DISCUSSION PAPERS IN ECONOMICS

Working Paper No. 13-10

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

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November 2013

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Abstract:

Successful management of common property resources requires cooperation among the users to provide public goods and appropriate the resource fairly and sustainably. Population stability and a relatively low number of users have been identified as important factors to maintaining positive outcomes by increasing trust and decreasing transaction costs. However, empirical work has neither addressed these issues in a dynamic nature utilizing longitudinal data, nor addressed the endogeneity of the user group. Therefore, through econometric analysis I identify the impact of the introduction of new users in a common property management system, distinguishing the impact of being new from that of being additional. Combining satellite imagery and water right transfer records, I build a unique panel data set of 50 communal irrigation systems (*acequias*) in Taos Valley, New Mexico with annual observations from 1984-2011. With these data I am able identify the role of repeated interactions and diagnose the extent of omitted variable bias through comparing various econometric specifications. The 400 year old *acequias* are robust to the introduction of new users but average production decreases with additional users. More notably, there is a positive bias present in cross-sectional treatment for both new and additional users—implying extant cross-sectional analysis underestimates the negative impact of additional users because entrants are attracted to systems that perform better. In regards to the non-negative effect of new users, the result is corroborated through follow up surveys of 17 *acequias*, indicating institutional rules have been substituted for trust.

Keywords: irrigation, repeated interaction, omitted variable bias, *acequias*

JEL: Q15, Q25

Acknowledgments: Support for my own efforts to gather water right transfers from the Office of the State Engineer in Santa Fe, New Mexico was provided by the University of Colorado Department of Economics. Collection of survey data was a funded as part of NSF Grant BCS-0527165 and aided immensely by the Taos Valley Acequia Association. I am in debt to Michael E. Cox for generously sharing the data he toiled to gather in Taos. Financial support was also provided by the Graduate School at the University of Colorado for the completion of analysis and writing. I must think Lee J. Alston, Krister Andersson, Michael E. Cox, Dustin Frye, Edward Kosack, and Zach Ward for their insightful comments. All remaining errors are of course my own.

1 Introduction

Sustainable management of common property resources (CPRs) requires continual cooperation. Once considered unattainable—the "tragedy of the commons" (Hardin 1969)—due to the disparity between individual incentives and group incentives (Gordon 1954), many advocated the need for private or state rights to address the externalities.[1] Other researchers, inspiring and inspired by Ostrom (1990), illustrated a number of exceptions. In successful cases the users in common utilize some combination of rules, trust, monitoring, and sanctioning to cooperate in managing and sharing CPRs. Several factors have been identified to alter the odds of successful collective action (Baland & Platteau 1996; Ostrom 1990), but are often implicitly treated as exogenous, particularly in empirical analysis due to data limitations. Specifically, user group characteristics are assumed fixed when they are at least partially determined endogenously and subject to disturbances. More valuable systems often attract new entrants (Alston et al. 2012). Extant CPR analysis fails to account for the dynamic nature of the user group, suffers from omitted variable bias, and provides little identification of the role of repeated interactions in building trust.

Whether a user group undergoing turnover, replacing old users with new, can maintain high levels of success in managing the CPR remains largely unanswered. Stability of the population has been given credit in long-lived common arrangements (Ostrom 1990) while new entrants attracted by economic opportunity have been blamed for breaking down CPR management regimes (Libecap 1995). The mechanism—a break down in trust, increased transaction costs, or additional strain on the resource—is not clear nor whether new entrants inevitably perturb the cooperative equilibrium. Because there is a movement towards prescribing policies in environmental management such as decentralization (Agrawal & Ostrom 2001), it becomes more important to understand how a well-established common property management system responds to the introduction of new users—distinguishing the impact of being new from that of being additional.

Often the difference between being new and being additional is overlooked; an additional user is inevitably new, but a transfer of access rights can introduce a new user without increasing the

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

number of users. The new user introduces a number of unknowns into a system dependent partially on trust while the additional user drives up transaction costs—costs of negotiating, monitoring and enforcing agreements (Coase 1960; Williamson 1979)—and often increases demand of the resource. The role of trust has been explored empirically with measures of homogeneity serving as proxies. While legitimate and important, those measures do not account for the role of inter-personal trust built up overtime often important in theoretical settings.

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

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

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

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

2. Background

2.1 Social-Ecological Systems

CPRs are well viewed through the larger framework of a social-ecological system or coupled human and natural systems. The hybrid systems combine natural elements, e.g. biodiversity, biomass, hydrology, soil, and wildlife with humanly devised elements, e.g. governance systems, harvesting, manipulation, relative prices, user group, and culture. A number of frameworks exist, each identifying a number of important components. For instance, a commonly utilized version put forth by Ostrom (2009) includes four core components—the resource units, resource system, governance structure, and the user group—each with ten or so second-level factors. For illustration, Ostrom's user group second-level factors are reproduced in Figure 1. The framework is not limited to CPRs, as the governance structure and property rights can vary. The resource units are most plausibly exogenous, as this serves to distinguish from forests, fisheries, oil, water and other resources. My study focuses on water, specifically snowmelt irrigation systems with no storage.

Agrawal (2003) summarizes facilitating conditions of successful CPRs from a variety of researchers. Of primary concern here is that of the user group. User group characteristics making success more likely includes small size, defined social boundaries, shared norms, past success (social capital), appropriate leadership, interdependence, and homogeneity of resources, interests and views. Even when a new entrant simply replaces a prior user, maintaining the group size, socio-economic composition, shared norms, and reliance on the resource may all change. Furthermore, there is a decidedly lack of history now between the new user and remaining users, decreasing so-called social capital. When the new user is an additional user as well, the group size will increase as well.

2.2 New Users and Game Theory

Like other situations where private outcomes are contingent on private decisions and strategies of others, game theory provides useful theoretical roots for the likelihood of cooperation. Though oversimplified, the tragedy of the commons is often given a prisoner's dilemma treatment.[2] In the simplest setting, two users must decide between cooperation and non-cooperation. The payoff structure takes a form like that given in Figure 2. While the social optimum is for both to cooperate, this strategy is strictly dominated by defection for both, producing the Nash equilibrium of non-cooperative behavior.

From a rational, theoretical standpoint, only once the game is repeated infinitely (or finitely with sufficient probability of another round) do cooperative outcomes become rational. Unfortunately, the application of the Folk Theorem is limited as it not only supports the always cooperate strategy as an equilibrium, but many other equilibria as well without offering information on which result is more likely. That aside, the important point is that the repeated interaction permits strategies to be history dependent, allowing for the use of punishment (sanctions) but also the accumulation of trust, norms, and reciprocity, yielding a path dependent possibility of sustained cooperation (Seabright 1997).

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

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

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

2.3 New Users and Trust

The failure of economic agents to behave rationally in one-shot games and other scenarios has led to efforts to create richer behavioral models for rational choice guided by information constraints and various motivations other than personal income maximization. Early on, Olson (1965) suggested that groups of users likely weigh the economic gains with the social costs of defecting. Ostrom (1998) provides a causal model of how user group characteristics interact with an internal positive feedback loop of trust, reciprocity, reputation and cooperation (recreated in Figure 3). This model relaxes the need for perfectly rational agents and allows for behavior based on personal interactions. New users will reduce the overall knowledge of past actions within the system; the lack of information is hypothesized to reduce trust levels and reputation. The implied outcome is a downward spiral due to the initial breakdown in trust. While helpful in illustrating the role of trust, the model lacks the intervention of endogenous institutions and rules.

Trust, prevalent in much of the literature, is often replaced by "social capital" when identifying factors related to successful management. While social capital and trust are similar, I find the concept of trust to be more appropriate. Both of which have been linked to one another and social networks and repeated interactions (Bordieu 1986; Grafton 2005; Paldam 2000). Often economists use social capital as the wording parallels other common forms of capital (human, physical, and natural), but Sobel (2002) highlights a number of economists critical on its use suggesting that social capital does not require costly investment and often appreciates with use. Social capital's lack of a firm definition provides no broadly accepted method of measuring it. Instead, often research falls into a circuitous argument in which social capital is assumed present where positive outcomes occur, resulting in positive outcomes (Portes & Landolt 2000; Sobel 2002).

Thus, while trust does not appear directly in either Ostrom's SES framework or Agrawal's synthesis of facilitating conditions, it is the more appropriate concept, particularly when the initial collective action has taken place the issue is continued cooperation. Sobel (2002) defines trust as the willingness to permit the decisions of other to impact your welfare. This can be applied broadly to general levels of trust in others, though the application here is special trust; trust specific to social networks and specific individuals (Paldam 2000). Paldam goes on to indicate that trust can be used in production in order reduce transaction costs. In this fashion, rules and sanctions can serve as a substitute to the use of trust and reduce its role in outcomes. On net, new users will reduce the extent of trust within the system, but institutional rules could mitigate the impact, making attention to the governance structure important.

2.4 Experiments and Trust

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

2.5 Additional Users

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

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

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

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

2.6 Heterogeneity

While not the focus of my research question, heterogeneity of the users has received much attention from the literature as well (Baland & Platteau 1996; Bardhan & Dayton-Johnson 2002;

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

2.7 Empirical Work

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

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

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

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

2.8 Omitted Variable Bias

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

For example, if success of an irrigation system varies based on the number of users and its position on the stream, failing to measure and include the position could yield biased estimates of the impact of the users if position on the stream also influences the size of the user group directly or indirectly. The direction of the bias depends on both the true coefficient of the omitted variable and the covariance with the omitted variable and the variable of interest. If upstream systems are more productive due to their ability to divert water first but are more populated because easy access to the mountains is desirable, the estimation (when omitting position) would yield a positive bias, understating the negative effect of additional users.[3] While an illustrative

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

example, stream position is readily observable and included in the analysis below. One could consider soil quality, water quality, or slope as the omitted variable.

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

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

3 Empirical Study Setting

To produce a panel data set on CPR systems, I utilize data on a number of irrigation ditches in Taos Valley of north central New Mexico, USA, highlighted in Figure 4. Farmers in this area rely on common property irrigation ditches rooted in Spanish tradition called *acequias*. The ditches are simple unlined, earthen ditches whose flows are subject to supply, gravity, and simple

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

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

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

Estimating the incorrect model introduces the following bias:

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

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

head gates. The water comes from the snowpack in the Sangre de Cristo Mountains to the east as the water drains to the Rio Grande. With only 33 cm (13 inches) of annual rainfall on the high valley floor, the fertile soil would produce very little without supplemental irrigation water.

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

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

The water itself is no longer common property as it was under Spanish and Mexican law when the *acequias* were established. The doctrine of prior appropriation prevalent in the arid regions of the United States requires communities to allocate individuals with private water rights.[4] Due to the requirement to apply the water to beneficial use, the courts determined that *acequias* could not own the water rights because it is the individual who uses the water (*Snow v. Abalos* (1914)

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

140 P. 1044, 18 N.M. 681). In Taos Valley, the adjudication process, commonly referred to as the Abeyta case, began in 1969 and is not yet settled officially after 43 years.[5] The private rights are notably limited. Right of management is shared by the community with the *acequia* capable of denying conveyance of the water to the right holder. Transfer of water right outside of the *acequia* requires approval by the community.[6] More general transfers, accompanying the irrigated land, are not subject to communal approval.

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

Within an *acequia* water is commonly divided by time, providing one or two *parcientes* the full flow of water for some period. For some *acequias* this is done on a fixed schedule, while others use a first-come, first-serve schedule. In either case, those that are not using their "private" water right allow others to utilize that water and any surplus or scarcity is spread equally through the rotation. The rotation-system, often administered moving downstream, lowers the cost of monitoring and enforcement through easy self-monitoring; if an irrigator does not receive water at their allotted time, it is easy to detect and subsequently walk upstream to the adjacent irrigator, the likely culprit (Trawick 2001). Notably, the proximity of the irrigators implies other interactions with one another, reducing incentives to disregard the rules at your neighbors' expense. The internal rotation is subject to the control of the *mayordomo*, an elected position charged with both the design, implementation, and monitoring of water division within the *acequia.* The position also provides the interface to other *acequias* to implement and enforce sharing agreements.

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

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

Across *acequias*, sharing water from the stream may be more contentious, but many have agreed to and practiced a proportional division of the water for decades (known as *repartimiento*). The Abetya settlement has resulted in irrigators formally agreeing to forego the priority system and maintain their historic sharing agreements across *acequias* on a stream (Richards 2008).[7] [8] In advocating for the need of legal recognition of *repartimiento,* Rivera (1998) notes that commissioners feared turnover, stating "If land or water rights were to be sold anytime in the near future, they feared new owners might not continue the custom on their own, imperiling communities with junior rights" (p. 169).

On net, while water is *de jure* private, it remains *de facto* common property, with shortfalls shared in times of drought and surpluses shared in wet years. No user interviewed in Rodríguez (2006) recalls anyone exercising their private right. Instead, most users explain the system as built on need and cooperation; that when water is scarce, they all sacrifice to make sure everyone receives a portion of the scarce water.

In recent history, the *acequia* users have been changing while the institution and technology used remain largely unchanged, making Taos ideal to study the effect of new users on CPRs. Around 40 percent of the irrigated land in *acequias* has been sold since 1969, both on average and in total. From 1984-2011, 2.2 percent of the users in an *acequia* are new each year (the median is zero while the average disturbance when there is turnover is 4.5 percent). Many of the transfers also divide irrigated land into smaller segments, introducing additional users as well. The variation in turnover across time and location allows me to identify the impact of new and additional users on cooperation and production. Importantly, the technology employed remains rather stable with recent survey data confirming ditches remain unlined and all irrigators still utilize flood techniques to irrigate, foregoing more modern sprinklers and drip systems.

The setting also provides an advantage by not confounding resource scarcity with the addition of new users. With irrigated lands determined and limited by state law, additional users do not expand the demand of the resource, as total irrigated land remains constant. With this, the

[7] The Treaty of Guadalupe Hidalgo provided the protection of all property rights including water rights pre-dating United States Annexation, providing legal standing to be free of the priority system. Additionally, the determination of dates has proved difficult without adequate historical records.
[8] The exception is for Rio Grande Compact requirements. If the Taos area is being curtailed, the priority system will determine the order in which the *acequias* are curtailed.

impact of additional users is mediated through user interactions and not increased strain on the resource aside from any scale effects which are explicitly controlled in the analysis. Additionally, the reliance on snowmelt removes the complication of misaligned conservation incentives, as the supply of water is stochastic and beyond the control of the users. These dynamics contrast other situations such as fisheries, e.g. the Sri Lankan fishery case in Ostrom (1990, p. 149-157) in which additional users caused the system to collapse. In that instance, new users put more demand on the resource while struggling to divide the resource both across users and across time periods.

4 Data and Methods

4.1 Data

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

4.2 Satellite data

Communal irrigation systems require solving issues of provision for infrastructure and division of water. In the Taos setting, use of surface water without storage facilities limits water allocation issues to spatial dimensions with little temporal concern for conservation (confirmed below).[9] With no direct measure, I utilize satellite data which captures the extent of healthy vegetation as a proxy that captures both issues of division and maintenance shortcomings that result in reduced water availability in the arid setting.

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

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

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

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

Use of NDVI as a source of overtime data on land usage is no longer uncommon (Nagendra et al. 2005; Ostrom & Nagendra 2006; Honey-Roses et al. 2011). It is somewhat unique to utilize it as an indicator of water usage (see Cox & Ross 2011 for an example). Visuals of the data are provided in Figure 5 and Figure 6 where higher NDVI values correspond with lighter pixels. Figure 5 includes a view of the entire study area, contrasting a normal year (1999) with a drought year (2002). Figure 6 provides greater detail, contrasting NDVI values with a corresponding aerial photo. The higher values are clearly correlated with the irrigated agriculture. Like Cox & Ross, I utilize this biophysical outcome to measure the performance of the *acequias*. Given the arid locale in which water is often the limiting factor for agriculture, it indicates the level of success in delivering the water. In addition, while NDVI is a biophysical measure, given the simple irrigation technology, water delivery remains reliant on successful collective action and the measure can be reasonably expected to be correlated to the social outcome of cooperation (Cox 2010). The measure has a number of favorable features for this research. First, it is objective. In most studies, cooperation or outcomes are measured by a survey question posed to a sample of users, introducing subjectivity (Bardhan 2000; Dayton-Johnson 2000; Ruttan 2006; Varughese & Ostrom 2001). Second, the satellite imagery is available retroactively; therefore it is unique in that I can create panel data dating back a number of years despite lacking surveys from that time period or relying on user recall.

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

The original NDVI data comes from the Landsat Satellite, publicly available back to 1984. Collection and calculation of these values are due in large part to Michael Cox (2010) generously sharing the data from his dissertation which also explored dynamics of irrigation in Taos Valley. Each year an image of the region is selected and overlaid with GIS data regarding which land is irrigated from each *acequia*. In all cases, the image selected comes from within the growing season with image dates spanning from June 9th to July 28th. The variation in timing is due in part by the timing of the orbit and in part by the need of cloudless images. The satellite images are calibrated and analyzed to calculate NDVI for each pixel. Once the 30x30 meter pixels are assigned to the appropriate *acequia*, a spatial average of NDVI is calculated for each *acequia* every year.

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

In order to substantiate the dependence of NDVI on irrigation water, a brief valley-wide treatment is provided here. Figure 7 plots the annual average flow of water with the annual average NDVI value across *acequias*.   The stream flow, in cubic feet per second, is the sum of the annual average of four streams in the region—the Rio Hondo, Rio Lucero, Rio Pueblo de Taos, and Rio Grande del Rancho—all monitored by USGS stream gages.[10] *Acequias* themselves do not measure intake, limiting the use of stream flow data. Regardless, the correlation of stream flow and NDVI is apparent in Figure 7. In Table 1 I provide the results from a simple regression of NDVI on the average annual flow of the streams including a lagged term for the flow with standard errors clustered by both year and *acequia* (Cameron et al. 2011). The first column uses the additive measure of annual flow for the entire region. The second column uses the stream specific measures, limiting the analysis to only *acequias* from the four streams. In either case, there is a strong positive relationship with water availability in the concurrent year, but no statistical relationship to the prior year's flow. Using the total regional average, another CFS of flow increases NDVI by 0.0576 while the specific stream measure yields a stronger relationship of 0.296. The results serve to demonstrate the need for water to produce healthy vegetation in the region and to validate the discount of temporal conservation concerns.

4.3 Water right transfers

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

In order to create a panel, I combine these records with water right transfers that are filed at the New Mexico Office of the State Engineer (OSE). The OSE records: 1) which irrigated parcel

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

was transferred; 2) the acreage; 3) when it was transferred; and 4) the grantees and the grantors, as well as the amount of water rights which accompanies the land—a constant, technically determined 2.5 Acre-Feet/Acre in the Taos region. These records are not digitized in any form, requiring manual input from the physical copies maintained at the OSE in Santa Fe, NM. A total of 3638 transfers were recorded over the course of two weeks. These data, when combined, allow me to construct the user group in each year for each *acequia*. One should note that the documentation of the transfer is not legally necessary and the forms are filled out by the users themselves resulting in some measurement error.[11] The process and assumptions made to construct the user group are described in full in Appendix 1 while the extent of missing transfers is treated below.

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

Other time-invariant controls are utilized in some specifications, many coming from Cox & Ross (2011), including social measures—water agreements, land fragmentation, and urban presence—and some biophysical measures—hydric soil and irrigation corridor. A statistical summary of the relevant variables are reported in Table 2. The *acequias* vary greatly in size spanning 4 to nearly 400 users and covering anywhere from 7.7 to 1415.4 acres. Greater detail is provided for percent new users and number of users in Figures 8-10; illustrating the variation of entrants. Concern of the larger, more urban, *acequias* driving the results is addressed by excluding the outliers of 100 or more users seen in Figure 8.

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

Additionally, the correlation matrix of the main variables is reported in Table 3. Of note is the first column, particularly the number of users having a significant negative correlation with NDVI. Percent of users that are new also has a negative correlation with NDVI though much smaller.

Finally, I conducted hour-long surveys with commissioners from seventeen *acequias* in Taos in September 2013. The sample was selected in order to ensure geographical representation, including ditches from the various streams but was ultimately determined by the needs of a larger project.[12] Looking at observables available for all *acequias*, the survey sample is representative, though slightly further upstream and incurring more turnover. Here, the survey data serve a supportive role providing qualitative data. However, it can also be used to measure the prevalence of missing transactions and the soundness of assumptions made in determining the user group. In order to assess the extent of the issue, 2011 user counts based on my algorithm are compared to commissioner reported values in 2013 for sixteen *acequias*. One *acequia* is removed from the analysis because the commissioner simply reported the number of users the original 1969 survey.[13] Reported in Table 4, the correlation between my count and the commissioner count is 0.97 while the OLS regression coefficient suggests that for every additional user I record there are 1.18 in actuality. The results confirm that my algorithm performs well despite the presence of some measurement error, some of which due to growth occurring after 2011.

I conjecture that the unreported transfers are most likely family inheritance that are treated with less rigor than outside transactions, though this cannot be confirmed. A statistical bias will emerge if these types of transfers are systematically more prevalent in certain types of *acequias*. If not, the simple measurement error will add noise to the estimation, attenuating the results. Concerning new users, bequeaths to children likely do little to interrupt the trust and norms developed due to their upbringing within the system. Therefore the missing transfers likely have little effect on the estimates.[14]

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

[13] The survey corresponds to the outlier in Figure 9, gaining nearly 200 members.

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

4.4 Methodology

Regressions are used not only to test the impact of changing user groups, but also as a diagnostic tool to assess the presence of OVB and ultimately correct for it. To do so, three main specifications are utilized—1) pooled OLS, 2) between-effects (BE), and 3) fixed-effects (FE). Ultimately the preferred the specification is the FE. The use of OLS estimation could be a concern with the dependent variable being a normalized, bounded measure. However, the NDVI values do not approach the bounds and the distribution appears normal. The histogram is provided in Figure 11 and the kernel density estimation given in Figure 12, overlaid with a normal distribution.

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

$$\overline{NDVI}_i = \alpha_0 + \beta_1 * \overline{Users}_i + \beta_2 * \overline{New}_i + \beta_3 * \overline{Gini}_i + \beta_4 * \overline{Hisp}_i \quad (1)$$

$$+\beta_5 * \overline{AveAcres}_i + \boldsymbol{X}_i + \epsilon_i$$

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

The pooled-OLS specification takes the following form:

$$NDVI_{it} = \alpha_0 + \beta_1 * Users_{it-1} + \beta_2 * New_{it-1} + \beta_3 * Gini_{it-1} + \beta_4 * Hisp_{it-1} \quad (2)$$

$$+ \beta_5 * AveAcres_{it-1} + \boldsymbol{X}_i + Y_t + \epsilon_{it}$$

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

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

$$NDVI_{it} = \alpha_0 + \beta_1 * Users_{it-1} + \beta_2 * New_{it-1} + \beta_3 * Gini_{it-1} + \beta_4 * Hisp_{it-1} \qquad (3)$$

$$+ \beta_5 * AveAcres_{it-1} + A_i + Y_t + \epsilon_{it}$$

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

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

4.5 Predictions

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

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

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

5 Results

The main results are presented in Table 5. The first four columns ignore the panel structure of the data, reporting the BE (equation 1) and the pooled-OLS regression results (equation 2). Even without fixed effects or time-invariant variables, the user group characteristics explain a large portion of the variation in greenness evident by large R-squared values. Without the use of other controls, an additional user reduces NDVI by 0.024. With the controls, the impact is negligible both statistically and economically. The standard deviation of mean NDVI is 10.62, meaning an increase in one standard deviation of the number of users (81.91) explains 10 percent of the variation in production. Because NDVI measures lack a firm economical interpretation, it is useful to keep in mind that an additional CFS increases NDVI by 0.0576. Each additional user is akin to reducing 0.5 CFS of annual stream flow.[15]

Somewhat surprisingly, *acequias* with new users perform better. When 2.23 percent of the users are new, the average disturbance, NDVI increases by 0.0015-0.065 depending on the model (1.5-60 percent of the NDVI variation). Production is negatively related to economic heterogeneity, reducing by around 0.20 for every 1/100 increase of inequality on the Gini scale. Meanwhile, the more Hispanic groups perform better, increasing NDVI by 0.10 with each additional percent. The results also confirm that small plots are inefficient; *acequias* with larger average plots perform better. Notably, while utilized as an example of potential OVB, the position of the *acequia* is observable, controlled for, and influential with average production higher for *acequias* further east, meaning further upstream.[16] In unreported regressions, user groups were also more likely to expand east, however the inclusion or exclusion of the coordinates has no discernible impact on the main results of the user group.

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

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

Column (5) reports estimates of the fixed effect regression (equation 3), leveraging the panel structure of the data. In this specification, the impact of additional users is statistically significant; within an *acequia*, adding members influences the outcome negatively with the point estimate 3-10 larger in magnitude than in the non-FE specifications. Furthermore, the percent new user coefficient is no longer significant and closer to zero. Both results are consistent with a positive OVB in the other specifications; underestimating the negative impact of additional users while overestimating a positive impact of new users. Figures 13-16 provide visualizations of the disparity between the specification of both the number and newness of users. Figure 13 plots the BE model residuals of the number of users and NDVI and Figure 14 repeats this but for the FE model. The fitted lines tell the story. The BE specification yields a very flat relationship while the FE model uncovers a steeper negative relationship. Figures 15 and 16 do the same for percent users new, showing how the positive relationship in the cross-sectional treatment dissipates greatly in the panel treatment.

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

Because NDVI is not a common measure, nor does it have a clear, direct, consistent physical interpretation, it is helpful to put the impacts found into perspective in order to assess the economic significance. Drawing on the main FE specification results, Table 6 provides alternative methods of scaling the estimates. For illustration, the estimated impact of one additional user is -0.0531. Overtime, the average standard deviation of the number of users within *acequias* is 6.93; adding this one standard deviation of users reduces NDVI by 0.37. Column (5) scales this to a percentage of the mean within *acequia* temporal standard deviation of average production—5.25 percent in the case of the number of users. Column (6) recognizes that year-to-year variation is the largest source of variation due to stream flow variation. Adjusting for the year fixed-effects, the standard deviation of users explains 11.46 percent of the remaining NDVI temporal variation. Finally, in Column (7) I offer an alternative interpretation scaling the impact of a one unit increase to an equivalent increase of stream flow based on the regression result in Table 1. Adding one additional user has the same impact of reducing the annual average stream flow by 0.92 CFS. Extrapolating over the year, this is a reduction of around 700 acre-feet of water. This should be considered a back-of-envelope calculation but serves to indicate the effect of another user is not negligible. The impacts of the other user group variables are also included in in Table 6.

Because a variety of spatial distributions could yield similar means, Table 7 considers similar specifications (with the additional controls) but using the spatial standard deviation of NDVI within the *acequia* as the dependent variable.[17] On the whole, there are few significant predictors of the spatial standard deviation. Looking at the FE regression results, the coefficient on the number of users compresses the NDVI distribution while more Hispanics does the same. Notably, the point estimate for the percent of users new is positive. The decrease in variation due to additional users suggests the entire system becomes more difficult to operate while the positive point estimate on the new users could indicate some winners and losers within the system.

In order to untangle the variation a bit more, Table 9 reports the FE specification looking only at land that has not been sold, remaining whole and under the control of one owner for the entire period. In short, the NDVI mean is calculated based only on the unsold land by reducing the *acequia's* footprint to only that land, then calculating the average NDVI based only on the pixels within the unsold land. This exercise serves two purposes: 1) help to identify the winners and losers when a new entrant arrives; and 2) free the analysis from unobservable farming ability or effort of the new users by considering only the land for which farmers remain the same. The overall analysis (Table 5) may be driven by the fragmentation of land and the new entrants ability/effort of farming, reducing the production on their particularly parcels only while I attribute their impact to the entire system due to their impact on the average. The other advantage of considering only the unsold land is that there is no fragmentation, meaning any change in production is not systematically related to scales of production.

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

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

5.1 Robustness

Motivated by the findings above, I provide robustness checks concerning specification, sample, and variable selection. First, Table 10 reports two alternative panel data treatments of the data. Column (1) provides the first difference specification. The magnitudes are similar to the FE specification however the new user impact is statistically significant whereas the number of users is not. The model is less efficient than the deviation from mean FE model and implicitly assumes the impact of the additional user is felt only the year following entrance, which is unlikely. In Column (2) and (3) results from random-effects models are reported. An alternative to using fixed effects, the specification assumes that the individual *acequia* effects are random variables independent of the other regressors. This assumption is tenuous and a Hausman test rejects the consistency of the estimator (Chi2[5]=12.84, Prob=0.0249). The results are reported in Column (2) and (3) nonetheless for comparison and largely mimic the FE results while allowing the identification of time-invariant variables coefficients.

Table 11 reduces the sample size, removing the 5 *acequias* that had over 100 users in 1984 in order to see if these large *acequias* greatly influence the estimated impact of additional users.

Notably, this removes the outlier from Figure 9, Acequia Madre Rio Lucero Arroyo Seco which nearly doubled in members, gaining 189 users over the twenty-eight years. The results are stable, with the coefficient on the number of users slightly larger; the main findings are not driven by extremely large *acequias*. For Table 12 I increase the sample, including another *acequia* isolated in the southern end of the valley. Its previous exclusion is based on it being wholly reliant on a steady spring rather than snowmelt as well as being the only *acequia* developed originally by Anglos. Physically and statistically an outlier, the inclusion of the 7 member ditch yields similar results, but the impact of new users is never significant while the point estimate in the FE model is negative. Discussion with members of this *acequia* confirmed a large new landholder did not irrigate and others experimented with many others crops, both influencing the estimated impact on NDVI.

Table 13 and 14 report the main analysis but alter two of the variables. In Table 13 percentage of acres transferred serves as the measure new users. Preference is given to the measure based on users to focus on the social interaction and minimize any mechanical declines in NDVI related to idiosyncratic land use by new large landholders. The results are incredibly stable with regard to the other variables and the magnitude of percent new remains similar, though lacks the statistical significance. In Table 14 I use a cultural homogeneity measure rather than percent Hispanic. The alternative measure yields the same value for a group that is 80 percent Hispanic as it does for a group of only 20 percent Hispanic. Implicitly, this assumes only two cultural groups exist with non-Hispanic last names sharing cultural ties. The estimated coefficient is positive, as one would expect, but not statistically distinguishable from zero. As in prior robustness checks, the estimates of the other coefficients remain stable.

6 Discussion

6.1 Statistics

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

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

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

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

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

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

6.2 Context and Institutions

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

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

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

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

7 Conclusion

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

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

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

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Figure 1

User Group Second-Level Variables

*Adapted from Ostrom (2009)

U1 Number of users
U2 Socioeconomic attributes
U3 History of use
U4 Location
U5 Leadership/entrepreneurship
U6 Norms/social capital
U7 Knowledge of SES/Mental models
U8 Importance of Resource
U9 Technology used
U10 Social Network

Figure 2: Prisoner Dilemma

Player B

Player A

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

Figure 3: Causal Model of Trust and Cooperation

*Adapted from Ostrom (1998)

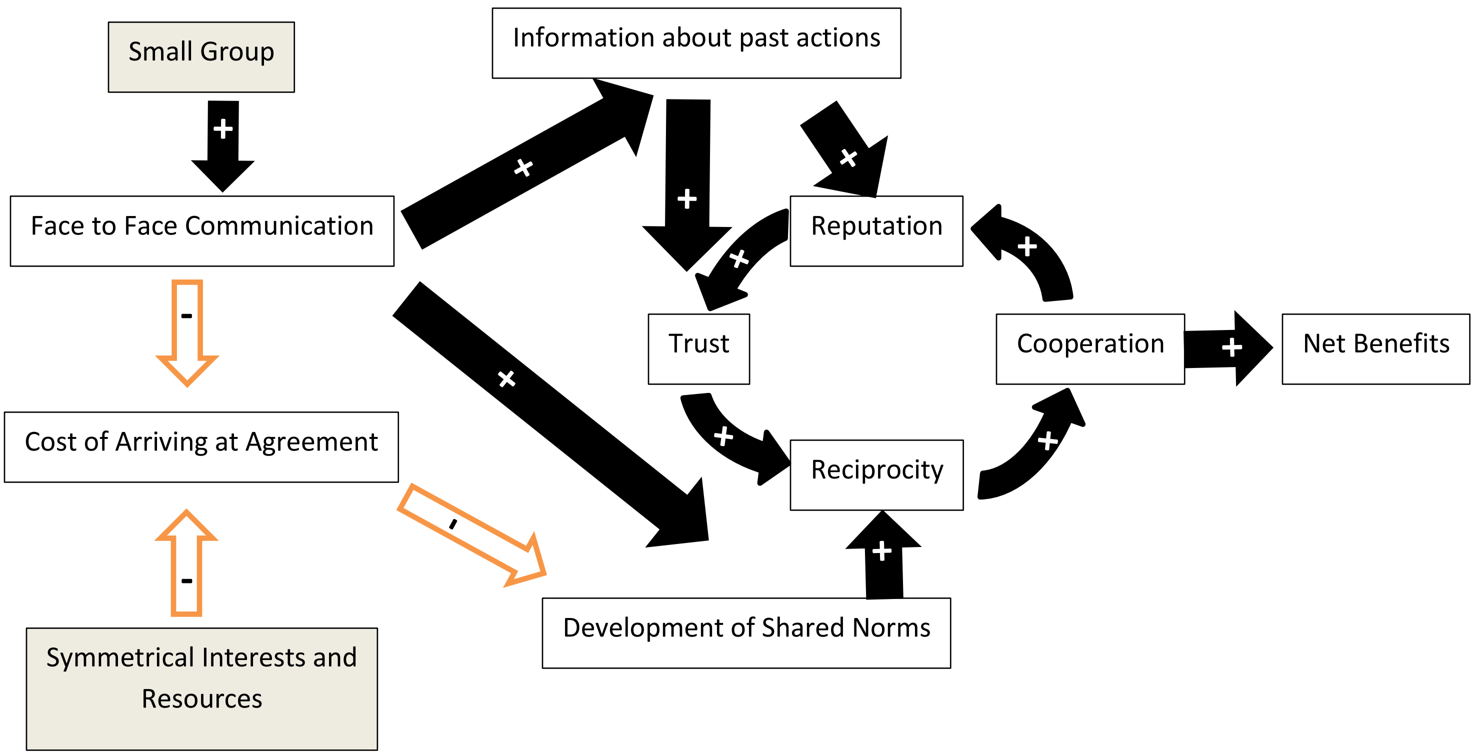

Figure 4: Study Region

*Source Cox (2010)

Figure 5: NDVI Visual

Taos Valley Acequias and NDVI (1999 and 2002)

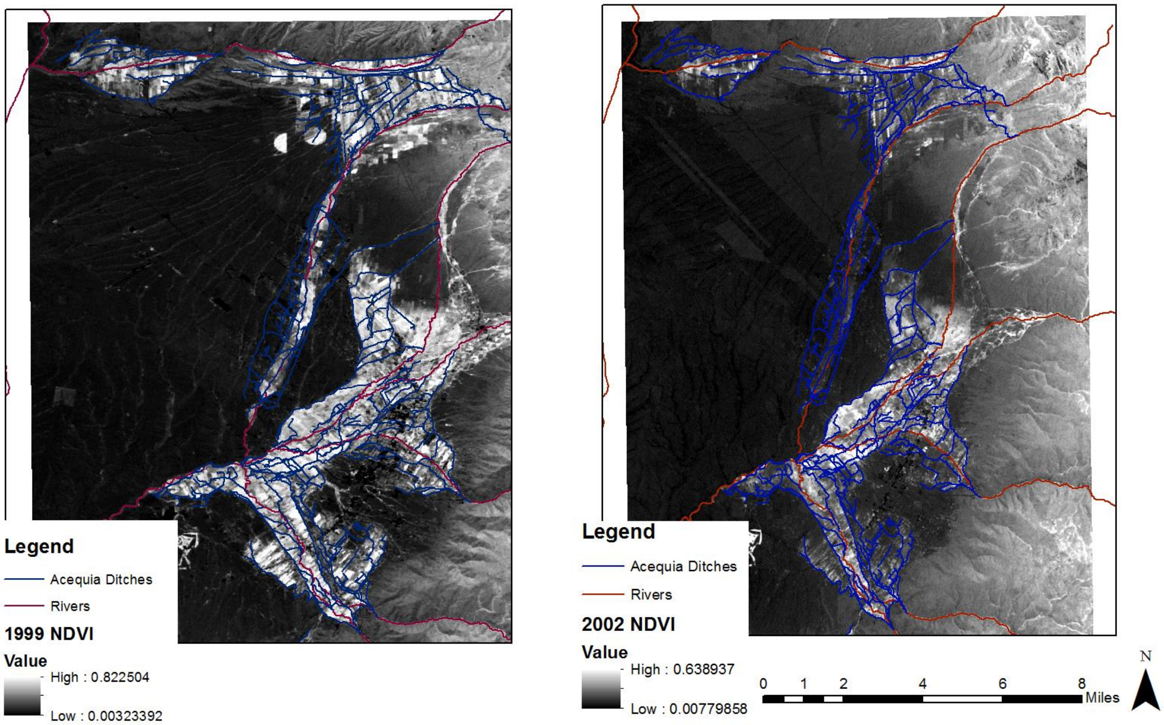

Figure 6: NDVI Visual

*Source Michael Cox

Aerial NDVI

Figure 7

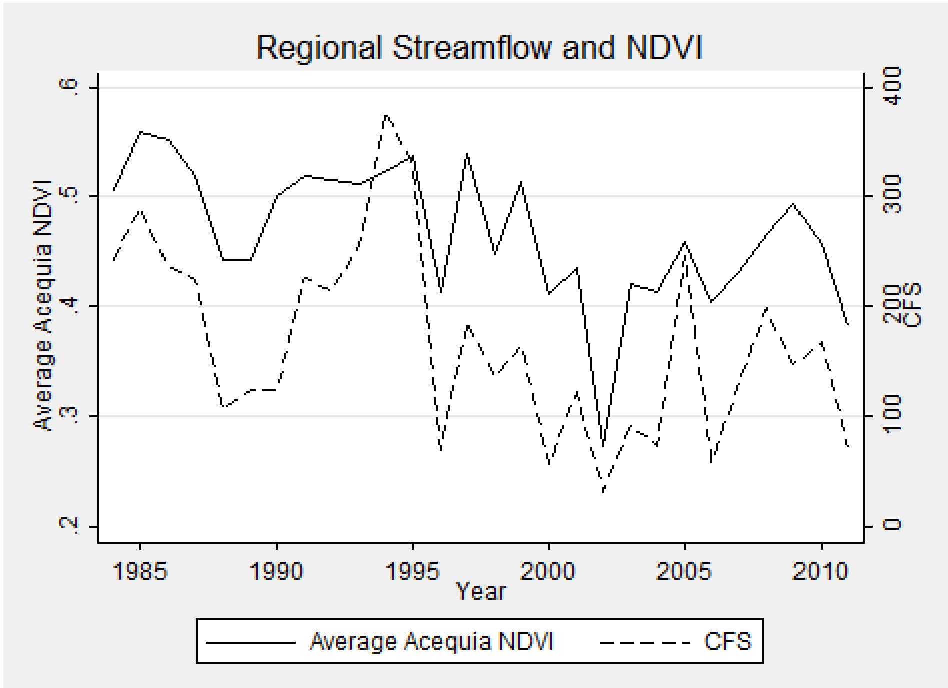
Regional Streamflow and NDVI
Average Acequia NDVI
.2
.3
.4
.5
.6
CFS
0
100
200
300
400
1985
1990
1995
2000
2005
2010
Year
Average Acequia NDVI
CFS

Figure 8

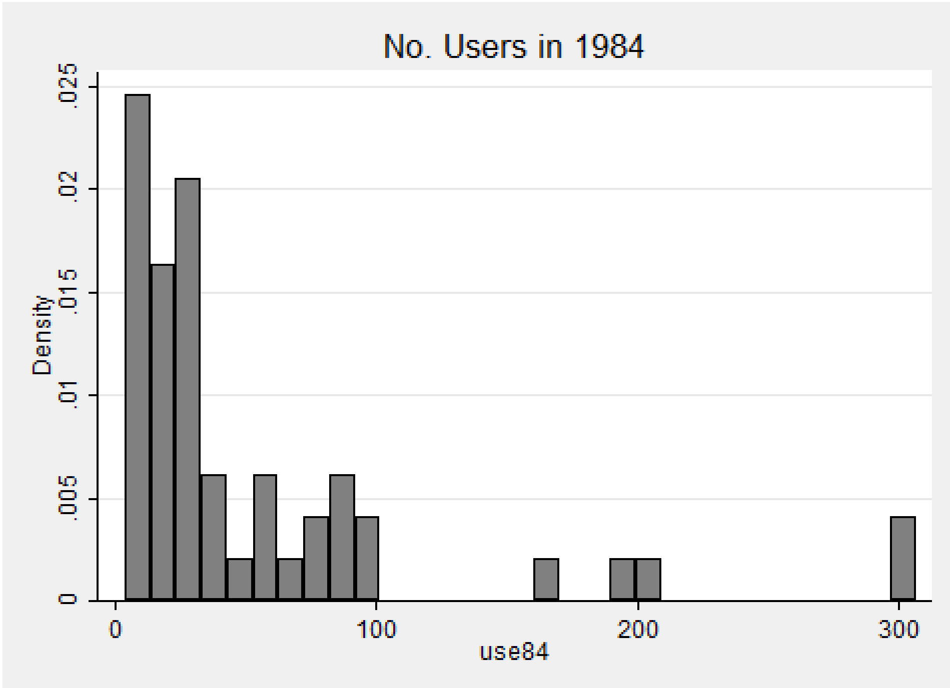

Figure 9

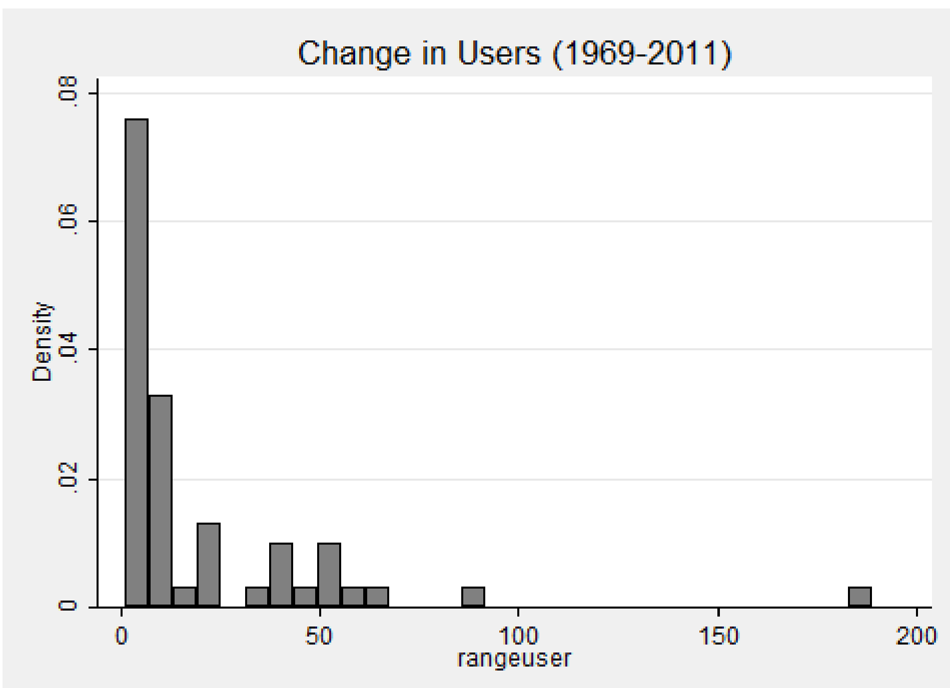

Figure 10

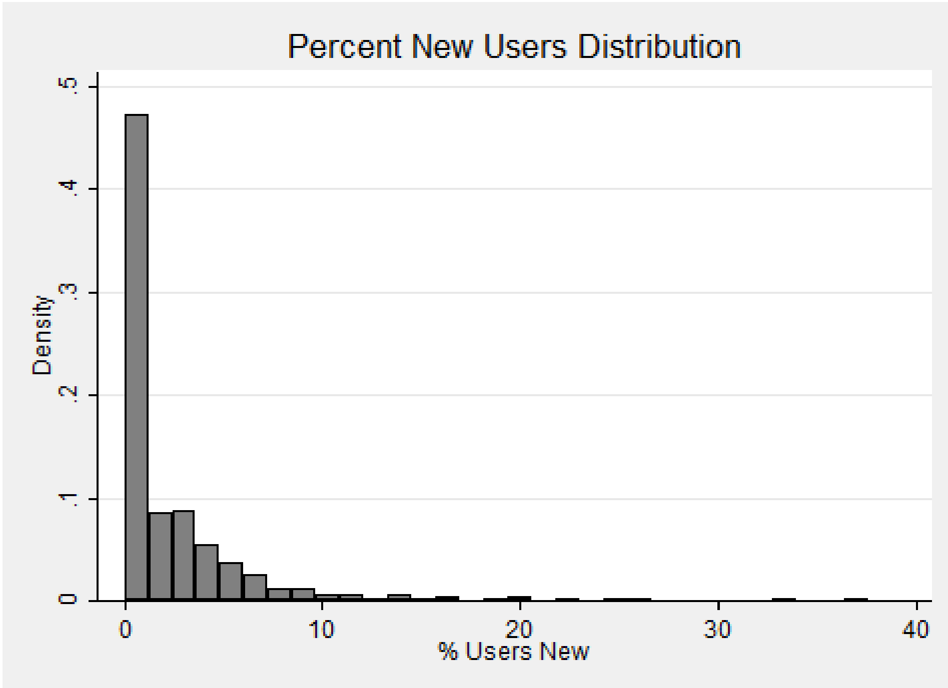
Percent New Users Distribution
Density
0
.1
.2
.3
.4
.5
0
10
20
30
40
% Users New

Figure 11

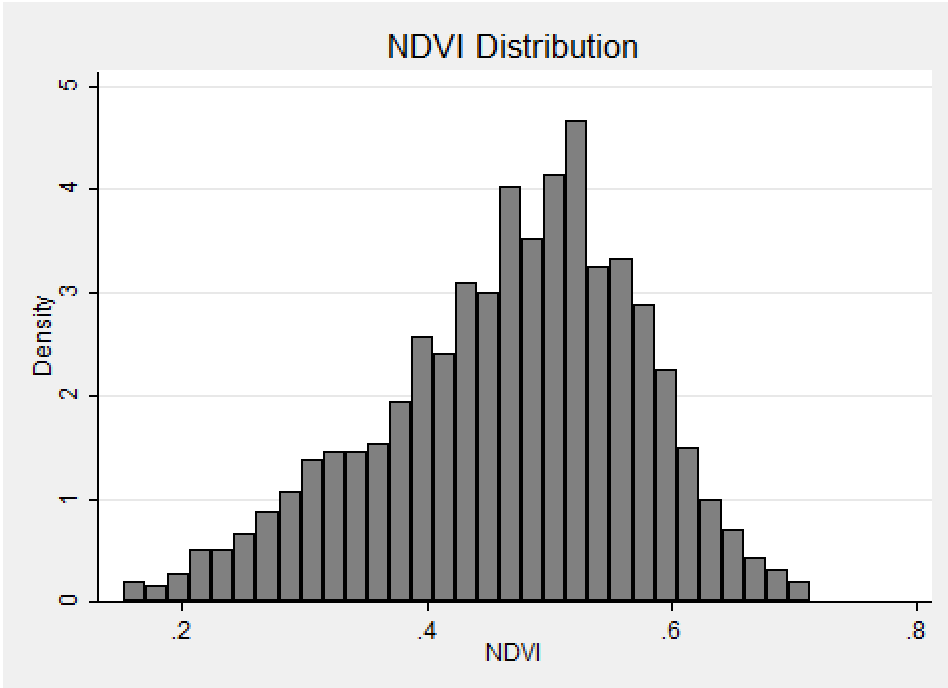

Figure 12

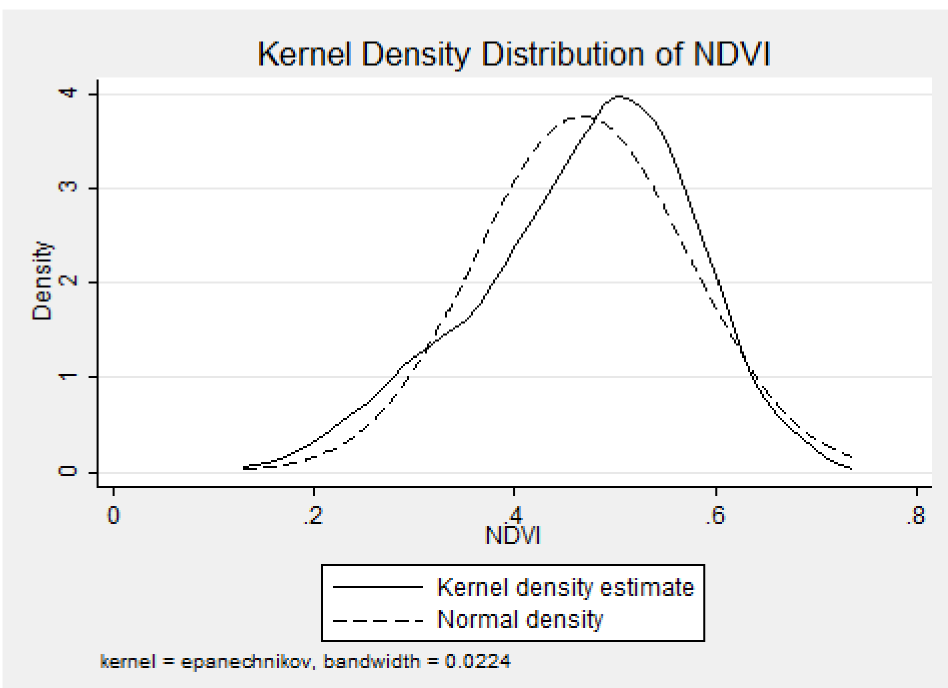

Figure 13

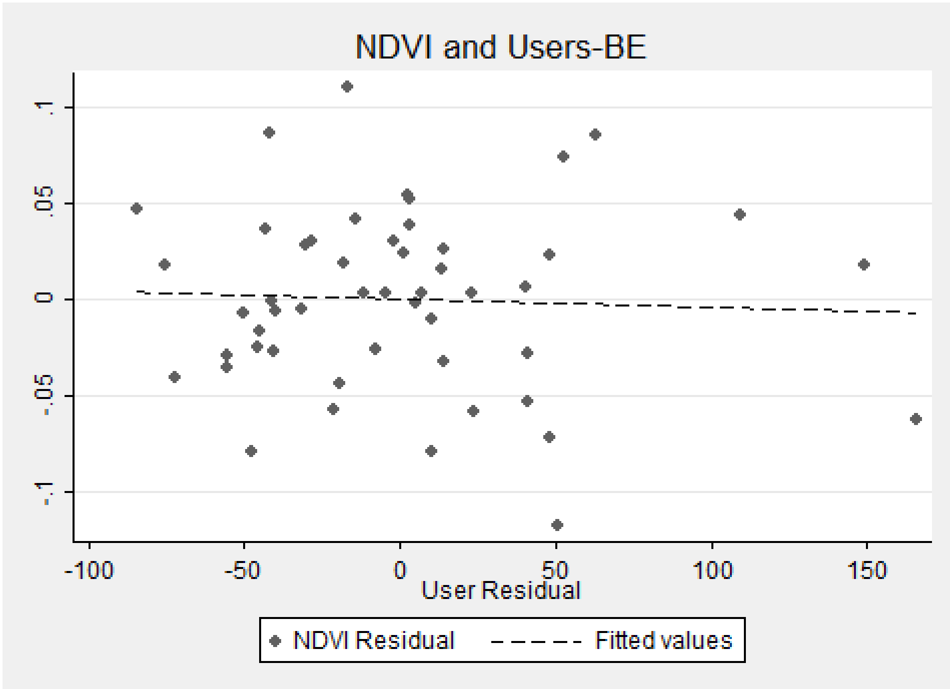

Figure 14

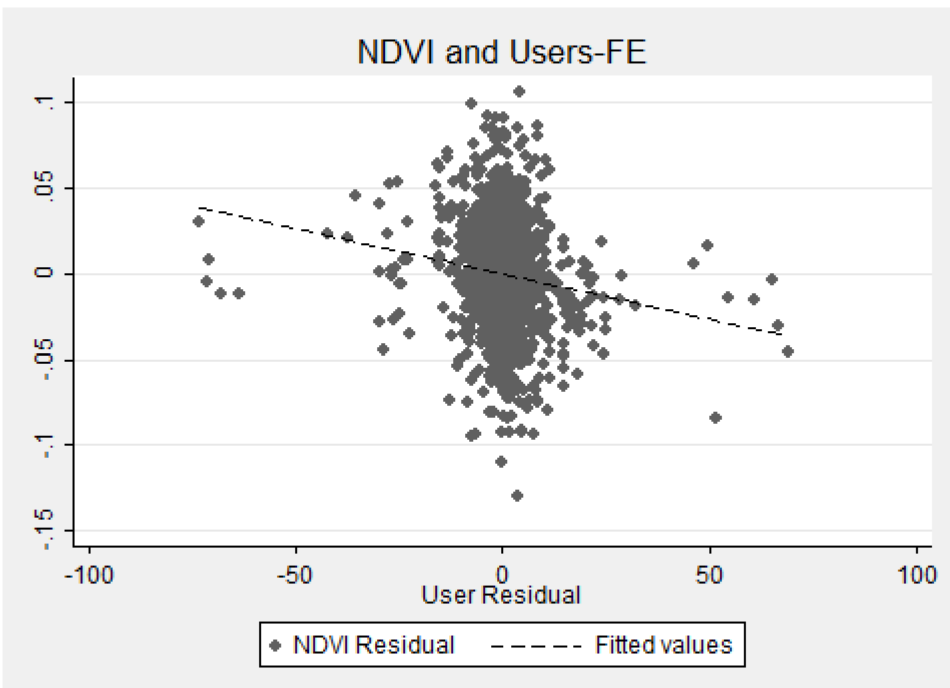

Figure 15

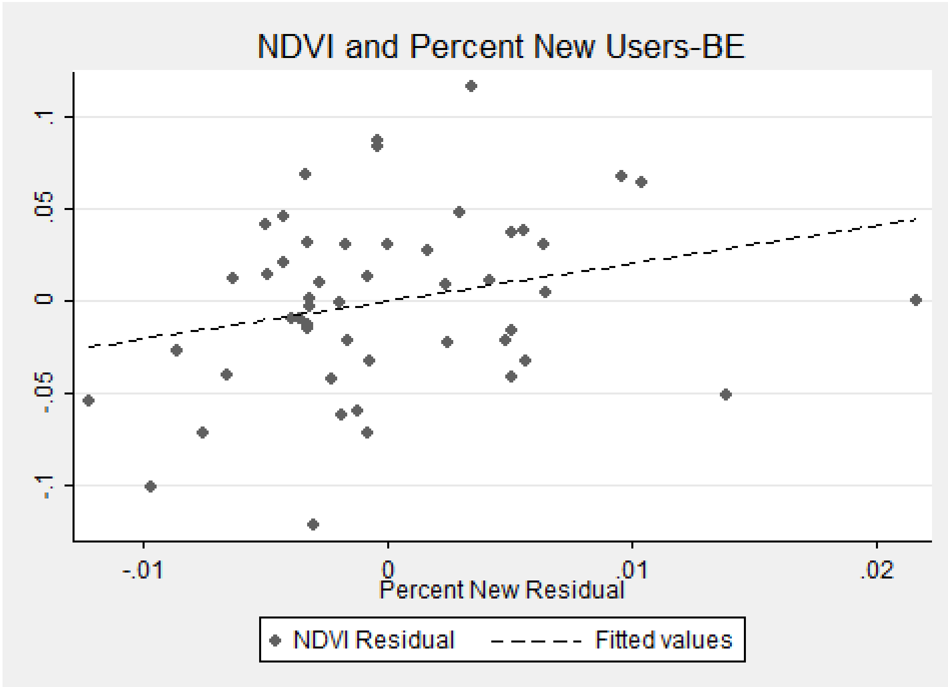

Figure 16

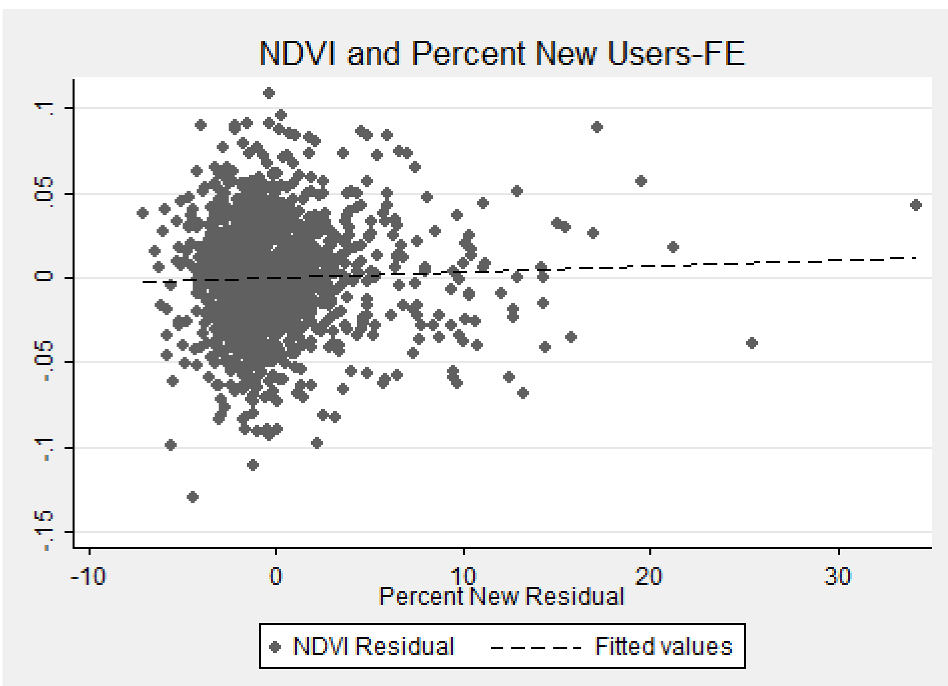

Table 1--Results: NDVI and Stream Flow

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

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

Table 2--Sample Means

Variable	Obs	Mean	Std. Dev.	Within St. Dev.	Min	Max
NDVI (Spatial Average)	1400	46.75	10.62	7.00	15.24	71.29
NDVI (Spatial Standard Deviation)	1400	11.63	2.69	1.92	2.40	19.25
No. Users	1400	64.00	81.91	6.93	4.00	398.00
Total Acres	50	260.72	305.97	N/A	7.70	1415.40
Cultural Homogeneity	1400	14.19	10.88	0.04	0.00	50.00
% Hispanic	1400	54.34	17.35	0.05	9.09	100.00
Average Acres	1400	4.79	4.00	0.50	0.59	25.12
Median Acres	1400	2.61	2.39	0.37	0.33	13.70
Land Gini Coefficient(x100)	1400	56.57	11.15	1.92	26.30	78.98
New Users	1400	1.39	2.66	3.26	0.00	39.00
New Acres	1400	5.06	14.16	0.40	0.00	181.98
% New User (per year)	1400	2.23	3.77	3.26	0.00	37.50
% New Acres (per year)	1400	2.19	6.01	4.38	0.00	57.28
% New Users 1969-2011	50	43.90	13.76	N/A	13.79	71.43
% New Acres 1969-2011	50	39.96	18.98	N/A	6.71	86.73
Average Annual Flow (CFS)	1107	24.57	13.31	11.68	2.92	63.50
Total Average Annual Flow (CFS)	28	167.86	86.38	N/A	31.11	377.40
Municipal Water Transfer	50	0.46	0.50	N/A	0.00	1.00
% Taos	50	16.01	32.31	N/A	0.00	100.00
Fragmentation	50	1.16	0.88	N/A	0.12	5.38
Sharing Agreement	50	0.48	0.50	N/A	0.00	1.00
Hydric Soil	50	40.19	25.58	N/A	0.00	91.86
Irrigation Corridor	50	48.31	41.13	N/A	0.00	100.00
Priority Date	32	1816.50	51.33	N/A	1675.00	1880.00

Table 3--Correlation Matrix

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

Table 4--Number of Users

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

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

Table 5--Results: NDVI and User Group Characteristics

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

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

Table 6--Results Interpreted

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

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

Table 7--Results: Standard Deviation and User Group Characteristics

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

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

Table 8--Results: Unsold Land NDVI and User Group Characteristics

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

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

Table 9--Results: NDVI and User Group Characteristics--Alternative Panel Treatment

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

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

Table 10--Results: NDVI and User Group Characteristics--Under 100

VARIABLES	(1) BE	(2) Pooled	(3) FE
Users	-0.0460	-0.0429	-0.0808**
	(0.0347)	(0.0304)	(0.0392)
Percent Users New	0.572	0.0497	0.0329
	(1.304)	(0.0375)	(0.0286)
Percent Hispanic	0.0402	0.00976	-0.0631*
	(0.0882)	(0.0480)	(0.0375)
Land Gini	-0.0957	-0.0998	-0.112**
	(0.0949)	(0.0970)	(0.0535)
Average Acres	0.461**	0.480***	0.174
	(0.208)	(0.112)	(0.577)
Percent Taos	-0.0804**	-0.0823***	
	(0.0304)	(0.0234)	
Fragmentation	-2.218**	-2.161***	
	(1.021)	(0.548)	
Water Agreement	-0.377	-0.466	
	(2.390)	(1.627)	
Hydric Soil	0.189***	0.201***	
	(0.0563)	(0.0395)	
Irrigation Corridor	-0.00119	-0.000438	
	(0.0290)	(0.0232)	
Taos	-1.975	-2.363	
	(3.830)	(3.019)	
Hondo	8.246	8.951	
	(7.231)	(6.622)	
Latitude	-36.72	-39.53	
	(36.76)	(31.32)	
Longitude	108.4***	114.0***	
	(37.69)	(33.33)	
Constant	12,834***	13,523***	68.02***
	(4,265)	(3,376)	(6.662)
Year Fixed Effect	N	Y	Y
Acequia Fixed Effects	N	N	Y
Observations	1,215	1,215	1,215
R-squared	0.751	0.765	0.786
Number of id	45		45

Standard errors in parentheses clustered by *acequia*

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

Table 11--Results: NDVI and User Group Characteristics--W/ Outlier

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

Standard errors in parentheses clustered by *acequia*

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

Table 12--Results: NDVI and User Group Characteristics-New Acres

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

Standard errors in parentheses clustered by *acequia*

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

Table 13--Results: NDVI and User Group Characteristics--Cultural Homogeneity

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

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

Appendix A: User Group Construction

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

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

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

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

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

3) No parcel listed

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

To construct the acequia-year user groups, an algorithm within Stata was written and utilized to automate the process. Here I provide a description of the process, including the assumptions made to deal with unclear transfers. The main assumptions are summarized in Table A1.

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

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

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

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

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

Table A1—Assumptions in constructing the user group characteristics

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