHEDULE NO.	SOURCE OF SUPPLY CODE	DRAINAGE BASIN CODE	CLASS CODE	DATE BEGUN CODE	WATER RIGHTS CODE
	98	1	28	1	4	6

V.—DESCRIPTION OF WORKS

CODE For office use only

12. General description of system: ....

13. Date of construction: (a) Begun 1889 (Year) (b) Finished .... (Year)
14. Diversion dams: (a) Number ...... (b) Material A-1,2
15. Storage dams: (a) Number ...... (b) Material A-3,4
10 16. Main canals: (a) Capacity (cubic feet per second) A-5
(b) Number 1 (c) Length (miles) A-6,7
17. Lateral canals (omit farm laterals): (a) Number A-8
(b) Length (miles) A-9
18. Pipe lines: (a) Size (inches) .... (b) Length (miles) A-10,11
(c) Material .... (Wood-stave, concrete, metal, etc.) A-12
19. Reservoirs: (a) Number .... (b) Capacity .... (Acre-feet) A-13,14
20. Flowing wells: (a) Number .... (b) Capacity .... (Gallons per minute) B-1,2
21. Pumped wells: (a) Number .... (b) Capacity .... (Gallons per minute) B-3,4
22. Pumping plants:
(a) Number B-5
(b) Kind of power .... (Wind, water, steam, electric, etc.) B-6
(c) Capacity (horsepower) B-7
(d) Kind of pumps .... (Centrifugal, rotary, reciprocating, etc.) B-8
(e) Number of pumps B-9
(f) Capacity of pumps (gallons per minute) B-10
(g) Average lift (feet) B-11

VI.—LANDS

23. Number of farms supplied with water by this enterprise in 1929 .... Number 4 B-12
24. Total irrigable acreage the project will cover when completed .... Acres 25 C-1 E-6
25. Area to which existing canals are capable of supplying water in 1930 .... Acres 1 25 C-2,3
26. Area actually irrigated in 1929 .... (Actual area irrigated, not area for which water was available nor total holdings of persons entitled to water) Acres 0 25 C-4,5
27. Lands available for settlement covered or to be covered by this enterprise .... Acres C-6
28. Average cost of preparing land for irrigation (per acre) .... (Include clearing and grading land and building farm laterals and farm irrigation structures) $ .... (Omit cents) C-7

VII.—CAPITAL INVESTED IN ENTERPRISE

29. Irrigation works and equipment .... $ 100 est (Omit cents) D-1
30. If works are not completed, estimate additional investment required for completion .... $ .... (Omit cents) D-2
31. Water rights .... $ .... (Omit cents) D-3

VIII.—MAINTENANCE AND OPERATION

32. Cost of maintenance and operation in 1929 (If work was done by owner or operator, estimate cost of labor and material) .... $ .... (Omit cents) D-4

IX.—DRAINAGE OF IRRIGATED LANDS

33. Area for which drains have been installed .... Acres E-1
34. Additional area in need of drainage:
(a) Total .... Acres E-2
(b) Wholly unproductive .... Acres E-3
(c) Available for pasture only .... Acres E-4
(d) Producing partial crop .... Acres E-5

EXPLANATIONS AND INSTRUCTIONS—Continued

Section V.—Under "General description" give the character of the water supply; the type of diverting, conveying, storing, or water-lifting works, and their relation to each other. Report also any important items of equipment not called for specifically in the list.

A *main canal* is any irrigating channel conveying water from the source of supply to the tract of land to be irrigated. A *lateral canal* is a branch of a main canal conveying water from a main canal to one or more farms. *Farm laterals*, which distribute the water within the boundaries of the individual farm, should not be reported.

If pipe lines of more than one size are used, the length of pipe of each size should be given, by writing between the lines on the schedule, or on an extra sheet.

If the capacity of a reservoir is not known, it should be estimated by multiplying the area of the water surface when reservoir is full, expressed in acres, by the average depth above the level of the bottom of the outlet, expressed in feet.

If capacities of either flowing or pumped wells are not known, get the best estimates possible. In the case of pumped wells, where capacities are not known and have not been determined beyond the capacities of the pumps used, the capacities of the pumps should be given as the capacities of the wells.

Under "Kind of power" state whether pumps are run by wind, water, steam, electricity, or internal-combustion engines. If electric power is obtained from a power company, report electricity, regardless of how the power is developed. If windmills are used, under "Capacity" give diameters of wheels rather than horsepower.

Under "Kind of pumps" state whether pumps are centrifugal, rotary, plunger, or other kind. If some unusual type of pump or other water-lifting device is used, describe it briefly under "Description of works," or on a separate sheet to be attached to the schedule.

Under "Average lift" give the average vertical distance between the level of the water in the source of supply when the pumps are running and the point to which the water is lifted. Do not consider friction and velocity heads or horizontal distances.

Section VI.—Under "Total irrigable acreage the project will cover when completed," only the acreage to which it is definitely planned to supply water should be reported. Possible extensions not yet definitely planned should not be included.

The answer to Question 25 should include all land to which the enterprise is ready and able to supply water, whether land is farmed or not.

The "Area actually irrigated in 1929" should be limited to land to which water was actually applied during that season. It should not include land which is under canals and sometimes irrigated, but which was not watered in 1929, nor land not yet irrigated on farms that are in process of reclamation.

If the same land received water from more than one enterprise (as in the case of a pumping plant serving land also served by the canals of an irrigation district or other large-scale enterprise), show the total acreage served by the enterprise to which the remainder of this report applies, but *show the extent of the duplication on the blank lines following Question 28 and give the name of the larger enterprise.* If the enterprise supplied water to other enterprises, and not directly to land, so that reporting the acreage here would cause duplication, state the facts on the blank lines, give the names of the enterprises supplied, but do not report the acreage here.

The answer to Question 27 should be limited to land for which water is available or is to be made available, and which is not yet settled. Land already settled should not be included even if it is for sale, unless the holdings are to be subdivided, when only the parts of such holdings that are to be sold for new farms should be reported as available for settlement. If the management of an enterprise is itself farming land pending its settlement, the land should be reported as available for settlement.

The answer to Question 28 should be the best estimate obtainable from the officials of the enterprise being reported or from farmers operating under the enterprise.

Section VII.—In answering Question 29, include the original cost of the irrigation works plus the cost of extensions and improvements; also the cost of equipment, buildings, and land used for maintenance and operation, but not water rights. If works are not completed, give investment to December 31, 1929. If there are no records of cost, or if the owners have done all or part of the construction, the best estimate of cost obtainable should be reported, including the estimated value of the work done by the owners. If drainage works have been built, do not include their cost in the answer to Question 28.

Under "Water rights" include filing and legal fees paid by the enterprise in acquiring them; and if they were purchased by the enterprise give the purchase price.

Section VIII.—In answering Question 32, report only the cost of maintenance, operation, and ordinary cleaning and repairs.

Section IX.—This section relates only to lands which have been irrigated or are to be irrigated by this enterprise. The "Additional area in need of drainage" and the distribution of this area under the subordinate inquiries will necessarily be estimated. Enumerators should make the best estimates possible, based on information furnished by the officials of the enterprise and by others in the community, and on their own observations, but they should not attempt to make extended observations.

The sum of the answers to Questions 34(b) to 34(d) must be the answer to Question 34(a).

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PRISM

PRISM Climate Group, Oregon State University 2014, http://prism.oregonstate.edu, created 11 Oct 2014

Census

Haines, Michael R. 2010. Historical, demographic, economic, and social data: The United States, 1790-2002. Ann Arbor, MI: Inter-University Consortium for Political and Social Research. http://doi.org/10.3886/ICPSR02896.v3

Census (additional)

Priority

Dos Rios Consultants, Inc. 1996, available: http://bloodhound.tripod.com/ACEQFINL.htm [2012, 5/17].

Colorado Division of Water Resources. 2012. "District 24 Call Sheet." Copy obtained during site visit, June 2012.

2. Variables

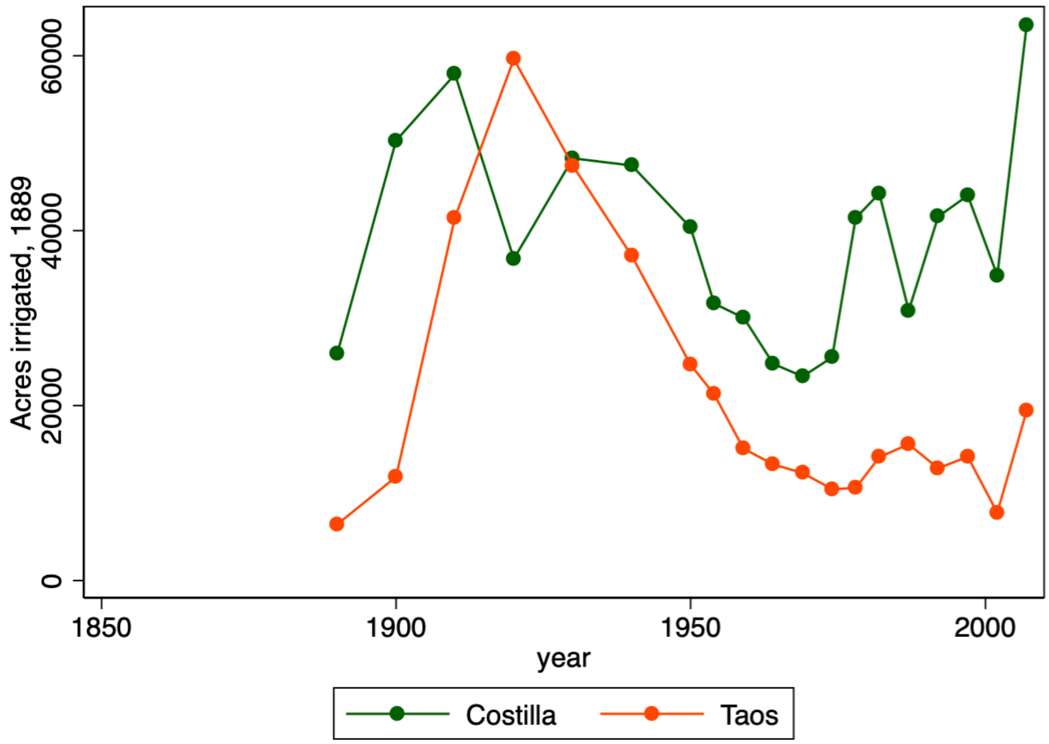
Irrigation Organization

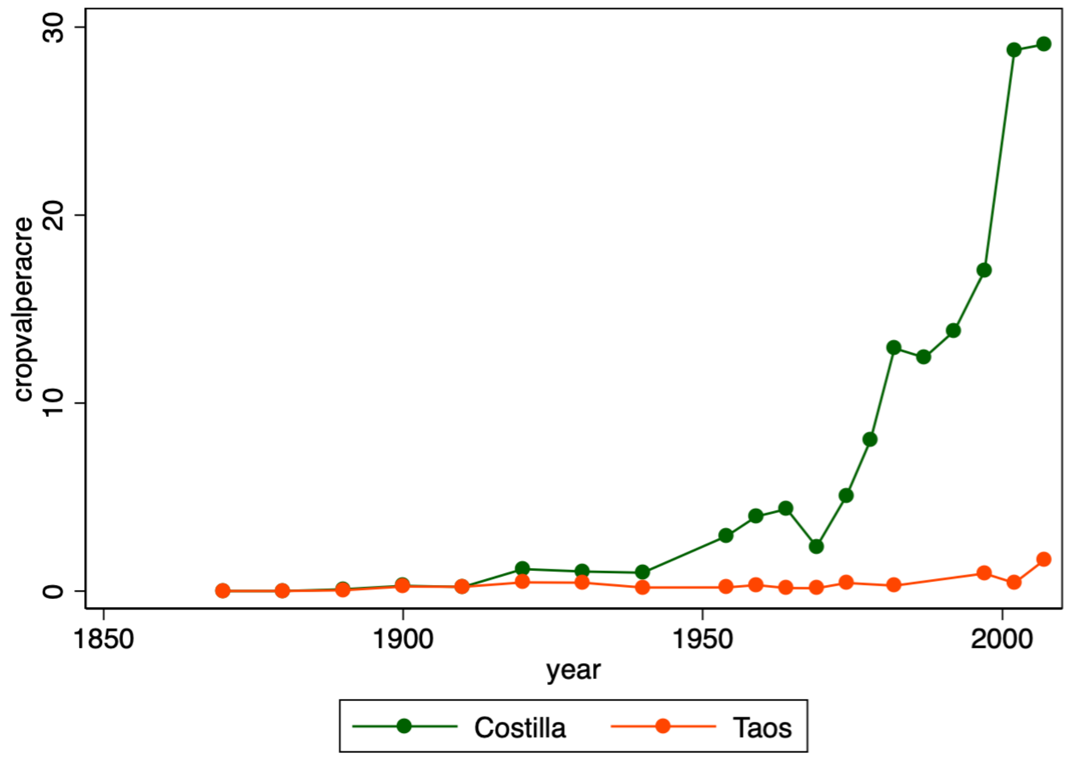
Investment: Question XXXX:

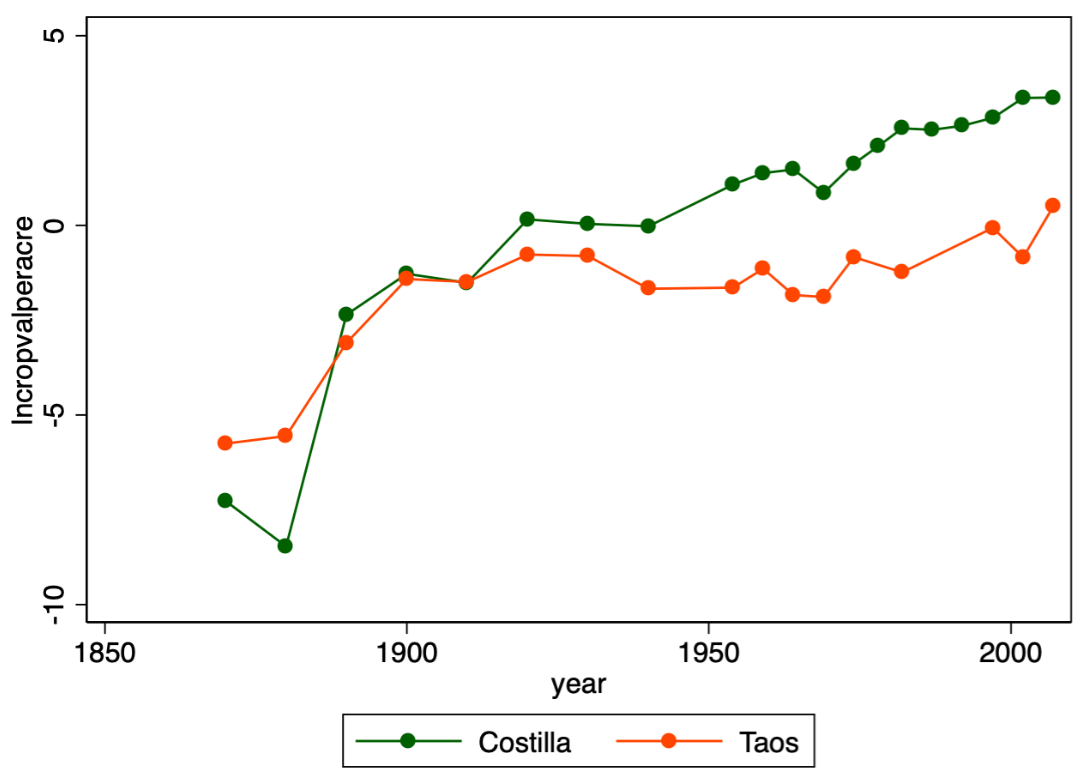
NDVI analysis

Appendix C: Additional Tables and Figures

Under construction.




30
20
10
0
cropvalperacre
1850
1900
1950
2000
year
Costilla
Taos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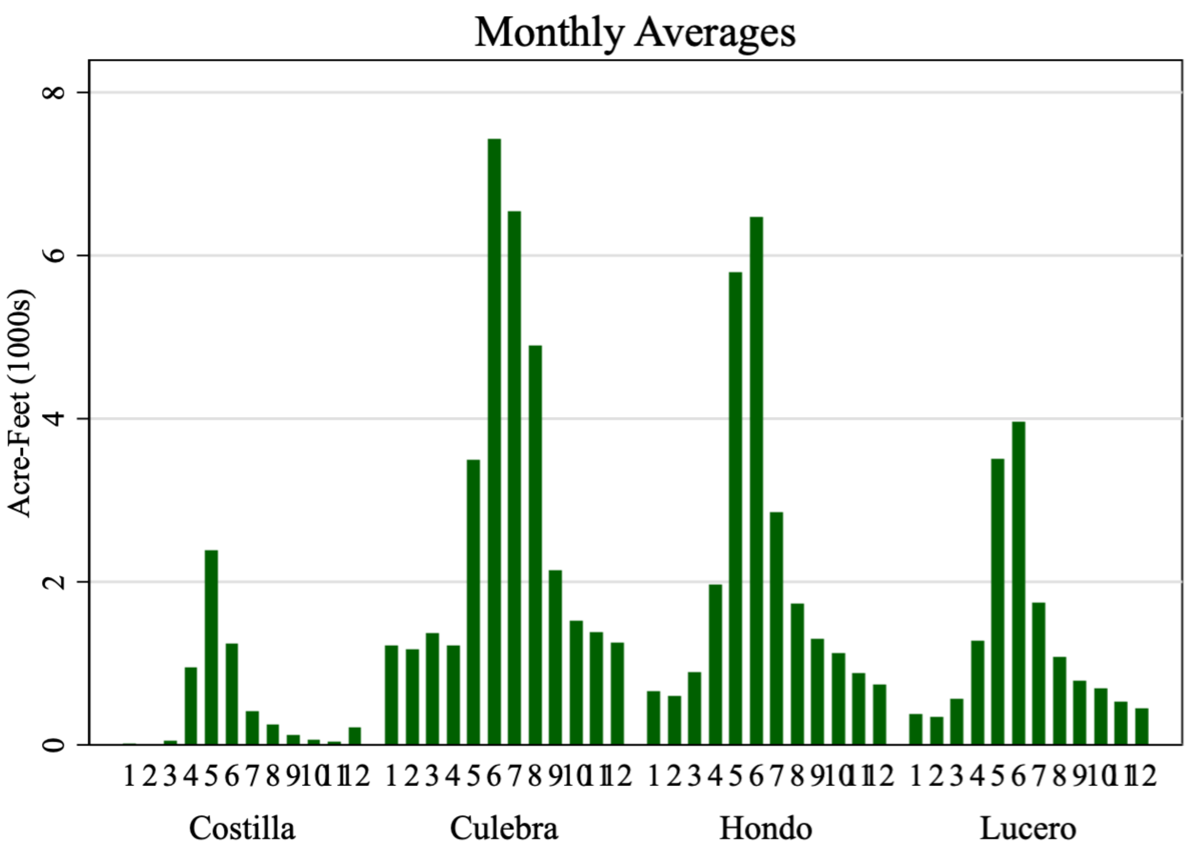
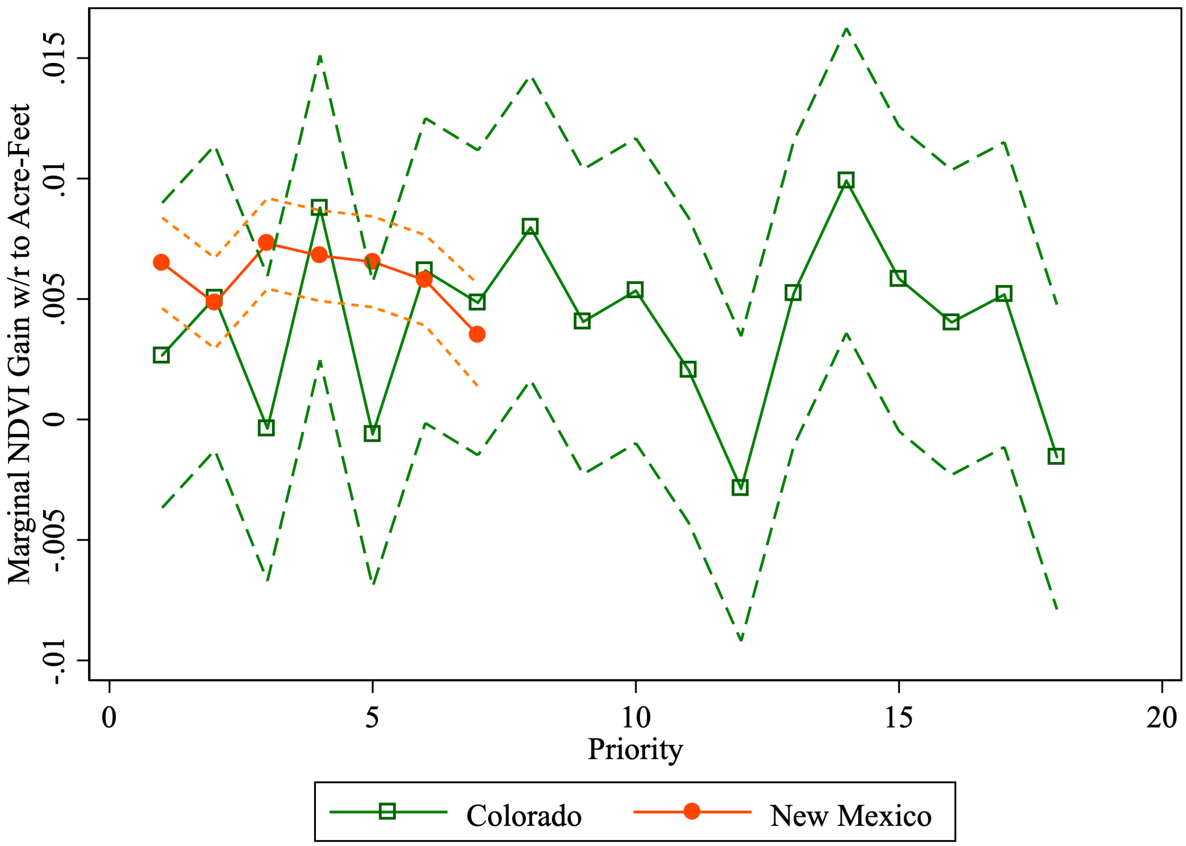
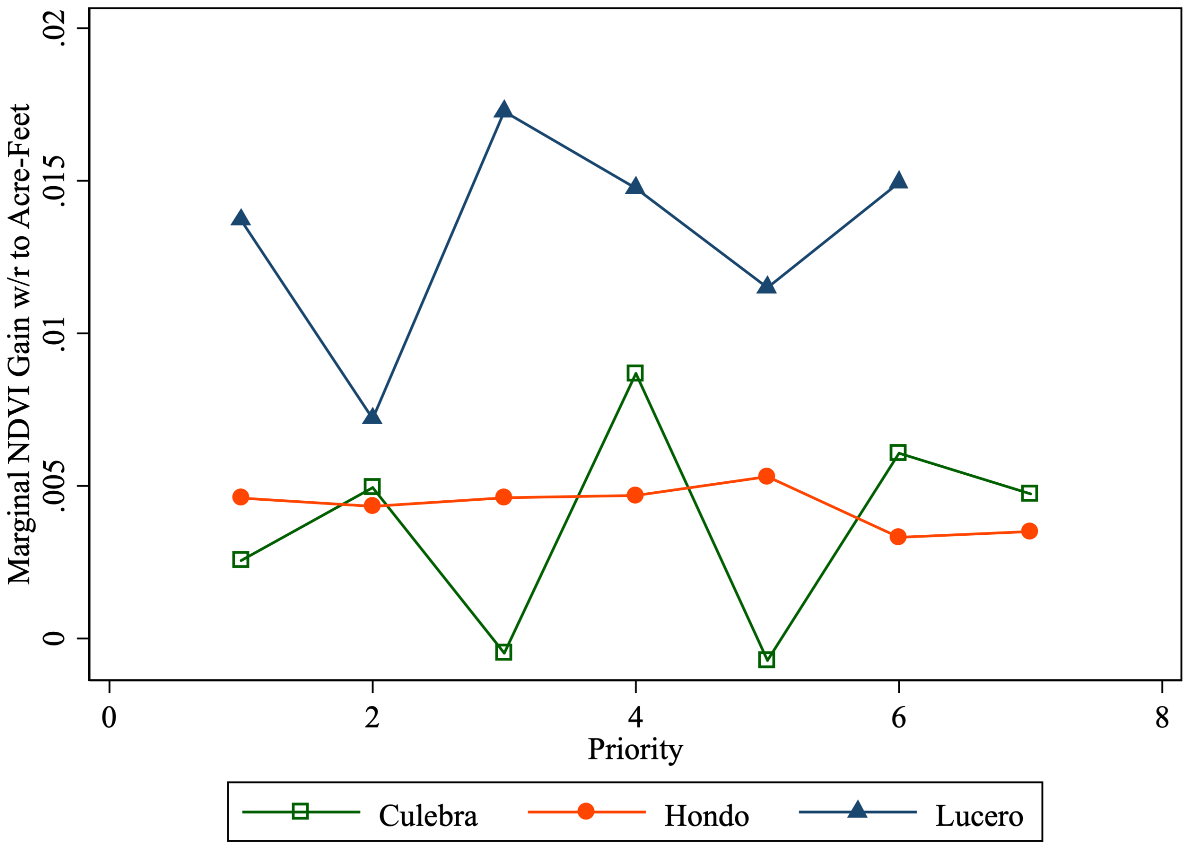
0
-5
-10
lncropvalperacre
1850
1900
1950
2000
year
Costilla
Taos



Monthly Averages
Acre-Feet (1000s)
0
2
4
6
8
1 2 3 4 5 6 7 8 9 10 11 12
Costilla
Culebra
Hondo
Lucero


Marginal NDVI Gain w/r to Acre-Feet
-.01
-.005
0
.005
.01
.015
0
5
10
15
20
Priority
Colorado
New Mexico


Marginal NDVI Gain w/r to Acre-Feet
0
.005
.01
.015
.02
0
2
4
6
8
Priority
Culebra
Hondo
Lucero

Stream Level NDVI Specification Robustness

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	NDVI	NDVI	NDVI	NDVI	NDVI	NDVI
Panel A: Culebra						
Acre Feet (1000s)	0.00317	0.00320	0.00298	0.00442	0.00441	0.0707**
	(0.00330)	(0.00324)	(0.00335)	(0.00297)	(0.00305)	(0.0275)
Acre Feet Squared						-0.00130**
						(0.000528)
Lagged Acre Feet			0.000540	0.00247	0.00243	0.0146
			(0.00405)	(0.00309)	(0.00321)	(0.0281)
Lagged Acre Feet Squared						-0.000228
						(0.000538)
Year Trend		1.94e-05	0.000134	-0.000141	-0.000147	-0.000424
		(0.00130)	(0.00143)	(0.00138)	(0.00142)	(0.00126)
Lagged NDVI					0.0167	
					(0.171)	
Observations	28	28	28	27	27	28
R-squared	0.060	0.060	0.061	0.306	0.307	0.338
Panel B: Costilla						
Acre Feet (1000s)	0.00190	0.00250*	0.00265*	0.00299**	0.00300**	0.0148***
	(0.00146)	(0.00131)	(0.00138)	(0.00137)	(0.00140)	(0.00484)
Acre Feet Squared						-0.000753**
						(0.000286)
Lagged Acre Feet			-0.000920	0.000877	0.000863	0.00883**
			(0.00168)	(0.00148)	(0.00158)	(0.00336)
Lagged Acre Feet Squared						-0.000463***
						(0.000127)
Year Trend		0.00113	0.000832	0.000695	0.000685	-0.00108
		(0.00115)	(0.00111)	(0.00108)	(0.00117)	(0.00107)
Lagged NDVI					0.00618	
					(0.213)	
Observations	28	28	28	27	27	28
R-squared	0.045	0.076	0.088	0.121	0.121	0.394
Panel C: Hondo						
Acre Feet (1000s)	0.00532***	0.00444***	0.00443***	0.00437***	0.00439***	0.0132***
	(0.00104)	(0.000901)	(0.000924)	(0.000943)	(0.000959)	(0.00336)
Acre Feet Squared						-0.000197**
						(7.32e-05)
Lagged Acre Feet			0.000206	0.000411	0.000692	0.000443
			(0.000748)	(0.000743)	(0.00114)	(0.00233)
Lagged Acre Feet Squared						1.05e-05
						(5.27e-05)
Year Trend		-0.00337***	-0.00330***	-0.00364***	-0.00385***	-0.00272***
		(0.000945)	(0.00101)	(0.000988)	(0.000878)	(0.000977)
Lagged NDVI					-0.0630	
					(0.136)	
Observations	28	28	28	27	27	28
R-squared	0.554	0.703	0.704	0.722	0.723	0.781
Panel D: Lucero						
Acre Feet (1000s)	0.0153***	0.0140***	0.0140***	0.0139***	0.0136***	0.0442***
	(0.00204)	(0.00219)	(0.00221)	(0.00219)	(0.00229)	(0.00396)
Acre Feet Squared						-0.00121***
						(0.000166)
Lagged Acre Feet			-0.000516	-0.000661	-0.00306	0.00924
			(0.00235)	(0.00240)	(0.00234)	(0.00767)
Lagged Acre Feet Squared						-0.000221
						(0.000238)
Year Trend		-0.00220*	-0.00234	-0.00221	-0.00195	-0.00112
		(0.00120)	(0.00144)	(0.00148)	(0.00156)	(0.00115)
Lagged NDVI					0.173	
					(0.183)	
Observations	28	28	28	27	27	28
R-squared	0.709	0.740	0.741	0.732	0.740	0.877

Note: Average NDVI is the dependent variable. Acre Feet is the total volume of water on the stream from April to October. Column (3) is the main specification from the text. Column (4) repeats this specification but without 1984. Robust standard errors in parentheses

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

Acequia Level Regressions

VARIABLES	(1) Acres	(2) Acres	(3) Acres	(4) Acres
Priority	-398.7**	-109.7***	-79.93	-105.8*
	(119.3)	(27.05)	(122.2)	(52.20)
Priority x Colorado				-292.9**
				(124.8)
Colorado				2,031***
				(681.0)
Constant	2,940***	826.0***	932.9*	908.8***
	(682.7)	(124.5)	(458.5)	(207.6)
Observations	7	7	6	20
R-squared	0.543	0.589	0.120	0.621
Stream	Culebra	Hondo	Lucero	All

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

Acequia Level NDVI and Priority

	(1)	(2)	(3)	(4)
VARIABLES	NDVI	NDVI	NDVI	NDVI
Acre Feet x *Order* :				
First	0.00256	0.00460***	0.0137***	0.00649***
	(0.00340)	(0.000899)	(0.00184)	(0.00105)
Second	0.00495	0.00433***	0.00720***	0.00483***
	(0.00340)	(0.000899)	(0.00184)	(0.00105)
Third	-0.000478	0.00461***	0.0173***	0.00730***
	(0.00340)	(0.000899)	(0.00184)	(0.00105)
Fourth	0.00869**	0.00469***	0.0148***	0.00680***
	(0.00340)	(0.000899)	(0.00184)	(0.00105)
Fifth	-0.000717	0.00531***	0.0115***	0.00654***
	(0.00340)	(0.000899)	(0.00184)	(0.00105)
Sixth	0.00607*	0.00332***	0.0149***	0.00577***
	(0.00340)	(0.000899)	(0.00184)	(0.00105)
Seventh	0.00474	0.00351***		0.00350***
	(0.00340)	(0.000899)		(0.00119)
Colorado x Acre Feet x *Order* :				
First				-0.00394
				(0.00315)
Second				0.000121
				(0.00315)
Third				-0.00778**
				(0.00315)
Fourth				0.00189
				(0.00315)
Fifth				-0.00726**
				(0.00315)
Sixth				0.000300
				(0.00315)
Seventh				0.00124
				(0.00319)
Observations	196	196	168	560
R-squared	0.079	0.603	0.724	0.419
Number of id	7	7	6	20
Stream	Culebra	Hondo	Lucero	All

Robust Standard errors in parentheses

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