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# Determinants of Household Contributions to Collective Irrigation Management: A Case of the Doho Rice Scheme in Uganda

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**Determinants of Household Contributions to Collective Irrigation Management: A Case of the Doho Rice Scheme in Uganda**

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**ABSTRACT.** In order to explore the conditions of successful irrigation management, this study investigates the determinants of household contributions to the cleaning of irrigation channels and the availability of water. By using primary data collected in an irrigation scheme in Uganda, we find that household contributions to the cleaning of irrigation channels are determined by the scarcity of irrigation water, opportunity cost of labor, and private benefit associated with plot size. We also find that the availability of irrigation water increases in the tertiary irrigation area where the coefficient of variation of plot size is large.

JEL classification codes: O12, O13, Q16, Q18
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## 1. Introduction

Facing an acute food crisis in 2008, deep concerns with deteriorating food security and poverty incidence in sub-Saharan Africa (SSA) were expressed by policy makers, practitioners, and researchers interested in poverty reduction and development in this region. Alarmingly, the yield of the grains in SSA has been stagnant while the population continues to grow rapidly over the last 40 years. As a result, food production per capita is already declining in the region (Otsuka and Kijima, 2009). This is in sharp contrast to the experience of Asia, where rice and wheat yields more than doubled in the same period due to the diffusion of fertilizer-responsive, high-yielding modern varieties (MVs), which is well recognized as the Green Revolution. Considering the increasing population pressure on limited land resources in SSA, one possible solution to achieve food security and reduce poverty is to seek for an Asian-style Green Revolution. At the same time, however, many studies are skeptical about this strategy, and one of the major reasons for this skepticism is the under-development of irrigation in SSA (Spencer, 1994; World Bank, 2008).

Gravity irrigation is the most popular irrigation system in SSA, which is characterized by common-property or common-pool resources (CPRs) and, hence, it is used jointly by a group of farmers. To manage irrigation facilities effectively and allocate water resources efficiently, it is critically important to enforce the rules of water allocation and maintenance of irrigation channels and drainages (Ostrom, 1990). Yet, past government-led large-scale irrigation projects generally failed because of the absence of enforced rules. Thus, recent studies emphasize the importance of rural communities in managing CPRs and recommend the transfer of irrigation management authority from governments to communal user groups (Ostrom, 1990). In fact, communities that are characterized by the close personal ties of their members often set and enforce rules effectively for irrigation management by such means as social sanctions and peer supervision among community members (Bardhan, 1993; Seabright, 1993; Hayami and Godo, 2005). However, not all communities are successful in organizing collective action to maintain irrigation schemes. It is therefore important to identify the conditions of successful collective irrigation management by a community.

Several studies find that the small size; the social homogeneity of a community, represented by the same caste or ethnic group; and economic inequality are important determinants of successful irrigation management (Bardhan, 2000; Dayton-Johnson, 2000; Meinzen-Dick et al., 2002; Fujiie et al., 2005; Kajisa et al., 2007; Ito, 2006). Most of these studies focus on community-level analyses and use the activeness of water-user groups or the cleanness of the irrigation channels, which is measured subjectively by 'good' or 'poor,' as an indicator of the performance of community irrigation management. The determinants of the contribution of individual users to the collective irrigation management and the allocation of water among them are seldom explored.[1] It must also be pointed out that studies on irrigation management in SSA are scanty.

In this study, we investigate important characteristics of water-user households and their group characteristics that affect their contribution to irrigation management and the availability of irrigation water at the plot level by using the data collected in an irrigation scheme in Uganda. We use the directly measured water depth at the plot level as an objective indicator of the performance of the collective action. We aim to reveal the mechanism by which specific characteristics of water-user households affect the extent of collective action, which community-level analyses cannot reveal. For this purpose, we conducted a household survey in the Doho Rice Scheme (DRS) in Uganda.

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[1] To our knowledge, Gyasi (2005), who analyzes the household contribution to irrigation management in 52 communities in Ghana, is an exception. Somewhat related is the study of household participation in watershed management in Haiti by White and Runge (1994; 1995), who conclude that farmers who are members of farmer organizations are more likely to participate in watershed management projects. Also related is Gaspart et al. (1998), who find that households with large plots of land located near drainage (and thus acquire large benefit from drainage) tend to devote more time to the construction of drainage facilities in Ethiopia.

The rest of the paper is organized as follows. Section 2 provides a general description of the study site and explains the data collection method. In Section 3, we develop testable hypotheses based on a literature review and field observations. Section 4 presents the results of the statistical analyses of the determinants of household contributions to collective irrigation management and water depth. The paper ends with the conclusions in Section 5.

## 2. The Structure of the Study Site and the Data

### *2.1 The structure of the study site*

Rice cultivation in Doho started in the 1940s. The Chinese government began to construct the irrigation scheme in 1976 and completed it in 1989. The DRS is the largest irrigation scheme in Uganda and is designed to serve irrigation water to 1,000 ha of paddy fields. It is located 260 km to the east of the capital city of the country, Kampala, and about 4,340 farmers grow rice in the scheme. The DRS is located in a bimodal rainfall zone, and farmers have engaged in double-cropping of rice for more than a few decades. Most of the farmers live in nearby villages and grow various crops in their upland fields, in addition to rice grown in lowland plots in the DRS. The farmers in the DRS grow modern varieties (MVs) of rice, which were either MVs developed by the International Rice Research Institute in the Philippines in the 1970s and brought by a Chinese aid agency when the irrigation scheme was constructed, or cross-bred varieties between local varieties and Asian MVs.

The scheme is still owned by the government, and farmers are entitled only to 99-year leases for their plots. There is now a government irrigation management office where several staff members are working. However, except for their salaries and occasional support for the maintenance of the channels, the government provides no financial support for the scheme.

Figure 1 shows the structure of the DRS, which consists of 13 blocks connected by three layers of channels: main, sub, and tertiary channels. The main channel provides irrigation water from the Manafwa River to the scheme. It branches out into the sub-channels, which provide irrigation water to each block. Basically, each block has one sub-channel and consists of 5 to 15 smaller zones called strips. Each strip is surrounded by a tertiary channel that provides irrigation water to the plots of 20 to 30 farmers and by a tertiary drainage. The tertiary drainage for one strip serves as the tertiary irrigation channel for the strip next to it, as is shown in the enlarged figure of a strip. After flowing through paddy fields, water is collected into the main drainage through the tertiary and sub-drainages and drained into the Manafa River again.

Farmers are responsible for cleaning the main, sub, and tertiary irrigation channels and the main, sub, and tertiary drainages. The cleaning of the main and sub- channels and the main and sub-drainages is supposed to be carried out collectively by the farmers in the block. In addition, each farmer is responsible for cleaning the tertiary irrigation channel and tertiary drainage that his plot faces. Under the leadership of a voluntary farmers' group, the Doho Rice Scheme Farmers' Association (DRSEFA), each block has 1 chairman and 10 counselors who are responsible for mobilizing farmers for cleaning the main and sub-channels and the main and sub-drainages. They are also responsible for monitoring whether the tertiary irrigation channels and drainages are cleaned. If a farmer does not clean the tertiary irrigation and drainage channels along which his plot is located for a long time, he is supposed to be punished and is not allowed to cultivate the plot for two seasons. However, this punishment is rarely implemented in practice.

Most of the water gates that control the water flow from the main channel to the sub-channels are broken, and there is no effective means to control water going into the sub-channels. Thus, there is no clear water rotation system implemented among the blocks. Furthermore, almost no strip has any explicit rules on water distribution among farmers in the strip. DORSEFA is also in charge of collecting irrigation fees. If a farmer does not pay the fee, he is not allowed to cultivate the plot for two seasons. However, this punishment for the non-payment of irrigation fees is also not fully implemented in practice, and only 40% of the irrigation fees are collected on average.

The downstream area of the scheme, covering 200 ha, is cultivated informally by a group of farmers using drained water from the main scheme. These farmers are called out-growers. The channels in the out-grower areas have structures similar to those of the DRS, and the out-growers collectively and voluntarily maintain the channels. Thus, we include the out-growers in our analysis and treat their whole plots as one block.

### *2.2 Data*

Three rounds of field surveys were conducted by the senior author from April to June in 2007, in November 2007, and in March 2008. Out of 13 blocks in the DRS, we excluded 3 blocks from our sample because there was no main drainage, and the channels have different structures in these blocks. Therefore, our survey covers the remaining 10 blocks and the out-grower area. We randomly sampled 55 strips in the 11 blocks out of 121 strips. We sampled plots from each strip, which are located at 200m, 400m, 600m, 800m, and 1000m from the water intake of the strip along the tertiary channel (Figure 1). The total length of the strip varies, ranging from 400m to 1000m, and is on average about 600m. We sampled three plots from one strip on average. Doing so enables us to investigate how the contributions of the household to the cleaning of the channels and the availability of water differ at different points in the irrigation scheme.

In the first round of the survey in 2007, we interviewed 158 cultivators to collect data on their household income and household contribution to the cleaning of the channels in 2006. In the second round of the survey in the same year, we physically measured the water depth in the sample plots 90 days after rice was planted, because water availability is critically important at the flowering stage of rice cultivation that takes place 90 days after planting. We measured the water depth in 103 plots in the second season of 2007.[2] In the third round of the survey in 2008, we again attempted to interview the original sample cultivators to collect detailed data on rice cultivation in the sample plots such as harvest, input use, and the contribution to the cleaning of the channels in the first and second season of 2007. We interviewed 142 households for the first season of 2007 and 146 households for the second season of 2007.[3] In this survey, we also collected some additional information about the cultivators in 2006. We could revisit and collect the recall data of 138 and 140 households for the first season and the second season of 2006, respectively.

## 3. Descriptive Analyses and Testable Hypotheses

Let us begin our analyses by developing our hypotheses based on a literature review and field observations. Existing studies suggest that the scarcity of irrigation water is one of the important determinants of the degree of cooperation among farmers (Fujiie et al. 2005; Ito, 2006). We can expect that the longer the distance from the main channel to the intake of the strip ($D_i$), the scarcer water is at the intake of the strip (Figure 1). The availability of irrigation water in the $j^{th}$ plot in the $i^{th}$ strip ($W_{ij}$) further depends on the distance from the intake of the strip to each plot along the tertiary channel ($d_{ij}$). The longer the distance is, the less water is expected to be available due to the use of water by upstream farmers as well as filtration and evaporation losses. The availability of water also depends on the total contribution to the cleaning of the tertiary channel made by the upstream farmers in the strip

2 We conducted a direct measurement of water depth in November 2007, when the rice was supposed to be at the flowering stage in most of the sample plots. However, in this year, there was a critical water shortage and some farmers planted rice late. This is the main reason for the reduction in the sample size.

3 The difference in the sample size in the two seasons stems from the fact that some of the plots are rented out and the cultivators in two seasons are not necessarily the same. We sometimes failed to interview the cultivators of the plots because they were sick or had moved out at the time of the interview.

and the cultivator's own contribution to the cleaning of the tertiary channel ($C_{ij}$). When the tertiary channels are well maintained, less water is lost and even plots far away from the intake of the strip can receive sufficient water. When irrigation water is scarce, the marginal value product of water is high, and hence farmers may have more incentive to contribute to the cleaning of the irrigation channels to increase available irrigation water.

Unlike cleaning of irrigation channels, farmers seem to have incentives to clean drainages, particularly when flooding occurs. Thus, the marginal gain from cleaning drainage channels tends to be large when flooding is severe, which is the case near the main and sub-drainages as well as near the intake.

Table 1 examines the relationship between the distance from the main channel to the intake of the strip ($D_i$) and water depth. Consistent with our expectation, water depth first decreases as the distance from the main channel to the intake of the strip increases. Contrary to our expectation, however, water depth increases as the distance increases to more than 2km. This may be because the land slopes downward away from the main irrigation channel, and water tends to accumulate near the main drainage, especially where the drainage does not function well. Therefore, we observe a U-shape relationship between the distance from the intake of the strip and water depth.

Table 1 also summarizes the relationship between the distance from the main channel to the intake of the strip and the household contribution to the cleaning of the main and sub-channels, the tertiary channel, and the tertiary drainage.[4] The household contributions to the cleaning of the main and sub-channels have inverted-U relationships with the distance from the main channel to the intake of the strip, with the peak around 2-3km. The fact that water depth first decreases and then starts to increase, whereas the household contribution initially

[4] We exclude the household contribution to the cleaning of the main and sub-drainages from our analysis because it is only 1.5 person-hours on average and most of the observations are censored at 0. Even if we add this variable to the household contribution to the cleaning of the tertiary drainage, the results are essentially the same.

increases but gradually decreases, can be explained by the tendency that when the irrigation water is scarcer and, hence, the marginal productivity of irrigation water is higher, farmers work harder to clean the channel to obtain more irrigation water. On the other hand, the household contribution to the tertiary drainage increases as the distance becomes longer. This may be because, in the downstream area where plots are located near the sub-drainage, farmers have more incentive to contribute to the cleaning of the tertiary drainage to avoid flooding.

The lower half of Table 1 shows the relationship between the distance from the intake of the strip to each plot ($d_{ij}$) and water depth and household contribution to the cleaning of the irrigation and drainage channels. Although an unexpected peak in water depth at 400m is observed, less water is provided to the farther plot as we expected. On the other hand, we cannot observe any clear tendency in household contribution to the cleaning of the main and sub-channels or the tertiary irrigation channel. As can be expected, households increase their contribution to the cleaning of tertiary drainage as the distance becomes longer. These observations lead us to the following hypothesis:

Hypothesis 1: The scarcer the irrigation water is, the more households contribute to the cleaning of irrigation channels. On the other hand, households in the downstream area of the main and sub-channels and tertiary channel contribute more to the tertiary drainage in order to avoid flooding.

Another important determinant of water management discussed in the literature is the private benefit associated with plot size (White and Runge, 1994; Gaspart et al. 1998), as farmers with larger plots enjoy larger benefits of well-cleaned channels and drainage. Hence, large cultivators would have more incentive to contribute to the cleaning of channels and drainage than small ones. Table 2 examines the relationship between the size of the cultivated area in the sample strip and household contribution to the cleaning of irrigation channels and tertiary drainage. It seems clear that the larger the size of the cultivated area is, the more contribution a household makes to the cleaning of both irrigation channels and drainage. Therefore, the second hypothesis is postulated as follows:

Hypothesis 2: The larger the plot size in the sample strip is, the more households contribute to the cleaning of irrigation channels and drainage.

One issue related to plot size is inequality in cultivation size or landholdings. The theoretical predictions of the impact of inequality in landholdings on the provision of public goods such as well-cleaned channels are mixed. Olson (1965) argues that inequality might be beneficial to the provision of public goods when a few members obtain a significant proportion of the total benefit from the public goods and, hence, have strong incentives to provide them, even if they have to pay almost all of the cost. Baland and Platteau (1997) support this argument by suggesting that only an agent with a strong interest will contribute to the provision of public goods, while others prefer to have a free ride on the agent's effort. The implication is that greater inequality in cultivation size within a strip may increase the provision of labor for collective irrigation management. Bardhan et al. (2006), in contrast, argue that a threshold level of landholdings exists such that a group member who has land more than this threshold contributes to the collective effort to increase irrigation water. They predict that equality among contributors may be beneficial to the provision of public goods to the extent that the average landholding exceeds the threshold level.

Table 3 compares water depth and household contribution to the cleaning of irrigation channels and drainage between strips with relatively equal and unequal land distributions.

Strips with equal or unequal land distributions are defined as strips with a coefficient of variation of plot size less than or more than its average value, 75%. A plot in a strip with larger inequality of plot size receives more irrigation water. Furthermore, a household that is in a strip with unequal distribution of plot size contributes more to the cleaning of main and sub-channels and tertiary drainage. These findings may be consistent with the argument of Olson (1965), who predicts that inequality may enhance the likelihood of collective action.

The household contribution also depends on the opportunity cost of labor associated with non-farm income and upland crop cultivation (Bardhan, 2000; Dayton-Johnson, 2000; Fujiie et al.2005). Farmers with high opportunity costs of labor may have lower incentive to cooperate in irrigation management. Since educational attainment is a good proxy of the opportunity cost of labor associated with non-farm income, Table 4 summarizes the relationship between the educational attainment of household members and household contributions to the cleaning of irrigation channels and tertiary drainage. Educational attainment is measured by the average years of schooling of household members who are older than 15 years of age. For descriptive analysis, we compare cases in which the average years of schooling of household members are less than or more than seven years, which corresponds to the completion of primary education in Uganda. Table 4 demonstrates that households with highly educated members contribute less to the cleaning of channels and tertiary drainage.

A related determinant of household contribution to cleaning of the channels is the number of adult household members. Since the agricultural labor market is imperfect due to the high monitoring cost of wage workers (Hayami and Otsuka, 1993), the supply of labor is significantly affected by the endowment of family labor. Thus, the number of adult household members may have a positive impact on the household contribution to the cleaning of channels. In Table 4, we compare the household contribution to the cleaning of irrigation channels and tertiary drainage between the two groups, where the number of adult household members is less than or more than its average of 4 people. Households with a large number of adult members are expected to contribute more to the cleaning of all types of channels than those with a small number of adult members. Therefore, we hypothesize that

Hypothesis 3: Households with highly educated members and with fewer members contribute less to the cleaning of irrigation channels and drainage.

Although an individual household may determine the household contribution to the cleaning of a channel based on its private benefit and cost, the availability of irrigation water will be determined importantly by the behavior of other farmers. In fact, if upstream farmers in a strip do not clean the channel or overuse water, downstream households cannot receive much irrigation water. Therefore, it seems reasonable to argue that water depth is determined primarily by the collective effort of strip members. Based on this reasoning, the fourth hypothesis is postulated as

Hypothesis 4: Since the availability of irrigation water in a particular plot depends critically on the collective effort of strip members, measured water depth depends on the characteristics of strip members more than individual household characteristics.

## 4. Regression Analyses

### *4.1 Methodology*

In order to examine the determinants of household contributions to the cleaning of channels and water depth in each plot, we estimate the following two types of regression functions:

$$C_{ij} = \delta_0 + \delta_1 D_i + \delta_2 D_i^{\,2} + \delta_3 d_{ij} + \delta_4 d_{ij}^{\,2} + \delta_5 A_{ij} + \delta_6 H_{ij} + \delta_7 U_{ij} + \delta_8 R_{ij} + \delta_9 O_{ij} + u_{ij} \quad (1)$$

$$W_{ij} = \gamma_0 + \gamma_1 D_i + \gamma_2 D_i^{\,2} + \gamma_3 d_{ij} + \gamma_4 d_{ij}^{\,2} + \gamma_5 A_{ij} + \gamma_6 H_{ij} + \gamma_7 U_{ij} + \gamma_8 R_{ij} + \gamma_9 O_{ij} + v_{ij} \quad (2)$$

where $C_{ij}$ is the household labor contribution to the cleaning of the main and sub-channels, tertiary irrigation channel, or tertiary drainage in a season measured by person-hours, whereas $W_{ij}$ is the water depth (cm) in the sample plot.

We include the distance from the main channel to the intake of the strip ($D_i$) and its squared term, as well as the distance from the intake of the strip to each plot ($d_{ij}$) and its squared term. One can expect that water depth decreases as both distances from the main channel to the intake of the strip ($D_{ij}$) and from the intake of the strip to each plot ($d_{ij}$) increase. However, as we discussed earlier, there is a possibility that water depth first decreases and then increases as the distance from the main channel increases ($D_{ij}$), because water tends to accumulate near the drainage. If so, we will observe a U-shape relationship between the distance from the main channel to the intake of the strip and water depth. Our first hypothesis argues that the scarcer the irrigation water is, the more a household contributes to the cleaning of the irrigation channel. Therefore, if the distance from the main channel has a U-shape relationship with water depth, it should have an inverted-U shape relationship with the household contribution to the cleaning of irrigation channels. On the other hand, if water depth decreases as the distance from the intake of the strip ($d_{ij}$) increases, then the household contribution should increase as the distance becomes longer.

In order to statistically test our second hypothesis that the private benefit associated with plot size influences the household contribution to the cleaning of channels, we include the total size of the cultivated area in the sample strip, including the sample plot. We also include their squared term. The size of the cultivated area in the sample strip is expected to have a positive impact on the household contribution to the cleaning of channels and drainage.

In order to test our third hypothesis, we include educational attainment, which is measured by the average years of schooling of adult household members, and the number of adult household members, both of which are subsumed under $H_{ij}$. The former should have a negative impact on the household contribution, while the latter should have a positive effect.

We also include $U_i$, which is a set of variables explaining strip characteristics. According to existing studies, the size and economic inequality of community members are identified as important determinants of the success of irrigation management (Bardhan, 2000; Fujiie et al., 2005). Therefore, we include the number of farmers in the strip to indicate the size of the user group, and the coefficient of variation of plot size in the strip as an indicator of inequality of landholdings.

Existing studies also point out the importance of community mechanisms such as social sanctions and peer supervision working among group members (Fujiie et al. 2005; Miguel and Gurgerty, 2005). We include the "density of farmers with close personal ties" in the same strip ($R_{ij}$). More specifically, we consider the number of relatives and the number of the same village members in the same strip, both of which are divided by the distance of the strip. If the density of farmers with close personal ties has a positive impact on the household contribution to the cleaning of irrigation channels and drainage, then we can attribute this to some kind of community mechanism for enforcing collective action.

In order to control for the effects of other factors, we include the size of the cultivated area in other strips in DRS and the size of the cultivated area in upland area, which are denoted by $O_{ij}$. These variables have negative effects on the household contribution, because the larger the size of these areas, the higher the opportunity cost of labor would be. Season dummies are also included.

Note that our fourth hypothesis predicts that strip characteristics such as membership size of the strip and the coefficient of variation of plot size in the strip may have significant impacts on water depth, but not necessarily characteristics of individual households such as the land endowment and educational attainment of household members. Also note that the coefficients of labor contribution function, i.e., equation (1), will be different among the three cases—cleaning of main and sub-channels, tertiary channel, and tertiary drainage. A particular difference occurs between the cleaning of irrigation channels and drainage, because the former pertains to the allocation of scarce water whereas the latter is related primarily to reducing excess water during flooding.

***4.2 Regression Results***

***The determinants of water depth***

Table 5 shows the regression results of the water depth function. We estimate the models using Tobit estimation since the observations are censored at zero. We report the results, which include no dummy, block dummies, and strip dummies, respectively, from (1) to (3).

According to model (1), the coefficient of distance from the main channel is negative and significant and that of its squared term is positive and significant, implying that distance has a U-shape relationship with water depth. In other words, water depth first decreases as the distance from the main channel to the intake of the strip increases up to 2km, after which it increases. This relationship is not observed when we include the block dummies in model (2), because they capture the impact of distance from the main channel.

According to model (3), the distance from the intake of the strip to each plot has an inverted-U-shape relationship. Although we are not sure why water depth increases initially up to 350m, it decreases after this point, as we expected.

Consistent with the fourth hypothesis, household characteristics such as cultivated areas and educational attainment of adult household members do not have significant impacts on water depth in all of the models from (1) to (3). On the other hand, strip characteristics such as the coefficient of variation of plot size have a significant and positive impact on the water depth in models (1) and (2). These observations suggest that the water depth of an individual plot is determined primarily by the contribution of group members but not by the effort of the individual household. The positive and significant coefficient of variation of plot size implies that inequality of plot size in the strip increases water depth at the plot level. As will be discussed later, households with larger plots contribute more than proportionately to the cleaning of the tertiary channel. This may be the reason the coefficient of variation of plot size has a positive impact on water depth.

Since some studies (e.g., Bardhan, 2000) predict the U-shape relationship between the inequality of cultivated plot size and the outcome of collective action, we add the squared term of the coefficient of variation in plot size in models (4) and (5). Model (4) does not include any dummies, while model (5) includes block dummies. The squared term of the coefficient of variation of plot size is insignificant in both models, (4) and (5). Other coefficients are essentially consistent with the models without the squared term of the coefficient of variation, shown in models (1) and (2).

***The determinants of the cleaning of irrigation channels***

Table 6 summarizes the regression results of the determinants of household contributions to the cleaning of the main and sub-channels (models (1) to (3)) and tertiary irrigation channel (models (4) to (6)). We estimate models (1) to (3) by employing the Tobit estimation method because some of the farmers do not contribute to the cleaning of the main and sub-channels at all, whereas we use OLS to estimate models (4) to (6). We report the results, which include no dummy, block dummies, and strip dummies.

The distance from the main channel to the intake of the strip has an inverted U-shape relationship with household contribution to the cleaning of the main and sub-channels, as well as tertiary channel, with the peak around 1.5km in models (1), (2), and (4). As we found earlier, water depth has a U-shape relationship with the distance from the main channel to the intake of the strip. Therefore, households contribute more to the cleaning of irrigation channels when irrigation water is scarcer, which is consistent with our first hypothesis.

The distance from the intake of the strip to each plot has a U-shape relationship with the household contribution to the cleaning of main and sub-channels, with its peak around 350m in model (2). Considering that water depth has an inverted-U shape relationship with the distance from the intake of the strip to each plot at a peak around 350m, this is also consistent with our first hypothesis that the household contribution is determined by the scarcity of irrigation water. Unexpectedly, however, the distance from the intake of the strip to each plot does not have any significant impact on the household contribution to the cleaning of the tertiary channel in models (4) to (6).

The density of relatives has a positive impact on the household contribution to the cleaning of the main and sub-channels and the tertiary channel in models (1) and (5). Also, *t*-statistics are not low in models (4) and (6). These findings suggest that the community mechanisms of enforcement work among closely related strip members, especially for the cleaning of the tertiary channel. This is consistent with existing studies, which emphasize the importance of community relations in collective irrigation management (Fujiie et al., 2005).

It is important to realize that the coefficients of the squared term of size of the cultivated area in the sample strip are positive and significant in models (1), (4), and (5). This means that households increase their contribution to the cleaning of channels more than proportionately as the cultivated area in the strip becomes larger. This seems to explain why the coefficient of variation of plot size has a positive impact on water depth. These findings are consistent with the argument of Olson and Zeckhauser (1966), who predict that inequality may enhance the likelihood of collective action as economic agents with large endowments may bear a larger portion of costs associated with cooperative action.

The coefficients of the average years of schooling of adult household members are all negative and four of them are significant for the household contribution to the cleaning of channels. The number of adult household members significantly increases the household contribution to the cleaning of main and sub-channels and tertiary channels in all the models. These findings are consistent with our third hypothesis regarding the opportunity cost of labor.

***The determinants of the cleaning of tertiary drainage***

In Table 7, we show the regression results of the determinants of household contribution to the cleaning of tertiary drainage. We estimate the models using Tobit estimation as some of the sample farmers do not contribute at all. We report the results, which include no dummy in model (1), block dummies in model (2), and strip dummies in model (3).

Both the distance from the main channel to the intake of the strip and the distance from the intake of the strip to each plot have U-shape relationships with the household contribution to the cleaning of tertiary drainage. This is likely because, in the extreme upstream and downstream areas of the sub- and tertiary channels, flooding is serious so that farmers have strong incentives to contribute to the cleaning of tertiary drainage to reduce floodwater.

The size of cultivated area in the sample strip has an inverted-U relationship with its peak at 1 ha in all three models. Since almost no household cultivates more than 1 ha in a sample strip, this means that the size of the cultivated area has a positive impact on the household contribution to the cleaning of tertiary drainage. This is consistent with our second hypothesis regarding the effect of plot size.

The size of other cultivated area in DRS has a U-shape relationship with its peak at 2 ha. Since less than 1 percent of sample households have other cultivated area larger than 2 ha in DRS, this almost implies that the size of other cultivated area in DRS has a negative relationship with the household contribution to the cleaning of tertiary drainage. This may be because when the size of other cultivated area is large, the opportunity cost of labor becomes high. Furthermore, since flooding tends to occur everywhere in the whole scheme more or less at the same time, farmers with many large plots in DRS contribute less to the cleaning of tertiary drainage in the sample strip than farmers with small plots.

The coefficient of the second season 2007 dummy is negative and significant, presumably because the whole scheme suffers from low rainfall and a shortage of water in this particular season. As a result, farmers may have more incentive to clean the irrigation channels rather than drainage.

## 5. Conclusions

This study examined the determinants of household contributions to the cleaning of irrigation channels and drainage as well as the water depth in each plot. By doing so, we aimed to identify critically important household characteristics that affect collective irrigation management. The empirical results demonstrated that the scarcity of irrigation water, private benefit associated with plot size, and the opportunity cost of labor are the important determinants of household contributions to the cleaning of irrigation channels. This is consistent with other studies that suggest the importance of private incentive to provide a collective good (White and Runge, 1994; 1995; Gaspart et al., 1998). Our empirical results also suggest that the community mechanisms of enforcing collective action work to some extent among closely related strip members, especially for the cleaning of tertiary channels. This is also consistent with existing studies that emphasize the importance of social sanctions and peer supervision based on close personal ties for the provision of public goods (Fujiie et al., 2000; Miguel and Grgerty, 2005).

In addition, we estimated the water availability function. We found that strip characteristics, rather than household characteristics, are important determinants of water depth in each plot. Especially, inequality in plot size in a strip has a positive and significant impact on water depth, largely because a household with a large plot contributes more than proportionately to the cleaning of irrigation channels. These findings are consistent with the argument of Olson (1965), who predicts that inequality may enhance the likelihood of collective action.

However, we should be careful to conclude that inequality in landholdings always improves collective irrigation management. For example, Dayton-Johnson (2003) cites field studies from Gujarat and Tamil Nadu, India, explaining that the egalitarian nature of the community, small variation in farm size, or both appear to be conducive to the formation of a water users' association. Tang's (1992) synthesis of several studies found that a low variance of average annual family income among irrigators tends to be associated with a higher degree of rule observance. Since collective action is seldom organized in DRS, a reasonable hypothesis may be that inequality increases collective effort when collective agreement is weakly enforced.

Our results suggest that farmers are responsive to their private benefit and cost when they determine their contribution to the cleaning of channels. Therefore, in order to make collective irrigation management more effective, we should set rules of punishment or reward so as to make farmers' private benefit and cost consistent with the social benefit and cost. Sethi and Somanathan (2006) suggest that the prospect of punishment against non-contributors should be sufficient to induce cooperative behavior of farmers. Tachibana et al. (2001) emphasize that support from the local government for a communal forest users' group, particularly the punishment of violators of management rules, is conducive to the effective management of minor forest resources in Nepal. In DRS, punishment for non-contributors to the cleaning of irrigation channels is seldom imposed. The government should support DORSEFA by establishing effective means to punish those who do not contribute labor in DRS.

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**Table 1. Water depth (cm) and household contribution to the cleaning of channels (person-hours) by distance from the main channel and along the tertiary channel**

| Distance from the main channel ($D_i$) | 0-1km | 1-2km | 2-3km | 3-4km | Average |
|---|---|---|---|---|---|
| *Water depth (cm)* | 3.78 | 1.53 | 1.63 | 2.26 | 2.81 |
| Sample Size | (55) | (22) | (16) | (10) | (103) |
| *Household contribution to the cleaning of channels (person-hours)* | | | | | |
| Main & Sub-Channels | 10.5 | 13.3 | 8.1 | 7.1 | 10.5 |
| Tertiary Irrigation Channel | 11.6 | 12.4 | 15.3 | 13.0 | 12.5 |
| Tertiary Drainage Channel | 5.8 | 6.6 | 6.4 | 8.4 | 6.3 |
| Sample Size | (292) | (139) | (84) | (51) | (566) |

| Distance along tertiary channel ($d_{ij}$) | 200m | 400m | 600m | 800m | 1000m |
|---|---|---|---|---|---|
| *Water depth (cm)* | 2.8 | 3.6 | 2.5 | 1.8 | 0.0 |
| Sample Size | (39) | (28) | (29) | (6) | (1) |
| *Household contribution to the cleaning of channels (person-hours)* | | | | | |
| Main & Sub-Channels | 10.3 | 11.7 | 8.9 | 9.1 | 22.4 |
| Tertiary Irrigation Channel | 12.3 | 13.0 | 12.0 | 12.8 | 13.7 |
| Tertiary Drainage Channel | 6.8 | 5.4 | 6.5 | 7.2 | 10.3 |
| Sample Size | (201) | (185) | (145) | (27) | (8) |

**Table 2. The size of cultivated area in a sample strip and the household contribution to the cleaning of channels (person-hours)**

| | 0-0.2 ha | 0.2-0.4 ha | 0.4-0.6 ha | 0.6-0.8 ha | 0.8-1.0 ha |
|---|---|---|---|---|---|
| *Household contribution to the cleaning of channels (person-hours)* | | | | | |
| Main & Sub-Channels | 10.6 | 8.9 | 10.5 | 13.5 | 16.0 |
| Tertiary Irrigation Channel | 9.2 | 11.2 | 13.8 | 15.0 | 26.8 |
| Tertiary Drainage Channel | 2.8 | 6.1 | 8.3 | 9.9 | 13.8 |
| Sample Size | (175) | (202) | (122) | (24) | (43) |

**Table 3. The coefficient of variation of plot size in a strip and water depth (cm) and the household contribution to the cleaning of channels (person-hours)**

| | Strips with equal landholdings[1] | Strip with unequal landholdings[1] |
|---|---|---|
| *Water depth (cm)* | 2.3 | 3.5** |
| Sample Size | (58) | (45) |
| *Household contribution to the cleaning of channels (person-hours)* | | |
| Main & Sub-Channels | 9.5 | 11.7** |
| Tertiary Irrigation Channel | 12.5 | 12.4 |
| Tertiary Drainage Channel | 5.3 | 7.5*** |
| Sample Size | (312) | (254) |

*Note:* Strips with equal or unequal landholdings are defined as strips with a coefficient of variation of plot size in the strip less than and equal to or more than its average value, 75%.
** significant at 5%, *** significant at 1% in the t-test comparing households in strips with equal and unequal landholdings.

**Table 4. The number of adult household members, average years of schooling of adult household members, and the household contribution to the cleaning of channels (person-hours)**

| | Average years of schooling less than or equal to 7 years | Average years of schooling more than 7 years | Number of adult household members less than or equal to 4 | Number of adult household members more than 4 |
|---|---|---|---|---|
| *Household contribution to the cleaning of channels (person-hours)* | | | | |
| Main & Sub-Channels | 11.0* | 9.2 | 9.8 | 12.0** |
| Tertiary Irrigation Channel | 12.8 | 11.7 | 11.2 | 15.5*** |
| Tertiary Drainage Channel | 6.4 | 6.1 | 5.6 | 8.0*** |
| Sample size | (404) | (162) | (395) | (171) |

*significant at 10%, ** significant at 5%, ***significant at 1% in the t-test comparing households with average years of schooling of adult household members less than or equal to and more than 7 years and those with less than or equal to 4 and more than 4 adult household members.

## Table 5. Determinants of water depth (cm)

| | Water depth (cm) Tobit | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| | No dummy | Block dummy | Strip dummy | No dummy | Block dummy |
| ***Geographical position of plot*** | | | | | |
| Distance from the main channel (km) | -3.998*** | -1.549 | | -4.154*** | -1.301 |
| | [3.49] | [0.62] | | [3.60] | [0.52] |
| Distance from the main channel (km) squared | 0.966*** | 0.714 | | 1.006*** | 0.689 |
| | [2.84] | [1.33] | | [2.95] | [1.30] |
| Distance along tertiary channel (km) | 8.350 | 12.778 | 12.180 | 6.68 | 10.385 |
| | [0.92] | [1.34] | [1.65] | [0.74] | [1.09] |
| Distance along tertiary channel (km) squared | -12.171 | -17.947 | -17.498** | -10.35 | -15.205 |
| | [1.19] | [1.63] | [2.10] | [1.02] | [1.39] |
| ***Strip characteristics*** | | | | | |
| No. of strip members | 0.055 | 0.034 | | 0.041 | 0.017 |
| | [1.41] | [0.80] | | [0.99] | [0.38] |
| Coefficient of variation of plot size in the strip | 0.061*** | 0.066*** | | 0.209 | 0.269* |
| | [2.96] | [2.88] | | [1.43] | [1.86] |
| Coefficient of variation of plot size in the strip squared | | | | -0.001 | -0.001 |
| | | | | [1.03] | [1.43] |
| ***Household characteristics*** | | | | | |
| Density of relatives | -1.131 | 0.669 | -2.736 | -1.388 | 0.523 |
| | [0.38] | [0.21] | [1.02] | [0.47] | [0.17] |
| Density of people from same village | 0.025 | 0.494 | 1.383 | -0.003 | 0.467 |
| | [0.01] | [0.26] | [0.77] | [0.00] | [0.25] |
| No. of adult hh members | 0.135 | 0.146 | 0.110 | 0.133 | 0.119 |
| | [0.71] | [0.71] | [0.47] | [0.71] | [0.58] |
| Average years of schooling of adult hh members | 0.189 | 0.155 | -0.001 | 0.195 | 0.157 |
| | [1.60] | [1.35] | [0.01] | [1.65] | [1.38] |
| Size of cultivated area in the sample strip (ha) | -3.451 | -3.559 | 0.215 | -3.672 | -3.613 |
| | [0.53] | [0.55] | [0.04] | [0.57] | [0.57] |
| Size of cultivated area in the sample strip (ha) squared | 4.735 | 4.144 | 0.719 | 5.240 | 4.649 |
| | [0.63] | [0.55] | [0.10] | [0.70] | [0.62] |
| Size of other cultivated area in DRS (ha) | 1.342 | 1.731 | 2.106 | 1.576 | 2.035 |
| | [0.61] | [0.79] | [1.01] | [0.71] | [0.94] |
| Size of other cultivated area in DRS (ha) squared | -1.426 | -1.663 | -0.976 | -1.600 | -1.899 |
| | [1.12] | [1.31] | [0.81] | [1.25] | [1.50] |
| Size of cultivated area in upland (ha) | 0.007 | -0.109 | -0.497 | -0.086 | -0.200 |
| | [0.01] | [0.17] | [0.77] | [0.13] | [0.32] |
| Size of cultivated area in upland (ha) squared | 0.028 | 0.049 | 0.079 | 0.044 | 0.065 |
| | [0.30] | [0.52] | [0.64] | [0.45] | [0.69] |
| Constant | -4.275 | -9.745 | -3.436 | -9.043 | -16.958** |
| | [1.18] | [1.90]* | [1.35] | [1.53] | [2.35] |
| Observation | 103 | 103 | 103 | 103 | 103 |

Absolute value of t statistics in brackets.

* significant at 10%; ** significant at 5%; *** significant at 1%.

**Table 6. Determinants of household contribution to the cleaning of irrigation channels (person-hours)**

| | Main & Sub (person-hours) | | | Tertiary (person-hours) | | |
|---|---|---|---|---|---|---|
| | Tobit | | | OLS | | |
| | (1) No dummy | (2) Block dummy | (3) Strip dummy | (4) No dummy | (5) Block dummy | (6) Strip dummy |
| ***Geographical position of plot*** | | | | | | |
| Distance from the main channel (km) | 5.160** | 7.834 | | 2.72 | -1.585 | |
| | [2.17] | [1.41] | | [1.54] | [0.38] | |
| Distance from the main channel (km) squared | -1.972*** | -2.175* | | -1.123** | -1.438 | |
| | [2.77] | [1.85] | | [2.13] | [1.63] | |
| Distance along tertiary channel (km) | -14.794 | -24.579 | -17.763 | 0.970 | 6.551 | 8.826 |
| | [0.96] | [1.60] | [1.18] | [0.08] | [0.57] | [0.72] |
| Distance along tertiary channel (km) squared | 19.525 | 32.607** | 23.008 | 3.085 | -4.697 | -7.478 |
| | [1.21] | [2.03] | [1.45] | [0.26] | [0.39] | [0.57] |
| ***Strip characteristics*** | | | | | | |
| No. of strip members | 0.099 | 0.156 | | -0.045 | 0.040 | |
| | [1.22] | [1.57] | | [0.75] | [0.55] | |
| Coefficient of variation of plot size in the strip | 0.108*** | 0.037 | | -0.021 | -0.015 | |
| | [2.62] | [0.78] | | [0.68] | [0.41] | |
| ***Household characteristics*** | | | | | | |
| Density of relatives | 12.978** | 6.636 | 6.378 | 7.089 | 9.379 | 9.800 |
| | [2.06] | [0.98] | [0.85] | [1.51] | [1.86]* | [1.59] |
| Density of same village member | -2.242 | 1.265 | 4.033 | 0.724 | -2.266 | -5.713 |
| | [0.64] | [0.34] | [0.85] | [0.28] | [0.83] | [1.48] |
| No. of adult hh members | 0.717* | 1.031** | 1.221*** | 0.938*** | 0.886*** | 0.709** |
| | [1.81] | [2.58] | [2.77] | [3.20] | [2.99] | [1.97] |
| Average years of education of adult hh members | -0.416 | -0.380 | -0.641** | -0.331* | -0.420** | -0.369* |
| | [1.63] | [1.48] | [2.30] | [1.78] | [2.23] | [1.66] |
| Size of cultivated area in the sample strip (ha) | -13.610 | -11.153 | 8.293 | 1.832 | -0.983 | 7.314 |
| | [0.98] | [0.80] | [0.55] | [0.18] | [0.10] | [0.60] |
| Size of cultivated area in the sample strip (ha) squared | 28.446* | 25.641 | 5.992 | 21.843* | 28.275** | 20.689 |
| | [1.78] | [1.61] | [0.35] | [1.86] | [2.40] | [1.49] |
| Size of other cultivated area in DRS | -0.168 | 0.485 | 1.367 | -2.070 | -1.547 | -0.435 |
| | [0.06] | [0.18] | [0.46] | [1.04] | [0.76] | [0.18] |
| Size of other cultivated area in DRS squared | -0.115 | -0.285 | -0.316 | 0.744 | 0.728 | 0.357 |
| | [0.17] | [0.42] | [0.43] | [1.46] | [1.42] | [0.60] |
| Size of cultivated area in upland (ha) | -1.069 | -1.526 | -0.875 | 0.325 | 0.859 | 0.180 |
| | [0.76] | [1.09] | [0.59] | [0.32] | [0.84] | [0.15] |
| Size of cultivated area in upland (ha) squared | -0.043 | 0.021 | -0.088 | -0.079 | -0.169 | -0.036 |
| | [0.20] | [0.10] | [0.39] | [0.52] | [1.10] | [0.20] |
| 2nd season 2006 | 3.437* | 3.533* | 3.556** | 0.425 | 0.343 | 0.310 |
| | [1.74] | [1.84] | [1.99] | [0.29] | [0.24] | [0.21] |
| 1st season 2007 | -0.382 | -0.520 | -0.369 | -3.096** | -3.128** | -2.945** |
| | [0.19] | [0.27] | [0.21] | [2.13] | [2.19] | [2.03] |
| 2nd season 2007 | -3.178 | -3.077 | -2.950 | -0.399 | -0.498 | -0.419 |
| | [1.61] | [1.59] | [1.64] | [0.28] | [0.35] | [0.29] |
| Constant | -0.938 | -3.729 | 5.148 | 9.485* | 22.938*** | 9.675* |
| | [0.13] | [0.33] | [0.76] | [1.81] | [2.71] | [1.75] |
| R-squared | | | | 0.17 | 0.21 | 0.25 |
| Observations | 566 | 566 | 566 | 566 | 566 | 566 |

Absolute value of t statistics in brackets. / * significant at 10%; ** significant at 5%; *** significant at 1%.

**Table7. Determinants of the household contribution to the cleaning of tertiary drainage (person-hours)**

| | Tertiary drainage (person-hours) | | |
|---|---|---|---|
| | | Tobit | |
| | (1) | (2) | (3) |
| | No dummy | Block dummy | Strip dummy |
| ***Geographical position of plot*** | | | |
| Distance from the main channel (km) | -1.007 | -7.494** | |
| | [0.73] | [2.34] | |
| Distance from the main channel (km) squared | 0.021 | 1.503** | |
| | [0.05] | [2.22] | |
| Distance along tertiary channel (km) | -18.736** | -18.850** | -16.663* |
| | [2.11] | [2.14] | [1.88] |
| Distance along tertiary channel (km) squared | 23.810** | 26.240*** | 23.116** |
| | [2.58] | [2.83] | [2.47] |
| ***Strip characteristics*** | | | |
| No. of strip members | -0.038 | -0.018 | |
| | [0.81] | [0.31] | |
| Coefficient of variation of plot size in the strip | 0.043* | 0.017 | |
| | [1.79] | [0.61] | |
| ***Household characteristics*** | | | |
| Density of relatives | 4.572 | 2.618 | 1.892 |
| | [1.27] | [0.68] | [0.43] |
| Density of same village member | -1.416 | -0.470 | -4.407 |
| | [0.71] | [0.22] | [1.52] |
| No. of adult hh members | 0.362 | 0.523** | 0.572** |
| | [1.57] | [2.27] | [2.19] |
| Average years of education of adult hh members | -0.042 | 0.021 | 0.133 |
| | [0.29] | [0.15] | [0.81] |
| Size of cultivated area in the sample strip (ha) | 34.529*** | 35.909*** | 35.370*** |
| | [4.32] | [4.47] | [3.93] |
| Size of cultivated area in the sample strip (ha) squared | -18.250** | -18.919** | -19.336* |
| | [2.00] | [2.08] | [1.92] |
| Size of other cultivated area in DRS | -3.758** | -3.146** | -2.568 |
| | [2.39] | [1.97] | [1.44] |
| Size of other cultivated area in DRS squared | 0.952** | 0.784** | 0.828* |
| | [2.43] | [2.00] | [1.93] |
| Size of cultivated area in upland (ha) | -0.678 | -0.800 | -0.586 |
| | [0.84] | [1.00] | [0.68] |
| Size of cultivated area in upland (ha) squared | 0.145 | 0.176 | 0.088 |
| | [1.22] | [1.49] | [0.67] |
| 2nd season 2006 | 1.512 | 1.539 | 1.472 |
| | [1.34] | [1.41] | [1.43] |
| 1st season 2007 | -0.480 | -0.460 | -0.246 |
| | [0.42] | [0.41] | [0.23] |
| 2nd season 2007 | -2.246** | -2.256** | -2.264** |
| | [1.97] | [2.02] | [2.14] |
| Constant | -0.864 | 4.053 | -1.520 |
| | [0.21] | [0.62] | [0.39] |
| Observations | 566 | 566 | 566 |

Absolute value of t statistics in brackets.

* significant at 10%; ** significant at 5%; *** significant at 1%.

**Figure 1. Structure of DRS**