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Impact of Water User Associations on Agricultural Productivity in Chile

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ABSTRACT

This article uses combined household- and community-level data collected from the Maule Region (VII) of Chile to evaluate factors affecting the decision to participate in yearly irrigation maintenance activities, and the influence of current behavior on farm revenues. Empirical results indicate that water user association characteristics explain much of the variation in participation decisions, contribution amounts, variable input purchases, and subsequent farm revenues.

Keywords: Chile, Water User Association, participation, irrigation

ABBREVIATIONS AND ACRONYMS

CdAs	Comunidades de Agua
WUA	water user association
JdV	Juntas de Vigilancia
AdC	Associacións de Canalistas
IMR	Mills ratio

1. INTRODUCTION

Water regulation has a deep and storied history in Chile, dating back nearly 200 years. From the first known water decree of 1819 to the renowned National Water Code of 1981, Chile has steadily earned international recognition for its innovative and market-oriented approach to water management. Today, water rights in Chile, in law, are fully transferable and separable from land, tradable through market negotiations, and independent of land use.

Theoretically, a market-based approach to the management of resources, particularly water, has many advantages over public management. When markets function correctly, the price reflects scarcity, and thus the opportunity cost of the resource. Optimally behaving individuals will buy and sell the resource until their marginal costs are equated to marginal benefits. Incentives to overuse the resource are reduced because the price reflects the negative externalities normally associated with overuse. Similarly, incentives to underinvest in the maintenance of irrigation infrastructure are reduced. Hence, overall economic efficiency should increase under a market-based approach.

However, markets do not always function perfectly. In the case of water markets, additional investments must be made in infrastructure and technology to ensure the flow and monitoring of the water across households and geographic areas. A variety of institutions are necessary at the national, state, and local level. Moreover, proper balance must be maintained between private and public interests to keep the market functioning. Despite Chile's advanced system of water management, in which local Comunidades de Agua (CdAs), or water communities, and their umbrella organizations manage the majority of local infrastructure, Bauer (1997) finds that geographic, infrastructural, legal, and administrative barriers greatly limit the amount of water traded.

In rural areas, where water tends to be traded less and is mostly used as an essential farm input via irrigation canals, CdAs have gained recognition as an alternative to national or state-run resource management institutions (Meinzen-Dick et al. 1997). Because rural communities tend to share irrigation infrastructure, which transforms the water into a common-pool resource, CdAs face many of the classical problems of collective action in their management (see Ostrom 1990).

From a household perspective, water users must decide whether or not to contribute to jointly used infrastructure. In communities where punishment for not contributing is rare or group size is large, incentives exist to free ride on the contributions of others. If monitoring of resource use is absent or weak, headenders (those at the front of the canal) have incentives to overuse the resource and undermaintain the infrastructure, imposing an externality on tailenders (those at the end of the canal), particularly in regions where market infrastructure to facilitate water trades is absent. Heterogeneity among users, in terms of the quality and quantity of land endowments, as well as human capital and the opportunity costs of labor, lead to differences in the marginal productivity of water and thus different incentives to use and maintain shared resources and infrastructure. Ultimately, the characteristics of the household, the community, and the CdA will influence the contribution decision (Fujiie et al. 2005; Ostrom and Gardner, 1993).

From the CdA's perspective, leveraging funds and maintaining canals will thus critically depend on the CdA's ability to coordinate support from a critical mass of heterogeneous users. Management skills, membership size, social connections, and regional history are a few of the many characteristics that will influence coordination efforts. If too few individuals contribute, maintenance funds and labor may be underprovided, causing existing facilities to deteriorate or even collapse and generating potential water shortages at the community and household level. Coordination of households' contributions to infrastructure maintenance is essential to the proper management of water as well as to the revenues of farmers reliant upon irrigation as an essential input.

The purpose of this study is to analyze the interplay of CdAs and water users in the Maule Region (VII) of Chile. Specifically, the study is concerned with answering the following questions:

1. Which household and CdA characteristics influence the type (labor/money) and amount of participation selected by households?
2. What factors appear to help or hinder collective action decisions at the CdA level?

3. How are variable input purchases and farm revenues influenced by factors driving the participation decision?

The study is organized as follows. Section 2 develops a theoretical model that integrates standard features of common-pool resource management problems. Predictions are made regarding the behavior of water users under a variety of circumstances. Section 3 reviews the area of study and the institutional framework of the water management system. The fourth section discusses the data used and relates the predictions of the theoretical model to key variables used in the analysis. Section 5 reviews the empirical approaches employed, and Section 6 summarizes the results. The final section offers conclusions and discusses policy recommendations based on the empirical results.

2. CONCEPTUAL FRAMEWORK

Relevant Theoretical and Empirical Literature Review

The modern theoretical underpinnings of common-pool resource management date back to Gordon (1954), Olson (1965), and Hardin (1968). The early literature focused on the behavior of self-interested individuals, predicting that unless group size is small or coercion mechanisms exist, individuals will not act to achieve common or group interests. Sandler (1992) synthesized the advances in understanding individual collective action since Olson's seminal work, mainly in the provision of public goods. Sandler's work emphasizes that few general predictions can be made regarding factors affecting the successful provision of public goods because outcomes will depend on the underlying technology generating the public good, strategic assumptions made about interacting agents, and agents' tastes and preferences. Baland and Platteau (1999) specifically evaluate how heterogeneity in wealth may or may not hinder successful collective action. To the extent that the wealthy gain more at the margin by provision of the public good, they may provide a large share of the good themselves; however, to the extent that the wealthy have greater opportunities to substitute for the collective good, collective action may be harder to sustain. In the context of irrigation user groups, Repetto (1986) modeled the negative impacts on individuals' incentives to participate in collective action where links with higher-level organizations (usually government agencies) were weak.

At the group level, Ostrom's (1992) seminal work on self-governing irrigation groups lays out eight design principles hypothesized to foster successful irrigation use and maintenance activities at the level of the water user association (WUA). These factors include clearly defined boundaries, proportional equivalence between the costs borne by members and the benefits they receive, collective choice arrangements, monitoring systems, graduated sanctions for enforcement, conflict resolution mechanisms, an external authority that either passively grants or actively supports members' right to self-organize, and the nested institutions required to ensure that management of complex irrigation systems occurs at the "right" level.

There is also a large body of empirical literature examining the success of collective action in managing irrigation systems, of which we will mention but a few examples.[1] Gulati, Meinzen-Dick and Raju (2005) present detailed analysis concerning the management of irrigation systems in India. Results indicate that the relationship between the WUA and the higher-level government agencies responsible for water flow and maintenance of primary canals affects intra-WUA capacity to support successful collective action; the importance of the links with higher-level organizations is also captured in Lam (1998), Rice (1997), and Wade (1995). Internal factors affecting WUA success include whether the WUA-managed canal covered just one village or multiple villages (as covering multiple village reduces effectiveness); whether other important social organizations were located in the village and whether a traditional leader or college graduates were present in the community (all of which are hypothesized to reduce the transaction costs of meeting and coordination); and whether the group was sufficiently large and close to a market, indicating that economies of scale in providing collective goods and services were particularly important, especially where crop returns were higher. Results obtained by Fujiie et al. (2005) indicate that when irrigation associations have many members, and when the ratio of nonfarm households is high, the collective action needed to maintain canals is difficult to organize and sustain; thus, economies of scale can be outweighed by increased coordination, monitoring, and enforcement costs. A number of authors have also found that social and/or economic heterogeneity has a negative impact on the functioning of WUAs, including Dayton-Johnson and Bardhan (2002), Khwaja (2000), Lam (1998), and Tang (1992).

[1] For a more complete review, compare Grootaert and Bastelaer (2002) and Lipton, Litchfield, and Faures (2003).

Model Development

The theoretical models discussed above are generally based on cooperative or non-cooperative game theory and concentrate on the single decision regarding how much of the public good to provide. Water is but one input into crop production, however, and in this section we develop a two-person, two-input non-cooperative model of farmers' decisions to provide a public good and purchase private inputs.

Consider the profit function, $\pi_i = f_i\left(k_i, w_i\left(\sum_{i=1}^{N} x_i\left(Z_j^{WUA}\right)\right); Z_i^{hh}, C_c\right) - c_k k_i - c_x x_i$, where

output price is normalized to 1; k_i is the variable input of the *i*-th player, the use of which does not affect others' profits directly; w_i is effective irrigation water applied, which is a function of the contributions of the N irrigation user group members in maintaining the irrigation canals; Z_i^{hh} and C_c are vectors of household- and community-level characteristics that affect the profitability of agricultural production; Z_j^{WUA} is a vector of the irrigation user group characteristics; and, c_k and c_x are the unit costs of the two variable inputs, respectively. Essentially, we can think of as purchased crop inputs and as the value of the contribution to operating and maintaining the canal infrastructure.

We assume that $\frac{\partial f_i}{\partial x_i} > 0$, $\frac{\partial f_i}{\partial k_i} > 0$, $\frac{\partial f_i}{\partial x_{\sim i}} > 0$, $\frac{\partial f_i}{\partial x_i} = \frac{\partial f_i}{\partial x_{\sim i}}$, $\frac{\partial f_i}{\partial k_j} = 0$; and $\frac{\partial^2 f_i}{\partial x_i^2} < 0$, $\frac{\partial^2 f_i}{\partial x_i \partial x_{\sim i}} < 0$, $\frac{\partial^2 f_i}{\partial k_i^2} < 0$, $\frac{\partial^2 f_i}{\partial x_i \partial k_i} > 0$ and $\frac{\partial^2 f_i}{\partial k_i \partial k_j} = 0$. These conditions ensure that each individual's agricultural production function is strictly concave in the two inputs, that water and the purchased input are gross substitutes in production, and that contributions to maintaining the irrigation canal generate a pure public good via perfectly substitutable contributions among members. Suppressing household and community characteristics in the production function, each individual maximizes the following:

$$\max_{k_i, x_i} \pi_i = f_i\left(k_i, w_i\left(\sum_{i=1}^{N} x_i\right)\right) - c_k k_i - c_x x_i$$

this results in the following first-order conditions (FOCs):

$$\frac{\partial \pi_i}{\partial x_i} = \frac{\partial \pi_i}{\partial w_i}\frac{\partial w_i}{\partial x_i} = \frac{\partial f_i}{\partial w_i}\frac{\partial w_i\left(\sum x_i\right)}{\partial x_i} = c_x \tag{1}$$

$$\frac{\partial \pi_i}{\partial k_i} = \frac{f_i\left(k_i, w_i\left(\sum x_i\right)\right)}{\partial k_i} = c_k \tag{2}$$

and similarly for each player.

Next consider the social optimizer's problem, which, given that agents are homogeneous, is the same as joint maximization. This is written as follows:

$$\max_{k_i, x_i} \sum \pi_i = \sum f_i\left(k_i, w_i\left(\sum x_i\right)\right) - c_k k_i - c_x x_i$$

This yields the following FOCs:

$$\frac{\partial \sum \pi_i}{\partial x_i} = \frac{\partial \sum \pi_i}{\partial w_i}\frac{\partial w_i}{\partial x_i} = \frac{\partial f_i}{\partial w_i}\frac{\partial w_i\left(\sum x_i\right)}{\partial x_i} + \sum \frac{\partial f_{\sim i}}{\partial w_{\sim i}}\frac{\partial w_{\sim i}\left(\sum x_i\right)}{\partial x_i} = c_x \tag{3}$$

$$\frac{\partial \sum \pi_i}{\partial k_i} = \frac{f_i\left(k_i, w_i\left(\sum x_i\right)\right)}{\partial k_i} = c_k \tag{4}$$

and similarly for each *i*.

Comparing the derivatives with respect to x_i for the individual versus the social optimizer (comparing equations [1] and [3]), we immediately note that [1] < [3] when evaluated at the same x_i, k_i pair, since $\frac{\partial f_i}{\partial x_{\sim i}} > 0$. The following holds when evaluating the FOCs at the same x_i, k_i pair:

$$FOC_{xi}^{NC} < FOC_{xi}^{SO}$$

$$FOC_{ki}^{NC} = FOC_{ki}^{SO}$$

where SO and NC in the superscript refer to the inputs resulting under the social optimum and non-cooperative game, respectively. If second-order conditions are satisfied, then the only possible solution is for $x_i^{NC} < x_i^{SO}$ and $k_i^{NC} < k_i^{SO}$.[2] Thus, both private and public inputs are lower than optimal and total revenues are also lower than would be the case under the social optimum.

Extensions to the simple model above would include allowing for heterogeneity across players. First consider the simplification in which water is the only choice variable, and is given. In the two-player case, and assuming that player one uses water more productively than player two, the following results:

$$FOC_{x1}^{NC} > FOC_{x2}^{NC}$$

In this case, we obtain the standard result in the two-player game that the more productive player would be "exploited" by the less productive player, since the first player would have greater contributions in equilibrium. Considering now the private input, k_i, the decision for both players would depend on whether $x_1 + x_2$ with heterogeneity were greater or less than $x_1 + x_2$ where players are homogeneous. With linear reaction functions, for instance, $x_1 + x_2$ would be the same under both heterogeneity and homogeneity, and thus k_i would be unchanged.[3] Another source of heterogeneity arises from the location of the irrigator along the irrigation canal. Every irrigator has an incentive to keep the shared canal or canals clean above his or her own lateral, but the marginal incentives to do so will be greater for tailenders than for headenders, to the extent that the marginal return to keeping the canals well maintained increases as the water passing through declines (compare Freeman 1990).

An additional extension is to consider the game in a dynamic framework. The focus in this paper is on evaluating factors affecting the decision to participate in yearly maintenance activities; the "impacts" of current behavior occur in one period, with no further impacts on next-period production. In other words, there are no dynamic externalities. In a repeated game, then, the Folk Theorem tells us that

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[2] Because we assume that contributions to irrigation maintenance are perfectly substitutable, and that they generate a pure public good, second-order conditions for the four-equation system will be satisfied whenever second-order conditions are met for the corresponding two-equation individual maximization problem. Also note that this game has a unique solution; in other words, it has a "prisoner dilemma"-like incentive structure (compare Dasgupta and Heal 1979) and not a "coordination" type structure. This is due to the fact that we have assumed that $\frac{\partial^2 f_i}{\partial x_i^2} < 0$, that is, increasing effective water availability increases with contributions at a decreasing rate, which seems the most realistic assumption in this context.

[3] The reaction functions will themselves be a function of the substitutability between water and other inputs in production. Where, as here, substitutability is limited, it is more likely that total contributions will remain unchanged. Total contributions are more likely to fall where the public and private goods exhibit greater substitutability in production.

socially optimal maintenance levels can be achieved, but so can a bounded but infinite set of maintenance levels, including the Nash non-cooperative equilibrium. However, most irrigators form water user groups to manage these incentives and coordinate actions to reach the repeated-game possibility of socially optimal maintenance levels. That is the case in our study area, where the CdAs are the WUAs.

The goal of a WUA is to ameliorate directly the incentives to underprovide contributions to irrigation maintenance, which should also indirectly increase use of the private input and thus total output as well. The ability of the WUA to do so will depend on its ability to collect contributions, which, following McCarthy, Sadoulet, and de Janvry (1998), should depend on the incentives of group members to contribute or not contribute, as well as on the community-level characteristics discussed above.

The most important factors in our study area are the number of members, economic heterogeneity, and CdA links to other organizations in the irrigation scheme. There is limited social heterogeneity in the study area, and the roles and responsibilities of the CdAs are recognized in law. The CdA makes decisions regarding the level of monetary and/or labor contributions to request of members, and members subsequently decide on their contributions. While nonpayment of quotas for water rights made to higher-level water user organizations may lead to termination of irrigation water in the study area, we observed few punishments or attempts (other than through moral suasion) to force compliance with CdA contributions. The CdA thus chooses the value of contributions that maximizes the effective water supply for users given the costs of monitoring and enforcing those contributions.

Thus, the CdA chooses x^*_{CdA} as a function of the characteristics of the users (e.g., the number of users and economic heterogeneity), the characteristics of the water resources effectively available to the community (e.g., the location of the CdA canal within the irrigation system, the functioning of the higher-level irrigation authority in terms of operation and maintenance of the primary canals, and their links to neighboring CdA irrigation authorities in operation and maintenance), and the decision-making rules used by the CdA (e.g., whether votes or consensus are relied on to reach decisions). These factors comprise the vector Z^{WUA} in the profit function given above. Thus, the reduced form input and crop revenue equations can be written as:

$$x^* = f(Z_i^{hh}, Z_j^{WUA}, C_c, c_k, c_x) \tag{5}$$

$$k^* = f(Z_i^{hh}, Z_j^{WUA}, C_c, c_k, c_x) \tag{6}$$

$$\pi_i^* = f(Z_i^{hh}, Z_j^{WUA}, C_c, c_k, c_x) \tag{7}$$

3. REGIONAL OVERVIEW

The study focuses on the Maule Region (VII) of Chile. Located in central Chile and bisected by the Maule River, from which the region takes its name, the area is predominantly rural. Agricultural production, for both domestic and export purposes, is one of the primary economic activities. Due to the semiarid environment, irrigation water is an essential input into the agricultural production function and is delivered by a variety of mechanisms. Figure A.1. in the appendix provides a detailed view of the area.

The institutional setup of the private water sector in Chile is organized in a hierarchical manner, with some overlap in organizational responsibility (Berger et al. 2007). At the local community level, water users are organized into Comunidades de Agua (CdAs). These groups are primarily responsible for distributing water to users' plots, maintaining secondary and tertiary irrigation channels, and collecting fees for higher-level organizations. At the next highest level, Associaciónes de Canalistas (AdC, canal associations) and/or Juntas de Vigilancia (JdV, watch committees) are compromised of CdAs receiving water from one irrigation channel. In some cases, a CdA may belong to an AdC, which may in turn belong to a JdV, while in other cases, a CdA may belong directly to a JdV; this generally depends on whether the CdA receives water through the main canal or a secondary channel. These bodies mainly oversee the distribution of water into canals serving the CdAs and the maintenance of primary channels, as well as managing the distribution of water from larger bodies of water (e.g., streams, reservoirs, and lakes) to primary channels. The AdCs and JdVs may also provide additional services to CdAs; for instance, some JdVs have permanent hydrological engineers on staff who can provide advice to CdAs considering alternative infrastructure upgrades or investments, some have developed sophisticated computer databases that are used to provide strategic planning and investment information, and others organize various maintenance tasks for the CdAs themselves. Finally, in some cases CdAs receive water directly from rivers or streams, or from spillovers from other CdAs; in these cases, the local CdA is not linked to either an AdC or JdV. Whereas all the CdAs that belong to a JdV or AdC are formally registered, five of the CdAs that are not directly tied are not formally registered, and thus are not legally recognized WUAs; however, individual farmers' rights to water may still be recognized, with the possible exception of spillover rights. Because we do not further distinguish between membership in either a JdV or AdC, hereafter we simply use "JdV" for convenience, even though the CdA may actually belong to either an AdC or JdV.

4. DATA

While theoretical models provide a foundation for examining and predicting a household's contribution decision, data capturing the actual conditions of the environment permit the testing of theoretical results through statistical inference. The data used in the study are from two surveys administered under the auspices of the International Food Policy Research Institute (IFPRI). The purpose of the surveys was to collect information on the empirical conditions of the water management institutions (primarily CdAs) and households. As a first step in data collection, lists of all CdAs were obtained from all relevant JdVs in the study region; these lists included all CdAs in the JdVs' areas of influence, whether or not the CdAs actually formally belonged to the JdVs. Next, from the list of CdAs, 35 were randomly selected and interviewed. During each CdA interview, enumerators collected lists of all households holding water rights within the CdA. From these lists 8–12 households were randomly selected and interviewed. Information from both the household and CdA level were integrated to form a final data set, which contains 318 households falling within the jurisdiction of 35 CdAs distributed across five JdV areas.

Comunidades de Agua

While every household falls within a CdA jurisdiction, and each CdA within a JdV jurisdiction, only 19 of the 35 CdAs are members of their respective JdVs. In total, 174 households are members of CdAs that are also members of JdVs. This leaves 144 households as members of CdAs that are not directly tied to their local JdVs. As discussed in the section on the empirical approach, the CdA's membership status within a corresponding JdV may influence a household's decision to provide monetary or labor support to the local CdA, since this support will be in addition to quotas paid to the JdV. As noted above, besides ensuring the operation and maintenance of the primary canal, JdVs may also provide information and technical services, and may help organize—or even manage—maintenance and repair of the secondary canal system, so that accounting for membership in a JdV is required to control for household-level contributions to the CdA. The potential impact of membership in a JdV on overall expenditures for maintenance and repair are reflected in the total monetary contributions made by irrigation users. Table 1 below presents descriptive statistics on users' contributions to the CdA and the JdV. Using the daily agricultural wage rate, the value of labor is far higher for users belonging to CdAs that do not belong to a JdV than for those that belong to a JdV—12,653 Chilean pesos (CP) versus 4,851 CP, a difference that is statistically significant at the 1 percent level. In terms of cash contributions, for users in CdAs that are part of a JdV the average figure is 12,624 CP, compared to 27,449 CP for users whose CdAs do not belong to a JdV, which is also significant at the 1 percent level. The total value of contributions is more than double; however, where a CdA belongs to a JdV, the quota is nearly the same as the total value of contributions for those whose CdA does not belong to a JdV, so that total contributions are higher for users who belong to a CdA that belongs to a JdV. Net revenues per hectare are also higher for those whose CdA belongs to a JdV, a difference that is statistically significant at the 5 percent level.

Table 1. User contributions to CdA and JdV

	Belongs to JdV	Does Not Belong to JdV
Outcome Variables		
Value of labor provided to CdA (pesos)	4,851	12,653
Cash outlays to CdA (pesos)	12,624	27,449
Total value of labor and cash	17,474	40,102
Quota paid to JdV	39,494	
Total CdA and JdV contributions	56,968	40,102
Net revenues per hectare	1,035,791	933,466
	174	144

Source: Authors

As noted above, one factor distinguishing CdAs is their relationship with higher-level organizations, and whether or not they are registered (most are registered, but many are not formally linked to higher-level organizations). From the literature review, it appears that the most important factors affecting collective action in such organizations are membership size and heterogeneity among members. The smallest CdA in our sample had just 10 members, whereas the largest had 200; the mean was 40 members. As a measure of economic heterogeneity, we asked about the smallest and largest landholdings in the community; landholdings ranged from 1.5 hectares to 200 hectares, with an average of 64 hectares.

Following Ostrom's design principles, as discussed above, internal structures may also affect households' decisions to participate in collective action. In terms of water allocation rules, all but one CdA followed a "by turn" distribution system, so there was very little differentiation along this dimension. In terms of monitoring and enforcement, all but two communities relied solely on "moral suasion"; even if a potential sanction was mentioned, very few sanctions were levied. Thus, CdAs did not differ along this dimension. The CdAs did differ in terms of whether or not decisions are made predominantly by vote or by consensus, and how actively the president interacts with other CdA presidents, higher-level water user organizations, and relevant government agencies. Decisions are taken by consensus in 14 of the communities.[4] The "connectivity" of the president with representatives of other water user organizations is captured by the number of different representatives that were met with during the past year; on average, CdA presidents met with just 0.4 representatives, with the number ranging from 0 to 3. Of the four unregistered CdAs, three in fact had no recognized "president" or indeed any formal CdA organization, and information on the structure and functioning of these CdAs is thus not applicable. We do have information on whether or not these CdAs belong to a JdV and on the total number of users for all CdAs; in the analysis below, we present results for two specifications: those including just the information on membership in a JdV and number of users, and an additional specification (with fewer observations) for those with a functioning CdA.

In terms of hypothesized impacts on households' contribution decisions, group size is generally thought to increase under provision in public-good games mainly due to increased transaction costs. However, some authors have argued that the relationship between collective action and group size may be positive or have an inverted U-shape (consult Sandler 1992), particularly for lumpy investments or maintenance activities exhibiting increased returns to scale over the relevant range (e.g., hiring equipment

[4] The relationship between consensus decision making and the number of members is negative, as might be expected; in fact, the simple correlation coefficient is -.15.

to clean all the CdA canals or repairing the main intake). In these latter cases, very small memberships may make collective improvements very expensive, while larger memberships reduce the required per member contributions. At some point, however, transaction costs will offset gains from reduced per member requirements, thus leading to lower overall contributions. We tested the U-shape hypothesis in the estimations below, using a quadratic specification; this specification did not reveal a U-shaped relation. Instead, we used the natural log of the number of members, which performed best in the estimations; this specification would capture increasing returns to membership at a lower rate as membership grows (and transaction costs figure more prominently). Next, we hypothesize that households located in communities that are members of higher-level JdVs should have lower contributions, as the JdV often organizes and spends resources on more than just the primary canal, as discussed above.

For the smaller subset with functioning CdAs, we hypothesize that heterogeneity, captured by the land difference within the community, reduces contributions.[5] Greater connectedness of the CdA president to other actors in the irrigation system should increase contributions by increasing the CdA's efficiency through increased information sharing, perhaps greater access to external resources, and better coordination. Finally, we include a dummy variable that equals 1 when the consensus method is used in decision making. On the one hand, voting should be more efficient, particularly in larger groups, but consensus may be more useful to successful negotiations when members have different incentives and constraints outside the landholding differences already accounted for in the estimations. A priori then, we have no specific hypothesis on this variable.

Households

In addition to labor and monetary contributions to the CdA, the relevant endogenous variables for the household are revenues per hectare and purchased inputs. Households grow a wide variety of different crops, including grains, contract crops, and perennials. Maize, wheat, rice, beans, and potatoes are commonly grown for domestic markets and local consumption. Raspberries are the primary export crop grown in the study area. Sugar beets and, to a far less extent, tomatoes are also produced, largely on a contractual basis. Five households did not cultivate any land, 13 households dedicated activities exclusively to livestock production, and 12 households planted a variety of "household-garden" crops on very small land areas (two-tenths of a hectare, on average). Because of the difficulty in valuing output per hectare from these farms, these observations were not used in this analysis. Finally, given available information on prices, an additional 18 observations were dropped for those households that produced crops with missing or no information on the relevant market rate.[6] For the remaining 270 households, 176 grow row crops only, 54 grow only high-value crops (raspberries or sugar beets), and 37 grow both row crops and high-value crops. While such crops do entail different investments and input requirements, we aggregate gross returns per hectare, which then reflects both yields and the crop mix chosen.[7,8] We also run two factor equations, one being expenditures per hectare on purchased inputs such as pesticides, herbicides, and fertilizers, and the second being expenditures per hectare on labor and/or equipment hire.

Exogenous Variables

At the crux of the study are the questions regarding how and why households contribute to irrigation maintenance, given CdA characteristics and factors directly affecting household-level incentives. As

[5] Though this is not a CdA "structure" variable, the question was not asked in communities without a formal CdA.

[6] Excluding only the 13 households that focused exclusively on livestock, the area cultivated in crops that were used in this analysis (wheat, maize, beans, rice, sugar beets, and raspberries) comprised 90 percent of the total area cultivated, on average.

[7] In the appendix, Table A.3, we present results for row crops separately, using a selection regression to account for the choice to grow row crops. Given the few observations on high-value crops, the selection regression never converged; thus, we cannot present results for this subset. Results for row crops are qualitatively similar to total gross revenues.

[8] Because certain households had very low yields for a variety of reasons (net revenues were negative for 18 households), we chose to run the regressions in log gross returns. The simple correlation coefficient between gross and net returns is .88.

noted in the discussion of the conceptual framework, a number of exogenous household- and community-level characteristics will have different effects on a household's contribution decision, use of purchased inputs, and total farm output. A full descriptive summary of the dependent and exogenous variables is reported in the appendix, in Table A.1.

At the household level, human capital measures—such as labor availability, measured as the number of adults in a household; the age of a household head; and the average years of schooling for adults in the household—are hypothesized to have a positive effect on overall contributions, purchased inputs, and farm revenues. However, in terms of labor or monetary contributions, the sign on labor availability may be ambiguous, as poorer households with more labor may tend to avoid monetary contributions in favor of labor. Higher levels of education and experience within a community should positively influence a household's contributions, to the extent that these variables increase the marginal returns to irrigation, thus leading to greater purchased inputs and farm revenues, both directly and indirectly. Farm management ability is captured by a dummy variable for whether or not the farm household maintains book-keeping records. Typically, households involved in keeping records are more cognizant of the optimal input mix, having learned from past experiences. The effect of book keeping is posited to have a positive relationship on contributions to the CdA, greater purchased inputs, and higher farm revenues, for similar reasons as education and experience. Total land endowments and the number of agricultural implements control for fixed inputs; both should lead to greater contributions to the CdA, to the extent that greater agricultural assets increase the marginal return to water. Given previous empirical work, gross returns and factor expenditures are likely to decrease or remain constant as the total land endowment increases. Agricultural assets may also have a positive or negative impact on gross returns and factor expenditures (though they should be positive for net returns), depending on the substitutability between such assets and other expenditures, for example, equipment hire. Household wealth, measured in terms of the number of consumer durables, controls for wealth differences across households. To the extent that greater wealth captures greater access to credit and reduced transaction costs in purchasing inputs and marketing outputs, greater wealth should lead to greater contributions to the CdA as well as more purchased inputs and higher overall net revenue. Finally, the distance to the nearest market is hypothesized to affect negatively contributions, purchased inputs, and farm revenue, as isolated households may face less pressure from social sanctions and the costs and the marginal revenue for marketing crops are lower.

Means Test

Given the hypothesized effect of household- and community-level variables, a cursory testing of means between contributors and noncontributors for each activity provides a useful baseline from which initial comparisons can be drawn and hypotheses tested. While means testing is not conditioned on other explanatory variables, the exercise is useful, as it can uncover stark differences between the contributors and noncontributors. Table A.2, in the appendix, summarizes the results for each contribution category, with the null hypothesis in each test being that the means between the two groups are equal.

Of the 270 households, 157 provide labor to their local CdA. The means-testing exercise reveals that households living in communities with less land inequality and further away from agricultural markets give labor. Transitioning to monetary participation, the results show that 148 households provide money. Well-organized (book-keeping) households in well-connected CdAs are more likely to make monetary contributions. This may also reflect an advanced organizational capacity of the CdA. For households providing both labor and money, the results are similar. The following section extends the analysis, building on theses preliminary findings.

5. EMPIRICAL APPROACH

Modeling Participation and Contributions

This study is primarily concerned with (1) evaluating the household- and community-level factors that affect a household's decision to participate in yearly canal maintenance activities and (2) examining how variables that influence the contribution process also affect purchased input choices and farm revenues. The outcome variables of interest for the first question are the number of labor hours or pesos contributed. To analyze the first step of the problem, we must consider the possibility that an underlying decision process may directly influence the amounts contributed to each activity. Certain households may be more inclined to give labor rather than money, or vice versa.[9] If the sub-sample of labor contributors is not random, this *selectivity* may bias the coefficients in the regression estimating the number of labor hours contributed. To correct for this potential *selection bias*, we employ a Heckman two-step estimator to model each contribution process. In the first stage, we specify a probit regression for the binary decision to contribute labor (money/money or labor):

$$d^* = X\gamma + u_i$$
$$d = 1 \text{ if } d^* > 0, \text{ 0 otherwise} \tag{8}$$

where X is a vector of exogenous household, community, and CdA characteristics influencing the participation decision and is an error term with mean 0 and variance 1. The second stage then uses a truncated least-squares regression to estimate the level of contributions:

$$C^* = X\beta + v_i \text{, observed if d = 1} \tag{9}$$

where X is a vector of exogenous household, community, and CdA characteristics influencing the participation decision and v_i is an error term. We assume that u_i and v_i take on a bivariate normal distribution (ui, vi) ~ N (0, 0, 1, σ2, ρ) and ρ is the correlation between the error terms. In the second step, we obtain unbiased estimates by including the inverse Mills ratio (IMR) for selectivity bias obtained from the estimation of the first equation. Statistical significance of the t-statistic on the IMR variable in the second stage supports the conjecture of selection bias in the sample. We also adjust standard errors for clustering at the CdA level.

In total, the study uses three Heckman two-step estimators to model the contribution process of labor, money, and money and labor. Due to missing values for selected variables, the sample size is smaller than the total observations for each of the analyses.

Purchased Inputs and Farm Revenues

To determine how the exogenous household- and community-level characteristics influence variable input purchases and farm revenues, the study transforms the reduced form solutions above (equations 6 and 7) into a modified linear regression model:

$$\ln k_i = \beta_0 + \sum \beta_i Household_i + \sum \beta_j Community/Region_i + \varepsilon_i \tag{10}$$

$$\ln \pi_i = \beta_0 + \sum \beta_i Household_i + \sum \beta_j Community/Region_i + \varepsilon_i \tag{11}$$

[9] Though the CdA-level surveys provided information on the amounts of money and labor requested, either per household or per number of water rights held, informal discussions as well as the descriptive statistics indicate that poorer households appear to informally substitute labor for money, and vice versa, despite the "fixed requests" for labor or monetary contributions reported in the surveys. Instead, the total value of labor or money is likely to be an indicator of overall contributions.

where k_i is the logged value of variable input expenditures per hectare (pesticides and labor and/or machinery), farm revenues per hectare (Yi) are constructed as a logged sum of the revenues from the six primary crops grown among households in the sample (wheat, maize, rice, beans, raspberry, and sugar beet), the household- and community-level characteristics are those referred to in the descriptive analysis, and ε_i is a stochastic error term. Because certain households may be more inclined to use certain inputs, the factor expenditure equation is also modeled using a Heckman two-step estimator similar to the one above. Farm revenues are modeled using ordinary least squares (OLS) with adjusted standard errors for clustering at the CdA level.[10] Missing variables in the data limit the revenue analysis to 262 households.

[10] We also considered a stochastic production frontier model. We found that because of the different crop mixes across households, common production technology was not a plausible assumption.

6. EMPIRICAL RESULTS

Labor and Monetary Participation and Contributions

Tables 2–3, below, present the Heckman two-step estimator results from the contribution process. Table 2 reports two specifications for labor participation and subsequent contributions. The first specification indicates that households with fewer agricultural assets and those in communities that are not part of JdVs are more likely to provide labor contributions. The statistical significance of the incidental variable in the second-stage regression confirms potential selection bias for labor contributions. Given that a household contributes labor, the amount of labor contributed is largely determined by the amount of land and agricultural assets owned, with both variables having a positive influence on contributions. Results from a second specification, adding additional CdA control variables as well as a measure of community heterogeneity (land difference), are also reported. The results are similar to those of the first specification, with the same variables influencing participation. Group size appears to have a negative effect on labor participation. Owning more land and agricultural assets again positively affects labor contributions.

Table 3 summarizes the results for monetary participation and contribution amounts. The first specification indicates that whether or not a household undertakes book keeping strongly influences participation. Conditional on participation, the second stage suggests that owning more land increases contribution amounts, whereas membership in a JdV reduces contributions. The second specification shows a stronger effect on monetary participation decisions than was the case for labor participation. CdA connections and making decisions by consensus are both statistically significant and positive, suggesting that a socially connected CdA president and the more time-consuming but flexible consensus decision-making process are essential for inducing monetary participation. The need to control for selection bias vanishes in the second stage, as the incidental variable is no longer significant. Owning more land positively influences the amount of money contributed (a 1 percent change in landholdings increases monetary contributions by about 0.42 percent), whereas JdV membership decreases monetary contributions.

The analysis is rounded out in Table 4, with similar variables driving the decision and contribution process for both labor and money. One noticeable difference is the positive effect of the household labor supply on the participation decision. The importance of land differences, CdA connections, and consensus voting reappear in the second stage for the second specification.

In summary, the first round of analysis suggests that, for labor participation, households that do not belong to JdVs and that own few agricultural assets are more likely to participate. Of the households contributing labor, agricultural assets and the amount of land owned strongly influence the number of labor hours given. Land differences have little to no statistically significant effect on any of the contribution decisions. At the community level, the size of the CdA negatively affects the probability that a household will contribute labor or both money and labor. CdA size also tends to reduce the amount of labor contributed. There is no effect on monetary participation. The connections of a CdA president moderately affect monetary participation and contributions, and strongly influence the amount of labor and money contributed. JdV membership tends to reduce participation and contribution amounts across all categories.

Table 2. Labor participation results

Dependent Variable	Labor Participation [First Stage]	Labor Contribution [Second Stage]	Labor Participation [First Stage]	Labor Contribution [Second Stage]
Total adults in household	0.052	-0.034	0.0672	0.0221
	[0.0619]	[0.0430]	[0.0651]	[0.0427]
Age of household head (logged)	-0.2831	-0.0805	-0.8240**	-0.3659
	[0.3379]	[0.2691]	[0.3545]	[0.3176]
Average education	0.0480*	0	0.0389	0.0256
	[0.0259]	[0.0136]	[0.0315]	[0.0204]
Book keeping	-0.2505	0.0447	-0.1582	-0.0961
	[0.1964]	[0.1104]	[0.1806]	[0.1401]
Land owned (logged)	0.1216*	0.1218**	0.1390**	0.1901***
	[0.0701]	[0.0526]	[0.0670]	[0.0512]
Agricultural assets	-0.2728***	0.1893***	-0.3028***	-0.0324
	[0.0900]	[0.0677]	[0.0919]	[0.0593]
Distance to nearest agricultural market	0.0136	0.0097	0.0400**	0.0166
	[0.0182]	[0.0102]	[0.0204]	[0.0115]
Durables	0.0654	0.0217	0.1083**	0.0744**
	[0.0513]	[0.0331]	[0.0497]	[0.0332]
CdA belongs to JdV	-0.8205***	-0.0241	-0.8345***	-0.5035***
	[0.2499]	[0.1632]	[0.2658]	[0.1931]
CdA size (members)	-0.2215	-0.1312	-0.3454**	-0.2591*
	[0.1418]	[0.0992]	[0.1520]	[0.1354]
CdA connections	-	-	-0.1275	-0.0138
	-	-	[0.1508]	[0.1369]
CdA decisions made by consensus	-	-	-0.0316	0.0632
	-	-	[0.2158]	[0.1916]
Land difference	-	-	-0.0006	-0.0002
	-	-	[0.0021]	[0.0016]
Constant	1.647	1.5247	3.7729***	1.9935
	[1.4608]	[1.1216]	[1.4452]	[1.3812]
Athrho	-	-0.7174*	-	1.3749***
	-	[0.4315]	-	[0.2689]
Lnsigma	-	-0.3742***	-	-0.2647***
	-	[0.1075]	-	[0.0866]
Observations	270	270	244	244

Notes: The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels. Robust standard errors are in brackets.
Source: Authors

Table 3. Monetary participation results

Dependent Variable	Monetary Participation [First Stage]	Monetary Contribution [Second Stage]	Monetary Participation [First Stage]	Monetary Contribution [Second Stage]
Total adults in household	0.0977	-0.0018	0.0746	0.1117
	[0.0815]	[0.1488]	[0.0853]	[0.1068]
Age of household head (logged)	0.6235	-0.6126	0.4837	0.3087
	[0.3968]	[0.5884]	[0.4017]	[0.2857]
Average education	0.0305	-0.0195	0.0206	0.0081
	[0.0223]	[0.0329]	[0.0291]	[0.0201]
Book keeping	0.6458***	-0.243	0.6711**	0.3688
	[0.2466]	[0.4535]	[0.2797]	[0.2695]
Land owned (logged)	-0.0544	0.4482***	-0.0906	0.4147***
	[0.0692]	[0.1017]	[0.0825]	[0.0724]
Agricultural assets	-0.0249	0.0383	0.0022	-0.0558
	[0.1032]	[0.1517]	[0.1206]	[0.0760]
Distance to nearest agricultural market	-0.0035	-0.0184	-0.01	-0.021
	[0.0144]	[0.0177]	[0.0147]	[0.0152]
Durables	0.014	-0.0473	0.0503	-0.0097
	[0.0449]	[0.0711]	[0.0517]	[0.0501]
CdA belongs to JdV	0.3188	-1.0065***	0.3148	-0.7618***
	[0.2641]	[0.2515]	[0.2823]	[0.2802]
CdA size (members)	-0.0144	0.1464	0.0539	0.1428
	[0.1517]	[0.1169]	[0.1794]	[0.1759]
CdA connections	-	-	0.5304***	0.1782*
	-	-	[0.1558]	[0.0985]
CdA decisions made by consensus	-	-	0.5985**	0.143
	-	-	[0.2477]	[0.1657]
Land difference	-	-	0.0001	-0.0013
	-	-	[0.0024]	[0.0021]
Constant	-3.3385*	13.1924***	-3.2980*	7.4666***
	[1.7816]	[2.9759]	[1.8146]	[1.5768]
Athrho	-	-1.4664***	-	-0.1196
	-	[0.4383]	-	[0.1217]
Lnsigma	-	0.4517*	-	-0.1484*
	-	[0.2683]	-	[0.0884]
Observations	270	270	244	244

Notes: The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels. Robust standard errors are in brackets.

Source: Authors

Table 4. Labor and monetary participation results

Dependent Variable	Labor or Monetary Participation	Total Monetary Value (labor & money)	Labor or Monetary Participation	Total Monetary Value (labor & money)
	[First Stage]	[Second Stage]	[First Stage]	[Second Stage]
Total adults in household	0.3086***	-0.0709	0.3053***	0.0428
	[0.0736]	[0.1027]	[0.0833]	[0.0727]
Age of household head (logged)	1.3582**	-0.3876	0.4786	-0.0541
	[0.6086]	[0.3749]	[0.6407]	[0.2753]
Average education	0.0919**	0.0161	0.0652*	0.0235
	[0.0384]	[0.0189]	[0.0393]	[0.0145]
Book keeping	0.3712	0.1776	0.4846*	0.2599*
	[0.2729]	[0.1882]	[0.2910]	[0.1562]
Land owned (logged)	0.0911	0.2549***	0.0644	0.2913***
	[0.0939]	[0.0706]	[0.1179]	[0.0654]
Agricultural assets	-0.3565**	0.1511*	-0.3086	-0.0007
	[0.1722]	[0.0910]	[0.1941]	[0.0499]
Distance to nearest agricultural market	-0.0254	0.0154	-0.0188	-0.0057
	[0.0239]	[0.0169]	[0.0365]	[0.0119]
Durables	0.0274	0.007	0.1109*	0.0136
	[0.0664]	[0.0382]	[0.0619]	[0.0289]
CdA belongs to JdV	-0.5626*	-0.3076	-0.7866*	-0.4971**
	[0.3048]	[0.2686]	[0.4565]	[0.2146]
CdA size (members)	-0.3066*	0.044	-0.5007**	0.1305
	[0.1745]	[0.1512]	[0.2290]	[0.1530]
CdA connections	-	-	0.0378	0.2714***
	-	-	[0.2512]	[0.0972]
CdA decisions made by consensus	-	-	0.0073	0.2933*
	-	-	[0.3046]	[0.1687]
Land difference	-	-	0.006	-0.0026*
	-	-	[0.0038]	[0.0016]
Constant	-4.1131*	10.6028***	-0.3884	8.8563***
	[2.4364]	[1.6979]	[2.6437]	[1.3727]
Athrho	-	-1.3187***	-0.7069	
	-	[0.4286]	-	[0.4601]
Lnsigma	-	0.1381	-	-0.1543**
	-	[0.1660]	-	[0.0781]
Observations	270	270	244	244

Notes: The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels. Robust standard errors are in brackets.

Source: Authors

Table 5. Pesticide expenditure results

Dependent Variable	Pesticide Participation [First Stage]	Pesticide Expenditures [Second Stage]	Pesticide Participation [First Stage]	Pesticide Expenditures [Second Stage]
Total adults in household	-0.0912	-0.0503	-0.1028*	-0.0862
	[0.0607]	[0.0672]	[0.0562]	[0.0743]
Age of household head (logged)	-0.6284*	0.3124	-0.557	0.1159
	[0.3402]	[0.3601]	[0.3415]	[0.3444]
Average education	0.0258	0.0317	0.021	0.0376
	[0.0291]	[0.0222]	[0.0345]	[0.0248]
Book keeping	0.3339	0.2575	0.2758	0.2382
	[0.2290]	[0.1691]	[0.2491]	[0.1773]
Land owned (logged)	0.2897***	-0.2504***	0.3286***	-0.2145***
	[0.0827]	[0.0765]	[0.1005]	[0.0649]
Agricultural assets	0.2552**	-0.1317*	0.2765**	-0.118
	[0.1180]	[0.0776]	[0.1204]	[0.0781]
Distance to nearest agricultural market	0.0002	-0.0294***	0.0075	-0.0288**
	[0.0184]	[0.0099]	[0.0196]	[0.0125]
Durables	-0.0259	-0.0038	-0.0284	-0.017
	[0.0479]	[0.0304]	[0.0560]	[0.0300]
CdA belongs to JdV	0.3486	0.09	0.7135***	0.1048
	[0.2462]	[0.1322]	[0.2485]	[0.1544]
CdA size (members)	-0.2202*	-0.1443**	0.0034	-0.1722
	[0.1237]	[0.0719]	[0.1538]	[0.1155]
CdA connections	-	-	0.2136	-0.044
	-	-	[0.1350]	[0.0752]
CdA decisions made by consensus	-	-	0.2855	0.0734
	-	-	[0.1794]	[0.1135]
Land difference	-	-	-0.0063**	0.0012
	-	-	[0.0027]	[0.0018]
Constant	1.5397	10.8093***	2.6537*	9.9797***
	[1.6001]	[1.4120]	[1.4546]	[1.4275]
Athrho	-	-0.0367	-	-0.0219
	-	[0.1319]	-	[0.2424]
Lnsigma	-	-0.2862***	-	-0.2688***
	-	[0.0761]	-	[0.0704]
Observations	270	270	244	244

Notes: The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels. Robust standard errors are in brackets.
Source: Authors

Table 6. Labor/machinery expenditures

Dependent Variable	Labor/Machinery Participation	Total Expenditures (labor & machinery)	Labor/Machinery Participation	Total Expenditures (labor & machinery)
	[First Stage]	[Second Stage]	[First Stage]	[Second Stage]
Total adults in household	0.03	-0.0722	0.0156	-0.0687
	[0.0908]	[0.0467]	[0.0968]	[0.0446]
Age of household head (logged)	0.0627	-0.1289	0.3187	0.063
	[0.3942]	[0.2517]	[0.4062]	[0.2947]
Average education	0.012	0.0162	0.0196	0.0219
	[0.0289]	[0.0233]	[0.0322]	[0.0229]
Book keeping	0.122	0.7740***	0.0885	0.6215***
	[0.2720]	[0.1682]	[0.2943]	[0.1592]
Land owned (logged)	0.4333***	-0.1959***	0.4329***	-0.1630***
	[0.0903]	[0.0583]	[0.0990]	[0.0610]
Agricultural assets	0.1032	-0.3679***	0.1339	-0.3795***
	[0.1371]	[0.0590]	[0.1397]	[0.0606]
Distance to nearest agricultural market	0.0062	0.0081	0.026	0.0123
	[0.0191]	[0.0098]	[0.0200]	[0.0099]
Durables	-0.0779	0.0366	-0.0584	0.047
	[0.0565]	[0.0333]	[0.0605]	[0.0345]
CdA belongs to JdV	-0.0218	0.4315***	0.1308	0.5460***
	[0.1972]	[0.1543]	[0.2458]	[0.1718]
CdA size (members)	-0.0525	-0.1859***	-0.0746	-0.1429
	[0.1332]	[0.0665]	[0.1617]	[0.1230]
CdA connections	-	-	-0.071	-0.0286
	-	-	[0.1503]	[0.0923]
CdA decisions made by consensus	-	-	0.5217**	-0.011
	-	-	[0.2204]	[0.1437]
Land difference	-	-	-0.0001	-0.0017
	-	-	[0.0028]	[0.0020]
Constant	0.1603	11.8919***	10.9229***	-1.4298
	[1.7555]	[1.1273]	[1.3197]	[1.9307]
Athrho	-	0.0439	-	0.0065
	-	[0.1105]	-	[0.1567]
Lnsigma	-	-0.0876	-	-0.1408**
	-	[0.0750]	-	[0.0631]
Observations	270	270	244	244

Notes: The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels. Robust standard errors are in brackets.
Source: Authors

Factor Expenditure Results

Tables 5 and 6, above, summarize the results from the factor expenditure equations. First-stage results point out that agricultural assets and the amount of land owned are the primary farm-level characteristics driving the decision to purchase pesticides. At the CdA level, group size negatively influences the decision, though the effect vanishes across specifications. Given that a household purchases pesticide inputs, owning more land and agricultural assets and belonging to a large CdA negatively affect expenditures. However, moving to the second specification, the results are somewhat different. First, whether or not a CdA belongs to a JdV strongly influences the decision to purchase pesticides, whereas CdA heterogeneity tends to reduce participation. While CdA characteristics may affect the decision to purchase pesticide inputs, they appear to have minimal influence on expenditure amounts. The quantity of land owned and the distance to the nearest agricultural market negatively affect pesticide expenditures.

The story differs for labor and machinery expenditures, summarized in Table 6. The amount of land owned again positively influences the decision to purchase labor or machinery inputs, but negatively affects the total amount purchased. Household book keeping and CdA membership in a JdV both have a positive effect on expenditure amounts. Moreover, focusing on the second specification, which adds additional CdA control variables, we see that voting by consensus has a substantial positive impact on whether or not a household decides to purchase labor or machinery inputs. Together, these results demonstrate that certain CdA characteristics may influence the binary decision to purchase a certain type of input, whereas other CdA connections, especially membership in a higher-level JdV, are essential in determining how much income a household allocates to factor input purchases.

Farm Revenues

Table 7 presents the results from three different OLS specifications for farm revenues. The first model is parsimonious and focuses on core household and CdA characteristics. The signs on all the coefficients are mostly consistent with expectations, yet only average education, whether or not a household kept agricultural books, and the distance to the nearest agricultural market were statistically significant. The second specification includes additional CdA control variables. At the household level, education and book keeping again have a positive and statistically significant effect on revenue, whereas agricultural assets and distance to the nearest market have negative effects. A larger CdA, in terms of the number of members, and the social connections of the president both positively influence revenues, but land differences slightly reduce the dependent variable.

To summarize, older, more educated households with greater managerial capacity earn more revenues on average. At the community level, households located in larger CdAs with a well-connected CdA president have higher farm revenues. But in CdAs whose members have vastly different landholdings, revenues are lower, as group heterogeneity appears to impose a cost on community members.

Table 7. Farm revenue results (all crops)

Dependent Variable	Farm Revenues I	Farm Revenues II
Total adults in household	-0.0324	-0.008
	[0.0329]	[0.0292]
Age of household head (logged)	0.1904	0.2222
	[0.1594]	[0.1739]
Average education	0.0321***	0.0360***
	[0.0114]	[0.0131]
Book keeping	0.3077**	0.2689*
	[0.1222]	[0.1428]
Land owned (logged)	-0.0713	-0.0446
	[0.0445]	[0.0472]
Agricultural assets	-0.0827	-0.0920*
	[0.0496]	[0.0450]
Distance to nearest agricultural market	-0.0192**	-0.0197**
	[0.0081]	[0.0079]
Durables	0.0097	0.007
	[0.0223]	[0.0245]
CdA belongs to JdV	0.0404	0.1746
	[0.1098]	[0.1183]
CdA size (members)	0.0503	0.1837***
	[0.0555]	[0.0598]
CdA connections	-	0.1644**
	-	[0.0718]
CdA decisions made by consensus	-	0.0142
	-	[0.0888]
Land difference	-	-0.0035***
	-	[0.0010]
Constant	12.4253***	11.8252***
	[0.7016]	[0.9004]
Observations	262	238
R-squared	0.12	0.138

Notes: The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels. Robust standard errors are in brackets.
Source: Authors

Simulating Policy Interventions

Based on the above analyses, CdA connections and community land differences appear to have opposing effects on monetary contributions and farm revenues. This result induces us to ask what the effect would be of an intervention maximizing the social connections of a CdA president while at the same time ameliorating the negative incentives to contribute money based on heterogeneity in landholdings. To estimate the consequences of such an intervention, we run simulations on monetary contributions and farm revenues, setting the value of CdA connections to the sample maximum (3) and the value of land differences to 0. The simulation results, presented in Tables 8 and 9 below, represent an upper bound on the potential gains. Under the intervention, monetary contributions increase, on average, by 9 percent (9.64 to 10.50), while farm revenues jump by 11 percent (13.32 to 14.73). These results are encouraging from a policy perspective, as they suggest the need for programs to connect CdA presidents across groups and to ameliorate the negative effects of landholding differences on contributions. The final section discusses these policy implications from a broader perspective, integrating the results from all the models.

Table 8. Simulation results for monetary contributions

Monetary Contributions			
	Sample Mean	Coefficient Value	Total
Total adults in household	2.7491	0.1117	0.3071
Age of household head (logged)	4.0186	0.3087	1.2405
Average education	7.0336	0.0081	0.0569
Book keeping	0.5472	0.3688	0.2018
Land owned (logged)	1.7645	0.4147	0.7318
Agricultural assets	0.8218	-0.0558	-0.0459
Distance to nearest agricultural market	1.6251	-0.0210	-0.0342
Durables	6.2764	-0.0097	-0.0608
CdA belongs to JdV	0.5564	-0.7618	-0.4239
CdA size (members)	3.2794	0.1428	0.4682
Land difference	0.0000	-0.0013	0.0000
CdA connections	3.0000	0.1782	0.5345
CdA decisions made by consensus	0.4145	0.1430	0.0593
Constant	-	7.4666	-
Predicted value (mean) / simulated value		**9.639986**	**10.502**
Percentage change			**9%**

Source: Authors

Table 9. Simulation results for farm revenues

Farm Revenues	Sample Mean	Coefficient Value	Total
Total adults in household	2.7491	-0.0080	-0.0221
Age of household head (logged)	4.0186	0.2222	0.8929
Average education	7.0336	0.0360	0.2532
Book keeping	1.7645	0.2689	0.4745
Land owned (logged)	0.8218	-0.0446	-0.0366
Agricultural assets	1.6251	-0.0920	-0.1495
Distance to nearest agricultural market	6.2764	-0.0197	-0.1238
Durables	67.4807	0.0070	0.4741
CdA belongs to JdV	3.2794	0.1746	0.5725
CdA size (members)	0.3927	0.1837	0.0721
Land difference	0.000	-0.0035	0.0000
CdA connections	3.000	0.1644	0.4932
CdA decisions made by consensus	0.4308	0.0142	0.0061
Constant	-	11.8252	11.8252
Predicted value (mean) / simulated value		13.31881	14.7318
Percentage change			11%

Source: Authors

7. CONCLUSIONS

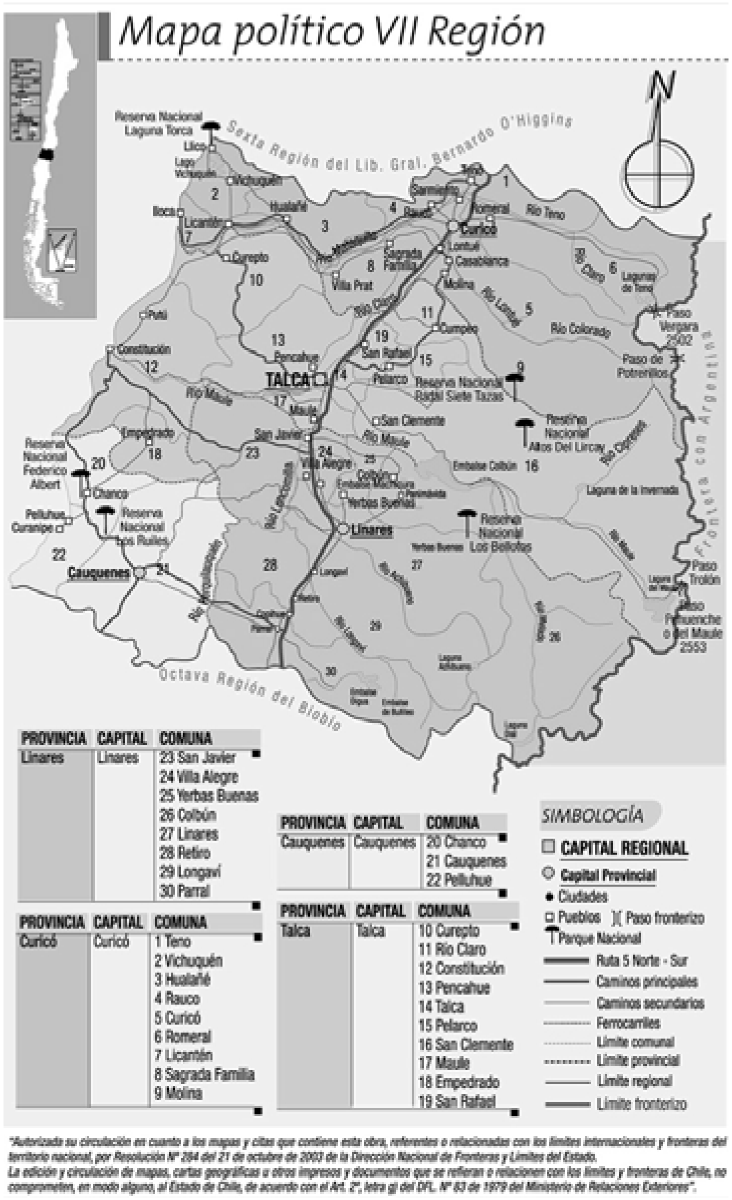
This article uses combined household- and community-level data collected from the Maule Region (VII) of Chile to evaluate factors affecting the decision to participate in yearly irrigation maintenance activities, and the impacts of current behavior on input purchase and farm revenues. A theoretical model is developed to highlight the impact of the decision to provide irrigation maintenance (through contributions) on the simultaneous decision to purchase private inputs and thus on total agricultural output. The empirical analysis reveals that CdA characteristics explain much of the variation in participation decisions, contribution amounts, and subsequent farm revenues. Similar to previous researchers, we find that group heterogeneity, captured by landholding differences within the CdA community, de-incentivizes households to contribute to irrigation maintenance activities and also lowers farm revenues. However, although CdA size tends to reduce labor-based participation, the effect on revenues is positive, indicating that an irrigation group may need to reach a minimum size to effectively implement canal maintenance activities. CdA membership in a higher-level JdV is detrimental to fostering support for CdA contributions but vital in the household's decision to purchase inputs. Membership appears to affect household expenditures on labor and machinery. Finally, connecting CdA presidents to higher-level water authorities and to other CdA presidents appears to have a twofold effect. First, these connections appear to induce monetary participation and increase contributions across all categories. This in turn enables CdAs to keep canals well maintained, thus yielding higher revenues for farmers.

To a policymaker, these findings are of direct relevance for two reasons. First, this study demonstrates the need for policy interventions that address CdA characteristics, specifically the need to account for economic heterogeneity among members and to lower the transaction costs of maintaining connections with other irrigation authorities—be it neighboring CdAs or the JdV. While an intervention may not be able to redistribute land, it can assist CdAs in recognizing and addressing the cost that group heterogeneity imposes on canal maintenance funding, activities, and thus factor expenditures and farm revenues. Alternatively, programs that connect CdA presidents both laterally, across groups, and vertically, to higher-level water authorities, should have positive effects on the ability of the CdAs to improve management of the internal canal infrastructure, due to better information flows and coordination with neighboring CdAs, better coordination with the JdV, and perhaps better infrastructure and reliability of water flows at the turnout. The effect of these connections and the process by which they induce contribution participation and affect farm revenues deserves further research.

Second, in light of the ever-changing climatic environment, our results suggest the need to critically analyze and carefully assess the ability of CdAs to manage resources. Although the Maule Region today relies on adequate mountain runoff, rising temperatures affecting the level of snowfall may place increasing pressure on CdAs and thus on household profit levels and welfare. As water levels ebb and flow, and water scarcity truly becomes an issue, marginal changes in CdA activities and/or characteristics may have dramatic effects on household welfare, food security, and overall irrigation infrastructure. The ability of the household, as well as the CdA, to adapt to climate change must be considered when assessing the impact. Thus, addressing CdA inefficiencies today may not only have immediate effects on household welfare; it may also enhance the ability of CdAs, and thus households, to adapt in the future.

8. APPENDIX

Figure A.1. Political map of Maule Region



Source: Authors

Table A.1. Summary statistics

Dependent Variables				
Participation variables	**Mean**	**Std. Deviation**	**Minimum/No**	**Maximum/Yes**
Labor	0.547	0.499	144	174
Money	0.528	0.500	150	168
Labor and money	0.862	0.346	250	68
Contribution variables				
Labor days	2.096	3.328	0.000	30.000
Total money (logged)	9.655	1.384	0.693	13.592
Total monetary value of labor and money	8.338	3.522	0.000	13.592
Input expenses				
Pesticide	5.40	5.40	0.000	12.43
Labor/machinery	7.90	5.06	0.000	13.81
Output variable				
Farm revenue	13.304	0.728	11.339	15.068
Explanatory Variables				
Household-level				
Adults in household	2.7	1.162	1	7
Age of household head (logged)	4.01	0.27	3.1	4.4
Average education	7.2	3.7	0	18
Book keeping	0.55	0.5	0	1
Total input costs	12.8	1.5	9	16.6
Land owned (logged)	1.6	1.5	-3.07	4.6
Agricultural assets	0.8	0.9	0	4
Distance to nearest agricultural market	**12.8**	**6.5**	**0**	**30**
Consumer durables	6.2	2.0	0	11
Received water on time	0.8	0.4	0	1
Water user group–level				
CdA belongs to JdV	0.55	0.5	0	1
CdA size (members)	40	47	10	200
Land difference	64.1	56.5	1.5	200
CdA connections	0.39	0.74	0	3
CdA decisions made by consensus	0.43	0.5	0	1
Number of observations	318			

Source: Authors

Table A.2. Means test by participation decision in water user associations

	Labor Participation			Monetary Participation			Monetary and Labor Participation			
Characteristics	No	Yes	t-test	No	Yes	t-test	No	Yes	t-test	Total
Household size	2.664	2.809	-0.984	2.639	2.838	-1.359	2.7	2.905	-1.188	2.748
Age of household head (logged)	4.05	3.995	1.699	3.994	4.038	-1.358	4.031	3.976	1.455	4.018
Average education	6.724	7.301	-1.348	6.671	7.38	-1.673	6.736	8.123	-2.806	7.06
Book keeping	0.593	0.58	0.218	0.443	0.703	-4.457	0.536	0.746	-2.997	0.585
Land owned (logged hectares)	1.711	1.823	-0.649	1.569	1.947	-2.225	1.712	1.987	-1.365	1.776
Agricultural assets	0.389	0.42	-0.436	0.344	0.459	-1.641	0.382	0.492	-1.335	0.407
Truck	0.991	0.701	2.391	0.721	0.905	-1.519	0.85	0.73	0.84	0.822
Distance to agricultural market	12.003	14.073	-2.543	13.54	12.931	0.746	12.613	15.159	-2.684	13.207
Consumer durables	6.159	6.363	-0.821	5.951	6.547	-2.45	6.126	6.778	-2.273	6.278
Land difference	81.868	57.221	3.326	54.296	77.224	-3.063	70.343	60.598	1.14	67.827
CdA connections	0.487	0.331	1.658	0.156	0.595	-4.901	0.333	0.603	-2.481	0.396
CdA belongs to JdV	0.743	0.42	5.542	0.459	0.635	-2.934	0.589	0.444	2.035	0.556
Pesticide expenditures	3.444	3.156	2.909	3.225	3.319	-0.949	3.309	3.17	1.185	3.276
Voting by consensus	0.381	0.439	-0.968	0.262	0.541	-4.794	0.333	0.683	-5.144	0.415
Labor/machinery expenditures	5.515	6.289	-1.266	5.57	6.291	-1.187	5.752	6.666	-1.281	5.965
Total revenue	12.464	12.716	-1.378	12.371	12.8	-2.382	12.492	13.007	-2.439	12.612
Monetary participation	0.752	0.401	6.074	-	-	-	-	-	-	0.548
Labor participation	-	-	-	0.77	0.426	6.074	-	-	-	0.581
Total	113	157	-	122	148	-	207	63	-	270

Source: Authors

Table A.3. Grains and high-value crops

Dependent Variable	Row Crop Participation	Row Crop Revenues	Row Crop Participation	Row Crop Revenues
Total adults in household	0.0472	-0.0731*	0.0746	-0.0348
	[0.0796]	[0.0416]	[0.0970]	[0.0327]
Age of household head (logged)	0.315	0.2995**	0.1977	0.3342**
	[0.3774]	[0.1522]	[0.4400]	[0.1485]
Average education	0.029	0.0323**	0.0227	0.0317**
	[0.0293]	[0.0135]	[0.0347]	[0.0131]
Book keeping	-0.3104	0.0486	-0.3342	-0.0049
	[0.2219]	[0.1221]	[0.2196]	[0.1225]
Land owned (logged)	0.4000***	0.1093***	0.3919***	0.1251***
	[0.0930]	[0.0387]	[0.1007]	[0.0353]
Agricultural assets	0.0371	-0.0111	0.0572	-0.0194
	[0.0985]	[0.0543]	[0.1007]	[0.0460]
Distance to nearest agricultural market	0.0244	-0.0116	0.0202	-0.012
	[0.0230]	[0.0100]	[0.0227]	[0.0114]
Durables	-0.1252**	0.0001	-0.1294**	0.000
	[0.0526]	[0.0276]	[0.0562]	[0.0321]
Land difference	-	-	0.0005	-0.0043***
	-	-	[0.0030]	[0.0013]
CdA belongs to JdV	-0.1494	-0.1311	-0.28	0.0401
	[0.2818]	[0.1339]	[0.3385]	[0.1393]
CdA size (members)	0.1658	0.0947	0.2221*	0.2646***
	[0.1106]	[0.0673]	[0.1203]	[0.0653]
CdA connections	-	-	0.3580*	0.2039**
	-	-	[0.1944]	[0.0943]
CdA decisions made by consensus	-	-	0.2381	0.1285
	-	-	[0.2855]	[0.1122]
Constant	-1.2777	11.3581***	-1.0743	10.6010***
	[1.6829]	[0.7471]	[2.0938]	[0.8444]
Athrho	-	0.3204**	-	0.3707*
	-	[0.1329]	-	[0.2116]
Lnsigma	-	-0.4472***	-	-0.4803***
	-	[0.0584]	-	[0.0750]
Observations	270	270	244	244
Uncensored observations	-	209	-	191

Notes: The symbols *, **, and *** represent significance at the 10%, 5%, and 1% levels. Robust standard errors are in brackets.
Source: Authors

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