Trust, Repeated Interactions, and User Group Disturbances in Common Property Irrigation

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Abstract:

Common-pool resources as common property are no longer assumed to be destined to fail, but success is not inevitable. Trust and social capital have been identified as important factors in fostering cooperation, as they substitute for costly formal monitoring and enforcement of rules. This has been confirmed by both theory and empirics. However, the empirical research often is limited to cross-sectional analysis, using heterogeneity as proxies for trust, while theory emphasizes the repeated interactions of individuals. Additionally, given the myriad of variables identified in social-ecological systems to impact outcomes, the extant cross-sectional analysis likely suffers from significant omitted variable bias (OVB). I address both issues by focusing on trust as developed through repeated interactions while correcting for a large portion of the OVB problem. I construct panel data of 51 communal irrigation systems (*acequias*) over a 25 year period (1984-2008) located in Taos Valley, New Mexico. Having survived in the region for 150-250 years, the *acequias* have recently faced a new disturbance, undergoing a significant amount of turnover in the user group. This provides variation in trust developed through direct repeated interaction. Combining satellite imagery data, providing a measure of average agricultural production for each *acequia* each year, with user group characteristics constructed from New Mexico water right records, I explore econometrically the impact of new users. The use of panel data allows the inclusion of fixed effects, controlling for a number of unobserved variables which may be related to both turnover and agriculture. The results indicate that the systems are robust to the disturbance of new users, though smaller user groups struggle when they are subject to a large shock. The results also confirm the presence of OVB, as cross-sectional analysis here overstates the magnitude of the impact.

Keywords: Irrigation; Trust; *Acequia*; New Users; Panel Data

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1 Introduction

No longer is it held that common-pool resources (CPRs) are doomed to fail. Standard Neo-Classical economists predicted that common-pool resources would result in inevitable overexploitation (Gordon, 1954). This classic dilemma has become known as the "tragedy of the commons" which Hardin (1968) hypothesized as the fate of group behavior. For a time the result was a belief in policy panaceas that common property regimes must either be privatized or taken over by the state. In contrast to this belief, there are numerous examples where groups of users have escaped the tragedy through their own collective action and institutional entrepreneurialism, though success is not inevitable. Maintaining sustainable management of a CPR as common property requires collective-action and continual cooperation. The situation is often represented by a prisoner's dilemma game in which the dominant strategies yield the sub-optimal Nash-equilibrium of non-cooperation. However, in the repeated setting, cooperation is theoretically rational and often observed in empirical settings. This excess cooperation has been termed to be social capital (Paldam, 2000). A vaguely defined term, social capital has been repeatedly linked to trust and social networks. Trust has been cited as a property of communities having successfully managed a CPR, as it tends to lower monitoring and enforcement costs, relying on norms and reciprocity. What is less understood is how communities already engaged in sustainable management are able to adapt to a disturbance of their user group when they rely on trust.

When new users move into a system they lack the history with the other users making it more difficult to rely on trust and reciprocity. 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.*** In contrast to the difficulties that accompany more users, this question refers to the replacement of users. Empirical research is needed to answer this question as the institutions developed could prove resilient to such shocks or users exhibit a high level of trust to begin with and the disturbance proves insufficient to erode the successful management of the common resource.

In order to assess the role of repeated interactions in the field one must expand on the plethora of cross-sectional analysis and gather data over time. Reliance on cross-sectional analysis makes it difficult to evaluate the impact of disturbances within a system in statistical manner. Furthermore, the cross-sectional approach has been critiqued for its inattention to omitted variable bias (OVB). Agrawal (2003) argues that with so many factors influencing the social-ecological system (SES), many which also interact with one another, it is difficult or impossible to adequately control for everything in statistical analysis. The implication is that statistical results suffer from OVB and causality is ambiguous. By shifting to panel data of similar common-property institutions, it is possible to address both issues. The longitudinal aspect of the panel data allows for identification of disturbances within a system while fixed effects provide an opportunity to control for a number of stable variables which are simply omitted in cross-sectional analysis. The dearth of panel analysis in the literature is largely due to the high transaction costs of gathering data of CPRs, especially longitudinal (Poteete et al., 2010).

I conduct an analysis of panel data of user group characteristics over a twenty-five year period for fifty-one *acequias* (irrigation ditches) in Taos Valley, New Mexico in order to assess the impact that new users have on the cooperation level of the group in managing the CPR. The results indicate that in this context the existing users and institutions largely mitigate the shock of a few new users but suffer when a larger portion is replaced. Smaller user groups are more vulnerable to this disturbance as they are more likely to rely on trust. The presence of OVB in cross-sectional analysis is also confirmed. These results indicate it is important to continue further research to learn what features of the SES provided this resilience and to assess if similar impacts occur in other settings and with other resources.

2 Background

CPRs are a mix of private and public goods. Like private goods, CPRs are rival in consumption, meaning that a single unit can only be consumed once, reducing the available stock. Unlike private goods, though, CPRs are difficult to exclude others consuming. Common examples include fisheries, forests, water, and grazing land. In the case of irrigation, often there is also a separate but related public good aspect with regards to the physical infrastructure, such as ditches and reservoirs. The literature on CPRs often fails to distinguish between those that remain open-access, for which the tragedy of the commons is likely, and those which are common-property (Bromley 1998). As such, the "tragedy of the commons" has been applied too widely and dismisses common-property arrangements which have succeeded in the real world. Though even in common-property schemes, success is dependent on cooperation, either directly in day-to-day interactions or indirectly through the design of local institutions.

Choosing to cooperate or not is largely dependent on what you believe the other users will do. This can greatly be influenced by past interactions, social capital and the trust, or trust-like behavior shared among users. Empirical studies show that homogeneity along economic, social and cultural dimensions (all used as a proxy for social capital) provides a favorable environment for cooperation but the research fails to fully address the direct impact repeated interaction has, through trust, on cooperation. Ostrom (2011) demonstrates the importance of the distinction in discussing the comparative successes of various land policies on the U.S. frontier and their relationship to the irrigation institution that accompanied them. All struggled to some degree due to the lack of intimacy of the users, i.e., despite the users appearing very similar along economic and social dimensions, with no prior interaction with the specific users, they struggled to succeed. In her 1990 book, *Governing the Commons: The Evolution of Institutions for Collective Action,* Ostrom discusses a number a success stories and notes that they all have in common very little population turnover, saying;

> "In contrast to the uncertainty caused by these environments, the populations in these locations have remained stable over long periods of time. Individuals have shared a past and expect to share a future. It is important for individuals to maintain their reputations as reliable members of the community" (Ostrom, 1990:p. 88)

Yet, this dynamic has not been explored in the field beyond small-N case studies to assess how large of a threat population turnover poses to the sustainable use of the commons.

Game Theory

Though usually considered a simplification of CPR situations, game theory provides the theoretical roots. In simulations and experiments subjects are often playing a variation of the prisoners dilemma (Janssen 2008), the trust game (Cox et al., 2009), or a CPR game directly (Castillo & Saysel 2005). Simple repeated game theory shows cooperation in an infinitely repeated game as a possible equilibrium, though not the only one. In reality, the games are not played forever with the same players. Consider a prisoners dilemma game from Fudenberg and Tirole (1991:p. 169) of long-run and short-run players. One player plays every period and the second player is replaced every period. In this case, the typical folk-theorem result based on the min-max threat is not pertinent as the threat is not operational. However, cooperative equilibria could be sustained. If the newcomer has to move first and the long tenure player's strategy is to always do what the newcomer does and this is verifiable by the new user, then there is an incentive to cooperate. Crucially, this still depends on knowledge of past interactions. The general implication is that game theory permits sustained cooperation despite new players, but does not guarantee it. Even without these conditions, cooperative behavior has been observed in one-shot games (Cox et al., 2009). This 'excess' cooperation has been called social capital, though trust may be the more accurate term.

Social Capital and Trust

Social capital is a vogue term that attempts to capture a broad concept while giving it the weight of other capitals considered in economics, e.g. human, physical, and financial. However, there is little agreement on the correct definition or measurement of it. Among sociologists, the term first made a splash in Bordieu (1986) who defines it as a property of an individual within a social network which is acquired through purposeful actions and can be used to create economic gains. In this sense it is stock of capital which can be used in production just as physical and natural capital can be utilized. Among economists, the use of the term has suffered some criticism. Sobel (2002) synthesizes some economic literature and notes that social capital does not require a conscious sacrifice for future gains, separating it from other capital. Also different than most other capital, it often appreciates with use. Not only does it lack a firm definition, but the measurement of it remains unclear and much research falls into a circuitous argument in that social capital, assumed to be present where positive outcomes occur, results in positive outcomes (Portes & Landolt, 2000; Sobel, 2002).

In this vain, I find the definition applied to game theory to be lacking, essentially indicating that social capital is apparent when cooperation occurs, despite what economic theory predicts. Indeed, it seems impossible that social capital, a product of a social network, could have any bearing on a one-shot game in which the players are anonymous. Instead, it seems some innate trust is present. Sobel (2002) defines trust as the willingness to permit the decisions of others to impact your welfare. This is better suited for explaining why strangers may play the cooperative strategy, hoping the other person will do the same. In that context it is general trust. The focus of this paper is special trust; trust specific to social networks and specific individuals and interactions (Paldam, 2000).

Trust has been linked to social capital and social networks. Paldam (2000) yields relationships with causality running both directions between the three. Grafton (2005), on the other hand, proposes a unilateral causal direction from social networks to social capital to trust. I leverage this in order to bypass the contentious use (and abuse) of the term social capital. Instead I focus on trust, though continue to assume it is a function of social networks. In this sense, a new user disrupts this, either by adding a node or replacing a node. Either way the connections will be weaker to this node and the overall special trust in the group will decrease.

More directly, trust has been shown to be a product of repeated interaction in a number of studies (Sobel, 2002). In addition, Paldam (2000) indicates that trust can be used in production (most analogous to social capital), to reduce transaction costs (most relevant to initiating collective-action in the CPR setting), and to reduce monitoring/enforcement costs. It is an alternative to third-party enforcement and often relied on in informal community institutions, though the alternative of enforcement can reduce the reliance on trust, as might be needed in larger user groups.

Models

CPRs are part of a large complex SES. The hybrid system involves both natural elements, e.g. biodiversity, biomass, hydrology, soil, and wildlife, and due to economic benefits of natural resources, humanly devised systems come into play, e.g. governance systems, harvesting, manipulation, relative prices, user group, and culture. A few models of the system exist, but I rely on the model put forth in Ostrom (2009). The core attributes are the resource system, resource units, governance structure, and user group. Schoon & Cox (2012) builds on this typography by considering the various disturbances that these systems may encounter. Here I focus on shocks to the user group.

Figure 1

User Group Second-Level Variables

*Adapted from Ostrom (2009)

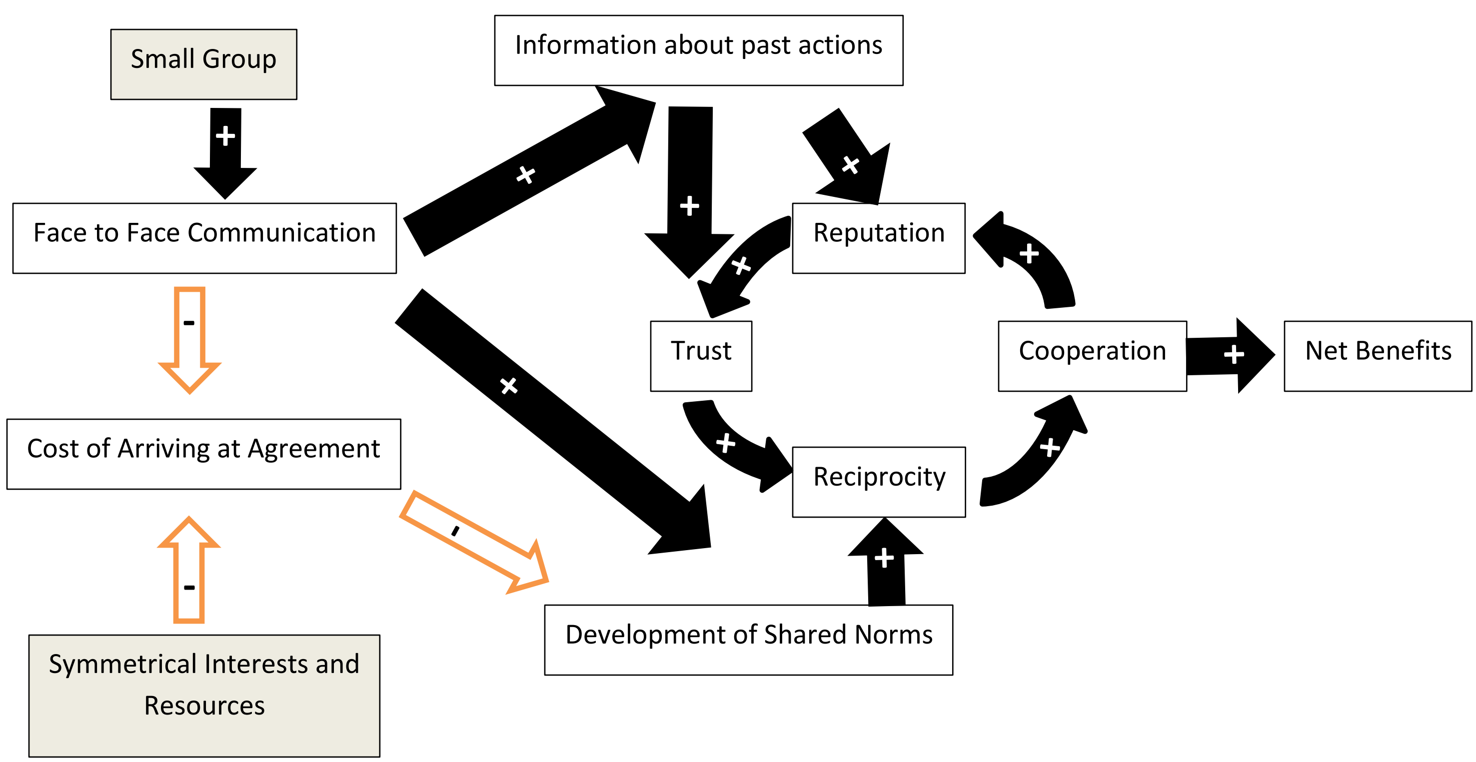
U1 Number of users
U2 Socioeconomic attributes
U3 History of use
U4 Location
U5 Leadership/entrepreneurship
U6 Norms/social capital
U7 Knowledge of SES/Mental models
U8 Importance of Resource
U9 Technology used
U10 Social Network

The core components of the SES can be further broken down into second-level factors. Those of the user group are listed in Figure 1. The introduction of a new user causes a number of social disturbances. For one, they will not have the trust and familiarity with the other users. With a lower level of trust there is an increased chance of rule breaking unless monitoring and enforcement increase (U6 and U10). The new user will not only lack familiarity with the other users, but also the resource system as whole (U7). Utilizing an incorrect mental model of the system will impact the outcome. Finally, the new user may or may not be like the other users along other dimensions. A major impact could arise if they do not value or depend on the resource the same as the previous user (U8). The remaining characteristics may change as well but are distinguishable and observable.

U6-8 and 10 can all be linked to trust through a rational choice model. Having recognized that the economic agent does not make rational decisions as prescribed by classical economics (Simon, 1955), some energy has been expended in creating richer behavioral models for rational choice guided by information constraints and varying motivation other than personal income maximization. Ostrom (1998) develops a pertinent model which surrounds the core positive feedback loop of trust, reciprocity, reputation, and cooperation with causal relationships to structural variables. This model, adapted in Figure 2, can be nested in the larger SES structure to gain some predictive power on the impact of a new user. A critical element is the internal positive feedback loop, predicting that if any of these elements decreases the impact amplifies and cooperation will unravel. Significantly, when information of past actions is reduced, as it is when a new user enters the system, it is posited that trust decreases, leading to a decrease in cooperation. Additionally, while the other disturbances above (U7 and U8) are not directly impacting trust, through this behavioral model we see an indirect impact. This model has been tested and used in experiments and simulations in order to describe the role of trust in cooperation but has not been explored in a natural, working setting.

Figure 5.2: Structural Model of Trust and Cooperation

*Adapted from Ostrom (1998)



Experiments & Trust

Experiments have been conducted to assess the role that trust plays in sustaining cooperation in the context of games. It has been shown feasible that 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, even more efficient than instances of top-down rule making (Castillo & Saysel, 2005). While theory predicts that repeated interactions build trust and trust facilitates cooperation, conditional-trust may be exhibited when there is possible profit in it. Experiments with the trust game have shown that even without prior interactions often the first mover will 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 general trust without past interactions

Empirical Work & Trust

Most empirical research uses measures of homogeneity and the assumption that those with more in common share more 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. In statistical analysis, 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, 2000; Johnson, 2000). The findings generally support that systems with more heterogeneity achieve lower levels of cooperative measures. These results align with the behavioral model, but ignore trust built up over time.

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 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, both within groups and across groups. The empirical works rely on single snapshots, simply comparing across various groups. The analysis likely suffers from OVB as the SES structure includes many elements that interact with one another and is difficult to measure and collect data. For instance the forest users who meet more may be better organized due to leadership, which also manages the forest better. In order to correct for this, and focus more directly on the question of if and how CPR management institutions handle or adapt to turnover, empirical work needs to incorporate panel data.[1]

3 Empirical Study Setting

In order to create panel data on a CPR, I study a number of irrigation ditches in Taos Valley in north central New Mexico, USA, highlighted in Figure 3. Farmers in this area rely on commonly owned irrigation ditches called *acequias* to grow alfalfa. The ditches are simple unlined, earthen ditches whose flows are subject to supply, gravity, and simple head gates. The water comes from the snow pack in the Sangre de Cristo Mountains to the east as the water drains to the Rio

[1] There is recent trend to engaging in repeat surveys to create some panel data, though analysis remains extremely rare. See Kebede (2002) and Gjertsen (2005) for some examples in CPR settings.

Grande. With only 33 cm of annual rainfall in the region, without the supplemental snowmelt, the fertile soil would produce very little.

Acequias

Figure 3: Study Region

*Source Cox (2010)

The word *acequia* itself has Arabic roots and means "to irrigate" (Rivera & Glick 2002). The institution accompanied the Spaniards as they settled in the new world. The first ditch in what is now New Mexico was dug when they began colonization of *La Provincia de Nuevo México* in 1598. The colonization process was guided by the Laws of the Indies in which water availability was central to issuing land grants. It is the Muslim practice that irrigation canals are the shared property of all those who labor on it and could not be subdivided into private property.[2] For more on the settlement and adoption of Muslim rooted irrigation practices, see Rivera & Glick (2002).

Water apportionment in *Nuevo México* was driven by priority, but not as defined under the prior appropriation doctrine (in which priority is based on date of first diversion). Instead of first possession, disputes were settled based on other factors including just title, prior use, need, injury to third party, intent, legal right and equity (Brown & Rivera, 2000; Ebright, 2001). For instance, small gardens typically were given water prior to large alfalfa fields, independent of first use. Overall, it was a flexible community-based irrigation system in which rarely did anyone get all they asked for, but everyone got something.

An *acequia* begins by building a diversion point upriver using a simple dam which directs the water into the *acequia Madre*, or main ditch. Farmers who help build and maintain the system are *parciantes*. During drought periods, users of a single *acequia* divide the water on a rotational basis (Rodríguez, 2006). The use of *temporalis*, or time shares, is seen as an easy way to monitor and enforce division (Trawick, 2001).

The ditch itself is unlined; a feature which allows it to expand the riparian zone and recharge groundwater (viewed as wasteful by current law), but also requires considerable maintenance. Each spring it falls on the *mayordomo*, or superintendent of the ditch, to organize the members to shore up the ditch. This position, as well as three other commissioners, is democratically elected from within the *acequia* annually. In contrast to ditch companies where voting is often in

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

proportion to land, voting is most often done one vote per *parciente*, though other arrangements are sometime utilized (DeLara, 2000). The other officers typically include a president, secretary, treasurer who oversee the work done by the *mayordomo*.[3] Each *acequia* forms an autonomous political subdivision of the state.

The *acequias* have been a model for communal and ecological benefits which can be provided beyond the economic benefits of irrigation. For many rural residents it is the most local form of government and builds a sense of community. Rodríguez (2006) explores the community nature of the institution and its intimate relationship with religion. On the ecological front, beyond the extended riparian zone, *acequias* utilize renewable energy (gravity) to provide water, typically utilize riparian long lots rather than the grid system, rely on natural pest and weed control and utilize local landraces and polyculture (Peña, 1999).

Taos

In Taos Valley there currently exist fifty-one independent *acequias*. Many of these were originally established centuries ago with the earliest priority date reaching back to 1747. Of those with dates, all except one was established prior to New Mexico becoming a state in 1912. Taos irrigators successfully fought off various irrigation district formations and nearly all *acequias* in the county continue to operate today. Recently the population has shifted slightly from Hispanic farmers and includes some second homes as the tourist industry of Taos grows. Throughout the study period, the number of irrigators ranges from 2700-3600. The *acequias* are divided geographically, defined by three main sources of water. Two smaller regions divert from the Rio Hondo to the north (8 *acequias*) and the Rio Grande del Rancho to the south (15 *acequias*) and the third, larger central region, draws from the Rio Pueblo de Taos (28 *acequias*).

It should be noted that the water is not common property anymore as it was under Mexican law when many *acequias* were established. The doctrine of prior appropriation prevalent in the arid regions of the United States forced the communities to allocate individuals with private water rights. The *acequia Madre* remains property held in common. The State Engineer of New Mexico has adjudicated water rights to the individual level to adhere to the 1905 water code, but will not interfere with delivery beyond the *acequia Madre* as *acequias* are a political subdivision of the state and all users within an *acequia* share the same priority date. Given this, 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. In times of scarcity, the water is delivered on a rotational basis, both intra-*acequia* (among those diverting from the same river) and inter-*acequia*. Prior to the adjudication, no user recalls anyone exercising their private right (Rodríguez, 2006) and this practice has been approved to persist in Taos through the settlement of the adjudication case, avoiding the future application of prior appropriation in the region (Richards, 2008).

In recent history, the *acequia* users have been changing. This turnover makes Taos ideal to study the effect of new users on CPRs. Nearly 40 percent of the irrigated land in *acequias* has been sold since 1969, both on average and in total. While some of this may be due to agglomeration and not a new user not already irrigating other land, from 1984-2008, 2.4 percent of the user

[3] Stanley Crawford provides an excellent account of spending a year as mayordomo in his 1988 memoir

groups of the *acequias* are new each year (the median is zero while the average disturbance when there is turnover is 5 percent).

4 Methods

Statistical analysis

To assess the impact of user group disturbances in the field, I create panel data consisting of the Fifty-one *acequias* over a twenty-five year period from 1984-2008 accounting for new users and the resulting outcome on cooperation. The large-N sample of *acequias* comes primarily from two sources: 1) Satellite imaging provides the biophysical outcome variable; and 2) the user group characteristics are derived from water right records from the New Mexico State Engineer's Office.

Satellite data

While common irrigations systems struggle in water appropriation and labor provision for maintenance, I focus on a measure of the former here.[4] I utilize satellite imaging data to construct the normalized difference vegetation index (NDVI). The measure is influenced by other factors, but has been shown to be positively related to biomass, thus serving as a proxy for successful agriculture production. NDVI is based on satellite imagery which processes a variety of wavelengths. Isolating two in particular obtains a measure of healthy vegetation present in an *acequia*. NIR (Near-Infrared wavelengths) is reflected back by healthy vegetation, while RED (red wavelengths) is not. NDVI is normalized to be between -1 and 1, with numbers closer to one representing more abundant, healthy vegetation.

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

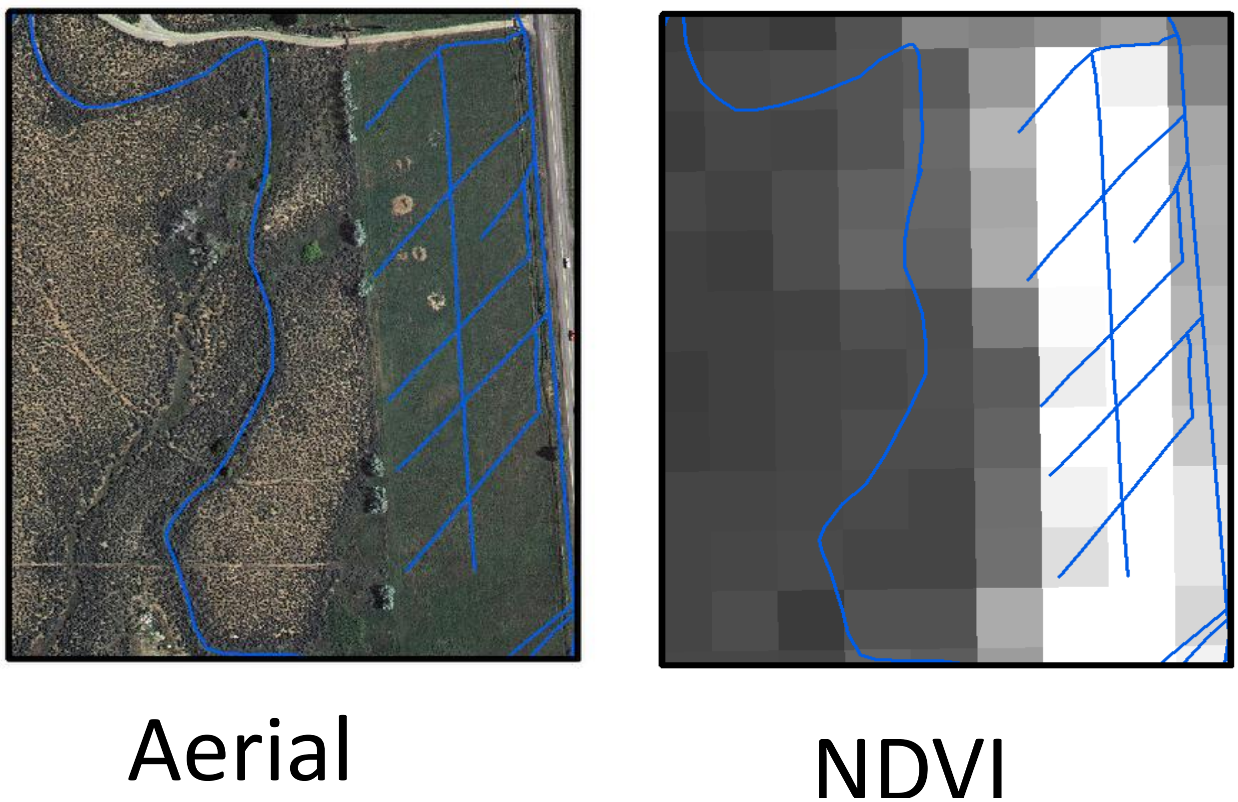
NDVI is being used more and more as a source of overtime data on land usage (Nagendra et al., 2005, Ostrom & Nagendra, 2006, Honey-Roses et al., 2011). It is somewhat unique to utilize it as an indicator of water usage (see Cox & Ross, 2011 for an example). A visual of the data is provided in Figure 4, contrasting NDVI values with the corresponding aerial photo. In this arid locale in which water is often the limiting factor for agriculture, NDVI indicates the level of success in obtaining sufficient water. In addition, while NDVI is a biophysical measure capturing the ultimate goal of the *acequias,* 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). This measure, while an imperfect proxy, 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 (Bardhan, 2000; Johnson, 2000; Ruttan, 2006; Varughese & Ostrom, 2001). Second, the satellite imagery is available retroactively; therefore it is unique in that it allows me to create a panel data dating back a number of years.

[4] The measure may indirectly pick up maintenance shortcomings if it results in less water available independent of division issues.

The original NDVI data comes from the Landsat Satellite which is available back to 1984. Each year an image of the region was selected and overlaid with GIS data regarding which land was irrigated from which *acequia*. Once the 30x30 meter pixels were assigned to the appropriate *acequia*, a spatial average of NDVI was calculated for each *acequia* every year. For initial analysis, this measure is utilized. Further robustness checks will be completed using a variety of NDVI metrics. The concern being that a variety of spatial patterns could result in the same average. In this manner, the simple mean may mask important dynamics created by new users.

Figure 5.4: NDVI Visual

*Source Michael Cox



Water right transfers

In addition to the NDVI, data is needed on ownership of parcels with water rights linked to the *acequias*. The collection of user data is possible thanks 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.[5] 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.

[5] This process is ongoing with many basins in New Mexico yet to begin. Taos County just finished what became a 40 year process in late 2012.

In order to create a panel, I combine these records with water right transfers which are filed at the New Mexico Office of the State Engineer (OSE). The OSE records: 1) which irrigated parcel was transferred; 2) the acreage; 3) when it was transferred; and 4) the grantees and the grantors, as well as the amount of water rights which accompanies the land.[6] These records are not digital, requiring manual input from the physical copies maintained at the OSE in Santa Fe, NM. A total of 3500 transfers were recorded. These data, when combined, allow me to construct the user group in each year for each *acequia*. The data has been gathered for fifty-one *acequias*, dating back to 1969; however the earliest satellite imagery comes from 1984. In addition to the water right and NDVI data, I utilize a report from 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 an additional control (Word & Perkins, 1996).

Methodology

The preferred model includes fixed effects to take advantage of the panel data and correct for some OVB which occurs in cross-sectional analysis. The panel, while obtained at the plot level, is collapsed to the *acequia* level, maintaining the number of users, the Gini coefficient of land holdings, the Hispanic/Anglo composition, as well as variables measuring the extent of new users in each year.

The main specification utilized is as follows:

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

The subscript i corresponds to the *acequia* and t corresponds to the year. It is important to include fixed effects for both. Due to the geographic position and hydrological features of an *acequia* it may be more or less productive on average. *Acequia* fixed effects (A_i) control for the relative productivity of the soil in the area as well as the seepage or alternative moisture availability. Utilizing this average as a benchmark also addresses some endogeneity issues which may arise in considering land bought and sold may not be random. Given information asymmetries, it is reasonable to assume that poor performing *acequias* will be more likely to be sold, suggesting a third component impacting both NDVI and new users which is not controlled for. So long as this unknown element is constant, say being a downstream diverter, the fixed effect will capture it.

Year fixed effects (Y_t) absorb the overall climactic environment in a given year as well as the particular timing in the growing season when the satellite image was taken. Notably, water supply varies greatly year-to-year depending on rainfall and snowpack. Using year fixed effects allows me to compare relative performance in a given year provided the water supply. Together, the fixed effects capture variables which change uniformly across the *acequias* over time and those which are different across *acequias* but constant within. The other four variables control for the shifting user group characteristics. Because *acequia* elections, maintenance, and planting of the fields occur relatively early in the year, I lag these variables one year in order ensure the changes occurred prior to the measurement of the outcome variable. The lag also leverages the

[6] This is set by the OSE based on land size and specific regional climactic attributes. For this region, each irrigated acre of land has a right to 2.5 acre feet of water per year.

time dimension of the data to further reduce endogeneity issues, though trends could still be present.

New_{it} is the main variable of interest. In order to be a new user, I require that purchaser of the land did not previously own land within that *acequia*. While an indicator function for the presence of a new user can be used, I prefer the fraction of all users in order to capture more information concerning the size of the disturbance. The impact on cooperation is likely nonlinear due to the influence of previous users which remain. Accordingly it will be helpful to allow New_{it} to enter the regression in a nonlinear fashion. This is accomplished by binning the disturbances into five levels. The empirical distribution of percent new users is calculated, ignoring those observations with zero, and then divided into quarters. Dummy variables are then utilized to indicate the position of the observation in the distribution, including a category (the omitted group) for no change.

The other three variables control for additional user group characteristics which have been shown to impact the probability of success. This includes $Gini_{it}$, which is the Gini coefficient as calculated by the amount of land under irrigation owned by users in the *acequias*. $Users_{it}$ captures the number of users in the *acequia*. Finally, in order to control for the cultural heterogeneity, $Cult_{it}$ is included. To construct the variable, I exploit the names of the owners to distinguish between Hispanic users and others. Drawing on the 1996 census report (Word & Perkins, 1996), I assume those with a surname which is among the most common 639 Hispanic surnames are in fact Hispanic. I assume the rest are of Anglo descent. The variable itself is then the extent to which the mix in a given system in a given year deviates from fifty percent. Table 1 summarizes these variables in addition to other measures which are observable.

Table 1--Summary Statistics

	Mean	Std. Dev.	Within Std. Dev.	Min	Max
NDVI	0.36	0.14	0.12	-0.16	0.65
No. Users	61.65	79.54	6.14	3.00	377.00
Total Acres	258.00	307.75	N/A	7.70	1462.75
Cultural Homogeneity	0.15	0.12	0.04	0.00	0.50
Average Acres	4.86	4.03	0.50	0.59	25.12
Median Acres	2.61	2.35	0.39	0.33	13.70
Land Gini	0.57	0.11	0.02	0.26	0.79
Fraction New Users	0.02	0.04	0.03	0.00	0.38
Fraction New Acres	0.02	0.07	0.05	0.00	0.57
Observations=1275					

5 Results

Table 2 presents the raw correlation matrix of the variables of interest. The first column contains the correlations with the outcome variable, NDVI. Most signs are as expected; more users, more inequality in land holdings, and more new users, whether measured by percent of all users or all acres, are all negatively correlated with NDVI. Cultural homogeneity is positively correlated, as expected as well. The strongest correlation is with the year, indicating a declining trend in overall agricultural productivity. Year is also correlated positively with new users. This underscores the importance of year fixed effects in order to control for this common trend. Without it, the impact of the new user would be negatively biased.

Table 2--Correlation Matrix

	NDVI	No. Users	Land Gini	Culture Homogen.	New Users	New Acres	Year
NDVI	1						
No. Users	-0.237	1					
Land Gini	-0.234	0.511	1				
Culture Homogen.	0.084	-0.164	-0.061	1			
New Users	-0.046	-0.016	-0.028	-0.002	1		
New Acres	-0.019	-0.066	-0.017	-0.035	0.674	1	
Year	-0.454	0.070	-0.010	-0.123	0.069	0.060	1

User group variables are lagged one year

The main specification results are presented in Table 3. Column (1) contains the results with the entire sample. Here the impact of new users is negative, but highly imprecise. The Gini coefficient is slightly positive, but also very imprecise. The number of users is negatively related NDVI, statistically significant, but very small in magnitude. Cultural homogeneity is positive, as expected and significant both statistically and in magnitude. Interpretation of magnitude is included below in the discussion.

Column (2) reports results when the regression is run on the full sample but fully interacted based on number of users. The impact of a new user is undoubtedly heterogeneous across user group size independent of the magnitude of the disturbance. Those which are defined as “big” had more than 25 users as of 1984. The smaller subset of *acequias* (22 of them) experiences a statistically significant decline in NDVI following the introduction of new users.

Table 3--Results: New Users

	(1) NDVI	(2) NDVI
No. of Users	-0.000630***	0.00839***
	(0.000213)	(0.00240)
Gini Coefficient	0.0401	-0.0575
	(0.121)	(0.0757)
Cultural Homogeneity	0.130***	0.231***
	(0.0425)	(0.0359)
New Users	-0.0496	-0.0899*
	(0.0464)	(0.0459)
No. of Users x Big		-0.00886***
		(0.00236)
Gini Coefficient x Big		0.110
		(0.147)
Cultural Homogeneity x Big		-0.221***
		(0.0675)
New Users x Big		0.182**
		(0.0739)
Acequia fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Sample	All	All
Observations	1,224	1,224
R-squared	0.898	0.903
Number of id	51	51

All controls lagged 1 year
*** p<0.01, ** p<0.05, * p<0.1

Subsequent analysis is performed on the 22 *acequias* which began 1984 with 25 users or less. This sub-set is utilized because the larger groups are more likely to substitute formal arrangement for reliance on trust, insulating the system from any shocks. This is discussed in more detail below in the discussion section.

Using the sub-sample, Table 4 reports the results using a variety of specifications to demonstrate the benefit of panel data. Column (1) pools the data, treating each observation independently. The coefficient on new user is -0.202, meaning a 1% turnover in the population reduces NDVI by 0.02. Column (2) averages the variables across time within each *acequia.* Here the impact of the new user is the largest, suggesting *acequias* which average a 1% turnover average an NDVI 0.16 lower than other those with no turnover. This specification is the closest to mimicking a cross-sectional analysis. Column (3) is the fixed effect specification. Here the impact of the new user is smaller than when the panel form of the data is ignored at 1% turnover reducing average NDVI by 0.010. Finally, column (4) utilizes a lagged dependent variable, allowing the unobserved omitted variables to vary overtime. The point estimate remains negative.

Table 4--Results: User Group and NDVI

Model	(1) Pooled OLS	(2) Between	(3) Fixed-Effects	(4) Lagged Dependent
New Users	-0.202	-1.586	-0.0951**	-0.0498
	(0.168)	(1.198)	(0.0457)	(0.0419)
Acequia fixed effects	No	No	Yes	No
Year fixed effects	Yes	No	Yes	Yes
Sample	Small	Small	Small	Small
Observations	528	528	528	528
R-squared	0.629	0.148	0.886	0.882
Number of id		22	22	

Robust standard errors clustered by *acequia* in parentheses
All specifications include other user group controls. All controls lagged 1 period
*** p<0.01, ** p<0.05, * p<0.1

Table 5--Results: New Users Robustness

Model	(1) Quartiles	(2) Quartiles& Trend	(3) Acres	(4) Outsider
New Users			-0.0990*	
			(0.0531)	
New Acres			0.00366	
			(0.0222)	
New Outside Users				-0.0985*
				(0.0531)
New Users Q1 (max=.053)	-0.00530	-0.00546		
	(0.00625)	(0.00600)		
New Users Q2 (max=.077)	-0.00536	-0.0105		
	(0.00708)	(0.00649)		
New Users Q3 (max=.133)	-0.000854	0.00407		
	(0.0101)	(0.0102)		
New Users Q4 (max=.375)	-0.0222**	-0.0112**		
	(0.00808)	(0.00400)		
Acequia fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Acequia specific time trend	No	Yes	No	No
Sample	Small	Small	Small	Small
Observations	528	528	528	528
R-squared	0.886	0.904	0.886	0.886
Number of id	22	22	22	22

Robust standard errors clustered by acequia in parentheses
All include other user group controls. All controls lagged 1 period
*** p<0.01, ** p<0.05, * p<0.1

Table 5 provides some more specifications to provide some robustness as well as more detailed information. Column (1) introduces the non-linear form of the percent new users in which we see that even in the smaller *acequias*, it appears only the larger disturbances have an impact. Column (2) adds *acequia* specific time trends in order to soak up any unobservable trends above and beyond the year fixed effects. The results are qualitatively similar though smaller in magnitude. Column (3) introduces the fraction of new acres in addition to the new user measure. Notably, the point estimate on the new users remains significant and relatively stable while the new acre measure is not significant (when included by itself it is significantly negative). Finally, Column (4) substitutes the fraction of outsiders for new users. This definition removes any transfer in which the surname of the new owner matches the previous owner, indicating a familial transfer in which some experience and prior interaction may be expected.

Finally, Table 6 considers the impact of new users over a longer period of time. In addition to the previous year's new user measure, the regression includes the measures two years later and from five previous years. Whether using the continuous measure or the indicator of experiencing the largest category of disturbances (only the continuous measure is reported), only the disturbances of the 4 years prior have statistically significant impacts on the NDVI of a given year.

Table 6--Results: New Users Lagged

	(1) NDVI
New User (1 year forward)	-0.0630
	(0.0439)
New User	-0.0375
	(0.0412)
New User (1 year prior)	-0.101***
	(0.0342)
New User (2 years prior)	-0.109***
	(0.0369)
New User (3 years prior)	-0.112***
	(0.0278)
New User (4 years prior)	-0.0548*
	(0.0309)
New User (5 years prior)	-0.0557
	(0.0428)
New User (6 years prior)	-0.0537
	(0.0459)
Acequia fixed effects	Yes
Year fixed effects	Yes
Sample	Small
Observations	440
R-squared	0.904
Number of id	22

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

6 Discussion

First, as NDVI is not a common measure, nor does it have a clear, direct, consistent physical interpretation, it is necessary to put the impacts found into perspective. To do this, recall the overall summary statistics. In the sample of small *acequias*, conditional on a new user entering, the average disturbance is 10.31 percent. Given the point estimate of the preferred specification (Table 4 (3)), this disturbance decreases NDVI by 0.010 (=0.1031x-0.951). Given that the average deviation of NDVI within an *acequia* is 0.12, this average disturbance explains just over 8 percent of the variation. However, when NDVI is adjusted for year effects, which is the largest source of variation, the remaining within variation is just 0.04, meaning the impact of average disturbance explains 25 percent of the variation in these smaller *acequias*.

Focusing additional analysis on the sub-sample of smaller *acequias* is informed by basic theory and intuition. While having few users has been shown to aid in initiating collective action to manage a CPR, here we are dealing with regimes which have already been established. Therefore the larger the group, the more insulated the community will be from a disturbance caused by new users. The underlying mechanism is that larger groups will have designed institutions which are more formal in order to handle the large number of users. In contrast, one would expect the smaller groups to rely more on informal mechanism such as norms, trust, and reciprocity. This is borne out in the data. Table 8 presents summary statistics for the small *acequias* compared to the larger ones.[7] Of particular note are two distinctions. First, the smaller *acequias* tend to have higher levels of NDVI on average, indicative of smaller groups being more successful in general. Additionally, the propensity to have a formal sharing agreement is much lower among the smaller *acequias*, perhaps illustrating the inclination to rely on more informal practices. Data on by-laws filed with the OSE, indicating more formal organization, is sparse in the region with only 6 *acequias* of the 51 having done so.[8] The small sample makes it far from conclusive, but 5 of the 6 do come from "big" *acequias*.

Returning to the issue of panel data and the ability to control for a number omitted variables, Table 4 displays the benefits of it. Both the pooled and between estimator yields point estimates larger in magnitude than the fixed-effects specification, in the case of the between estimator, an entire magnitude larger. This suggests that there is an omitted variable which is positively correlated with new users and negatively correlated with production measured by NDVI (or the vice-versa), as expected. Either way, it would lead cross-sectional analysis to overstate the impact of new users, as it precisely those user groups which do worse which are likely to be subject to more entry and exit. While the bias may go in other directions in other instances, this confirms the concern of OVB in cross-sectional analysis.

Including fixed effects does not necessarily solve the endogeneity issue. It could remain that even within an *acequia* that their remains an omitted variable which is changing over time. While lagging the user group one period helps, it does not remove the possibility entirely that there is an underlying trend. Column (4) of Table 4 uses the lagged dependent variable

[7] While I have defined small at 25 people or less, the results are stable when defining small as 20, 15, or even 10 people or less. Definitions including larger groups changes the results while limiting it to smaller groups leaves 4 or fewer *acequias* in the sample.

[8] This data is as of 1987. Additionally, it is possible *acequias* had written by-laws but were not formally filed.

Table 8--Sample Means

	Small Mean	Big Mean	Difference
NDVI	0.39	0.33	0.06***
No. Users	13.31	98.33	-85.01***
Total Acres	50.48	415.42	-364.94***
Cultural Homogeneity	0.16	0.14	0.02***
Average Acres	4.73	4.96	-0.23
Median Acres	3.03	2.30	0.74***
Land Gini	0.50	0.61	-0.11***
New Acres	1.72	7.92	-6.19***
New Users	0.34	2.21	-1.88***
% New Users	2.72	2.14	0.58**
% New Acres	3.44	1.73	1.71***
Average CFS	26.36	25.84	0.52
Municipal Water Transfer[a]	0.41	0.48	-0.07
% Taos[a]	24.33	9.15	15.17*
Fragmentation[a]	0.99	1.33	-0.34
Sharing Agreement[a]	0.18	0.69	-0.51***
Hydric Soil[a]	55.61	29.26	26.34***
Irrigation Corridor[a]	67.14	32.35	34.79***
Observations	550	725	

Statistically different means

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

[a] Only 1 observation per *acequia*--22 Small and 29 Big

Instead of fixed effects, allowing the omitted variables to change overtime. Here we see the magnitude of the impact is smaller indicating there could remain some OVB. Similarly, including the *acequia* specific time trends in Table 5, Column (2), absorbs those trends while maintaining the fixed effects. In these specifications, the impact is still negative, but smaller in magnitude.

Even among the smaller *acequias*, the impact of the new user is more sensitive to larger shocks, with only instances in the fourth quartile of the empirical distribution producing any significant impact (13.3-37.5 percent). Where trust and reciprocity are important to cooperation, when small disturbances occur the remaining users appear able to maintain system largely as it was before, somehow imposing the norms on the minority of new users.

Column (3) of Table 5 reinforces the social element of the disturbance. Here, the fraction of the acres which are now held by the new users is also included. When this measure is the only measure of new, it is significantly negative. However, when included with fraction of new users, it is insignificant. This bolsters the argument that the pathway is through a break down in the social interaction and not a mechanical relationship to the amount of new acres. Column (4) limits the disturbances to transfers to outsiders, removing intergenerational transfers. The impact is slightly more negative, though not by any significant amount.

Finally, it is worth discussing the model with additional lags of the fraction of new users. The fraction of new users in the next year and this year do not have a significant impact on this year's NDVI. If these were significantly related, there would be considerable concern over the identification strategy and the direction of causality. Going the other direction, the fraction of new users does impact NDVI up to 4 years later. The magnitude remains similar through this time period, though decreases in the fourth year. Then in the fifth year, the impact is no longer statistically significant. Crucially, this indicates that even these *acequias* which are somewhat vulnerable to the disturbance of new users, ultimately they are resilient and recover in a relatively short span of time. Additionally, the very existence of this recovery suggests that it is a social problem and not that the new users are no longer farming.

7 Conclusion

This research has two important contributions to the growing literature of CPRs. First, I identify the impact of introducing a new user into a system built on trust or trust-like behavior and reciprocity. This has important policy implications regarding the continuing use of common property management of resources when the user group appears poised for heavy turnover. Work has been conducted in labs and field experiments to explore this dynamic, but no empirical analysis has directly addressed this issue and how it impacts those that actually live and work with a CPR. The results indicate, in this context, the shock does not have a major impact. The impact is largest when the disturbance is big and the user group is small to begin with. However, even in these instances the shock is mitigated overtime as the users once considered new adapt to the system and build up trust and knowledge after 5 years. Larger turnover alters the social network more and decreases the ability for older users to impose their norms on the new users. Smaller groups likely rely on norms and trust more whereas larger groups have likely formalized more of the operation in order to overcome the issue of the large number. Oddly, this implies that while more users make it difficult to initiate a sustainable communal management regime, once done, it appears more robust to population turnover.

Second, this is one of the first large panel data analysis of CPR institutions. This 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 OVB. In this setting, analysis which ignored the panel structure of the data resulted in the impact of new users estimated to be larger in magnitude, indicating a negative bias. In other words, the *acequias* may experience more turnover due to some other variable which causes cooperation to be lower to begin with. By gathering panel data, research can continue to look at disturbances overtime as well as correcting for a significant amount of OVB.

The impact of user group disturbances needs to be studied in other contexts to assess whether the results are robust in other settings, particularly different resources. As trust is a substitute for monitoring, it is likely less important here where monitoring is eased by the rotational sharing of the water. Use of other communal resources are more difficult to monitor, meaning the role of trust and user group stability is likely more important.

The *acequias* of New Mexico have proven resilient to a number of disturbances throughout their 400 year history in the region. In particular, they have proven resilient to new users replacing the old, though the smaller user groups struggle for a short period. As irrigation in the west continues to change they will continue to be challenged. Of particular concern is the threat of transferring water rights to new uses in locations other than the land historically irrigated. This threat looms large in Taos now that adjudication is complete, giving individuals clear title to the water right. Once water (and its owner) starts leaving the system, the system will alter physically and socially. It will be of great interest to observe if and how the *acequia* users adapt to face this new threat.

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