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The Determinants of Collective Action in Irrigation Management Systems: Evidence from Rural Communities in Japan

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Abstract

We examine the characteristics of WUAs (Water User Associations) that affect the success of irrigation management by using a large panel dataset of rural communities. We introduce an objective indicator to denote different levels of collective action for irrigation management. The result of the econometric analysis verifies the hypotheses of the existing empirical literature and confirms the robustness of the theory of collective action in the context of irrigation management. Our results show that the collective action for irrigation management depends on the distance from the market, area of paddy field, share of non-farmers and elderly farmers, share of paddy field, and social capital. We also find that the number of farm households, diversity of farmer's landholdings, and diversity among a community's farmers have a curvilinear effect on the level of collective action for irrigation management. Furthermore, we find an inverted U-shaped relationship with the number of farm households and diversity in farmer's landholdings, and a U-shaped relationship with the diversity of a community's farmers. Therefore, policies aimed at suppressing deteriorating collective action for irrigation management need to enhance social ties in a community, as the characteristics of irrigation systems and user groups can hardly change in the short run.

Keywords: collective action, irrigation management system, water user association, Japan
JEL: O15, Q25

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1. Introduction

Irrigation systems are common-pool resources characterized by rivalry of consumption and difficulty of exclusion. They have been utilized as a typical case for analyzing collective action in the common-pool resources literature. As a result of the nature of irrigation systems, a free rider problem occurs in irrigation management as it is often hard to exclude particular users from irrigation systems. In addition, when anyone can access the irrigation system, without a proper management, the resources are overexploited and depleted. Collective action is a way to resolve these problems and use a resource in a sustainable way (Ostrom, 1990). In particular, the collective action for irrigation management is based on farmers' collective effort or cooperation, such as joint maintenance of canal under customary rules, and the establishment of shared norms in rural communities or water user associations (WUAs) to restrict open access. A number of case studies highlighted the success of collective action in the case of water user associations (WUAs) for irrigation management in developing countries (Ostrom, 1990; Tang, 1992), although collective action faces some difficulties in term of organizing resource users, monitoring, and enforcing the rules. An increasing body of literature discussed the determinants of the success of the management of irrigation systems and described such systems in detail. The robustness of those results needs to be confirmed in order to identify the characteristics of WUAs that proved successful in managing local irrigation systems. However, regardless a large number of case studies, the small sample size, the specialization of successful case studies, and the use of different independent variables negatively affected the robustness of the results.

In this study, we examine the characteristics of WUAs that affect the success of irrigation management by using a large panel dataset of rural communities. Empirical studies focusing on the irrigation system of different countries identified many factors affecting irrigation management, such as different governance systems, user group's characteristics, and resource system characteristics (Bardhan, 2000; Dayton-Johnson, 2000; Meinzen-dick and Raju, 2002; Fujiie et al., 2005; Araral, 2009; Gorton et al., 2009; Nakano and Otsuka, 2011; Ito, 2012; Takeda, 2015; Nagrah et al., 2016; Wang et al., 2016). The literature recognized more than 36 factors as essential (Ostrom, 1993;

Agarwal, 2001), but no consensus has been reached yet about the direction, size, and significance of their impact on irrigation management. The lack of consensus among previous studies can be largely attributed to methodological issues, such as the cost and difficulty of collecting data (Araral, 2009). This study aims to address these issues.

First, most empirical studies on irrigation management rely on cross-sectional data due to the difficulty of collecting information over the long term. Studies based on cross-sectional data cannot control for time-invariant unobserved characteristics of a WUA, such as its history of irrigation management or the quality of the WUA itself, and they potentially suffer from an omitted variable bias. Analyses based on panel data may help address this issue by controlling for unobservable characteristic of irrigation systems and WUAs. One of the main contributions of this study is to provide an opportunity to test the robustness of the findings regarding the characteristics of WUAs that proved successful in managing irrigation systems by using a large panel dataset (N = 209,046; 2 periods). Second, most empirical studies on irrigation management do not specify, or incorrectly define, the nature of the collective action problem (Poteete and Ostrom, 2004; Araral, 2009). For instance, most studies use a subjective indicator, measured by "good" or "bad," to evaluate the outcome or status of successful collective action, such as the level of activity of WUAs or the maintenance level of irrigation channels (Nakano and Otsuka, 2011). Indicators with subjective appraisal cannot precisely measure the exact levels of collective action in the irrigation management. In this study, we use an objective indicator of irrigation management systems to denote different levels of collective action for irrigation management. This indicator is observable and provides objective information on the status of collective action. Third, many empirical studies discarded a particular group of observations, such as non-functional irrigation associations (Araral, 2009), potentially causing a censoring bias (Meinzen-Dick, 2007; Poteete and Ostrom, 2008). In this study, we included WUAs in which irrigation management is not carried on or controlled by a community.

We focus on irrigation systems in Japan to overcome the methodological problems discussed above. The main crop grown in Japan is rice, for which irrigation is of particular importance. Gravity irrigation is the most popular irrigation system, and it is managed by WUAs. The country features more than one hundred thousand WUAs, with different characteristics. We use panel data for two periods and we focus on all WUAs in Japan. The depth of the dataset allows a fine-grained analysis of the effects of the characteristic of WUAs and irrigation systems on the level of collective action for irrigation management. Therefore, Japan seems an appropriate case study to examine the characteristics of WUAs that affect the success of collective action for irrigation management and to test the robustness of these success factors. Furthermore, in Japan, WUAs have experienced a significant change in the irrigation management system due to rapid depopulation, aging of farmers, and urbanization. The result of this study, which focuses on irrigation systems in Japan, provides meaningful implications for other developing countries.

The remainder of this paper is organized as follows. Section 2 provides an overview of farmer-managed irrigation systems in Japan. Section 3 reviews the empirical studies on farmer's collective action in the irrigation management in order to refine the fundamental indicator of irrigation management systems. The data and hypotheses are described in Section 4. Section 5 discusses the proposed methodology and empirical results. The last section summarizes the main findings and provides our concluding remarks.

2. Irrigation systems in Japan

The cultivation of rice using gravity irrigation is the standard in Japan. Historically, rural communities (the smallest units of regional society in rural villages) have been the WUAs responsible for the operation and maintenance (O&M) of irrigation facilities. After World War Ⅱ, both the national and local government began constructing large-scale irrigation facilities, such as dams, headworks, and main canals. Their management was transferred from the national and local government to Land Improvement Districts (LIDs), which are farmers' organizations created in 1949 to manage large-scale irrigation and drainage facilities. The members of LIDs are farmers and landowners (non-farmers). However, such members do not manage large-scale irrigation facilities, which are managed by LIDs' office staff and experts. In the area of

LIDs, there are some rural communities. Except for large-scale irrigation facilities, the Japanese government has endorsed a common rule for water use and assigned O&M to rural communities at the level of main and branch canals. Currently, the O&M of irrigation has been implemented by rural communities to assure that the water intake from the river is stably delivered to the paddy field area through irrigation canals and allocated to various areas efficiently.

Rural communities are responsible for cleaning, weeding, and repairing the main and branch canals. Participants in those activities are selected by each rural community and could be both farmers and non-farmers. Traditionally, all households in the rural community were required to participate in such activities. Most households were farmers, although even non-farmers use water from irrigation canals for their daily life. However, the aging, depopulation, and decreasing number of farmers in rural communities advanced with rapid economic growth in Japan, and the participation's rules for those activities have changed significantly over the last 50 years. In particular, the number of non-farmers and part-time farmers increased with the urbanization, inducing significant heterogeneity among the members of rural communities. As a result, the involvement of all households of a rural community in the irrigation management became more difficult. In the recent years, the participation in the irrigation management has dynamically changed, shifting from the participation of all households to the involvement of particular households (e.g., only farm households), or lack of management by WUAs. Therefore, from 2007, the government has been providing financial support to the collective irrigation management carried on by rural communities (through measures to conserve and improve land, water, and the environment) to sustainably revitalize the irrigation management.

3. Theory and evidence of collective action in the irrigation management

3.1 Factors influencing collective action for irrigation management

In the following sections, we briefly review the literature discussing how collective action for irrigation management is affected by the characteristics of irrigation systems and user groups.

3.1.1 The characteristics of irrigation systems

In this study, we assess the impact of the following characteristics of irrigation systems:

(1) Water scarcity

Most existing studies insist on the importance of water scarcity as a determinant of the cooperation among farmers (Fujiie, 2005; Araral, 2009; Nakano, 2011; Ito, 2012). Araral (2009) and Agrawal (2001) suggest the presence of a U-shaped relationship between the degree of water scarcity and the cooperation for irrigation management. This means that the users of irrigation facilities have difficulties in managing collective action with other users when water is scarce or extremely abundant. User groups have no incentive and no need to collectively manage irrigation systems when water is abundant, and conflicts among water users may become so large as to make collective action difficult when water shortage is severe (Fujiie et al., 2005). Water scarcity, to some degree, is ideal for the collective action for irrigation management. In addition, Araral (2009) found that the governance structure mediates the effects of water scarcity.

(2) Access to the market

The distance to the market has been widely recognized as an important factor for a successful collective action in the management of common-pool resources (Meinzen-dick and Raju, 2002). A site close to the market may lead to an increased opportunity of receiving non-farming income and to more exit options to other sectors. As a result, an easy access to the market loosens the traditional social ties that bind farmers into mutual dependencies (Araral, 2009). However, a high degree of penetration of the market may also increase the returns of irrigated farming. Therefore, the effects of the access to the market on irrigation management are different across studies (Dayton-Johnson, 2000; Meinzen-dick and Raju, 2002; Fujiie et al., 2005; Araral, 2009; Nakano and Otsuka, 2011; Ito, 2012; Mattoussi and Seabright, 2014).

3.1.2 The characteristics of the user group

We assess the impact of the following characteristics of groups using the irrigation system:

(1) Size of the group

The effect of the number of participants on the sustainability of a self-governing WUAs is ambiguous (Ostrom, 2002). Olson (1965) points out that acting collectively is more difficult for large organizations. In particular, as the number of users increases, the individual marginal contribution to irrigation management will not affect the provision of water from irrigation, and the incentives to free-ride on the effort of others increase. In addition, transaction costs, linked to negotiations to create common rules, may be higher in large groups. However, in the presence of efficient irrigation management systems, when the scale of the economy adapts to the increasing group size, the cost of monitoring and management decreases and collective action in the irrigation management is successful.

Earlier studies, such as Tang (1992) and Lam (1998), did not find a relationship between the performance of WUAs and the number of users. Several empirical studies found a negative effect of group size on WUAs (Fujiie et al., 2005; Araral, 2009; Ito, 2012; Mattoussi and Seabright, 2014), while others found no impact (Dayton-Johnson, 2000). The lack of consensus in the previous literature may depend on the curvilinear effect of group size on collective action. For example, in the case of community forest management, Agrawal and Goyal (2001) find a curvilinear relationship between group size and the mobilization of resources to hire guards for shared forest resources.

(2) Heterogeneity of the user group

Heterogeneity means that the different cultural background and asset holdings, interests, and general norms shared with other group members will differ across users. This heterogeneity is a significant variable for irrigation management (Baland and Platteau, 1996; Ostrom, 2002). Social and cultural heterogeneity increase the coordination cost of forming and enforcing a common rule among members. As a result, heterogeneity makes collective action more difficult. However, if a member of a group has abilities and resources that other members do not have and participants to the user group can cooperate with each other, the existence of community's heterogeneity may help promote cooperation (Olson, 1965).

Existing empirical studies show the mixed effects of social and economic heterogeneity on collective action in the irrigation management (Tang, 1998; Bardhan, 2000; Dayton-Johnson, 2000; Meinzen-dick and Raju, 2002; Nakano and Otsuka, 2011; Ito, 2012). Poteete and Ostrom (2002) suggest that the relationship between heterogeneity and collective action is non-linear.

(3) Dependence on irrigation systems

The extent to which a community depends on irrigation systems is recognized as one of the key factors to succeed in the collective action for irrigation management (Olson, 1965; Wade, 1988; Ostrom, 1990). When many farmers depend on the irrigation system, it may be easier to invest time and energy to create new institutions (Araral, 2009), which results in maintaining successful collective action.

(4) Social capital

Social capital is defined as the shared norms and networks that enable people to act collectively (Healy, T., Côté, S., 2001). It is considered to play a key role in the collective action for irrigation management. Communities with a high social capital can reduce the cost of coordination, monitoring, and enforcement of the rules. Social capital is a mix of intangible assets, and empirical studies introduced several variables to proxy social capital. Meinzen-dick and Raju (2002) use the number of temples and cooperatives as an indicator of social capital. The connections of individuals through temples have a strong influence on the organization of the irrigation management. However, the existence of cooperatives, introduced by Meinzen-dick and Raju (2002), and the age of the resource, as in Araral (2009), also represent reasonable proxies for social capital; however, they do not seem to have a statistically significant impact on collective action for irrigation management.

3.2 Outcome of collective action for irrigation management

Using an appropriate measure for the degree of collective action or the performance of irrigation management is critical for examining the characteristics of WUAs that affect the success of irrigation management (Wang et al., 2016), Most empirical studies do not specify, or incorrectly define, the nature of the collective action problem (Poteete and Ostrom, 2004; Araral, 2009). As we already discussed in the previous section, several studies use a subjective or qualitative indicator, measured by “good” or “bad,” to evaluate the performance of irrigation management, such as the level of activity of WUAs or the maintenance level of the irrigation channels (Nakano and Otsuka, 2011). However, self-reported maintenance efforts, inputs from household, or the subjective appraisal of the maintenance status recalled by interviewees might suffer from exaggeration bias in some circumstances (Wang et al., 2016). In addition, these indicators cannot precisely identify the different levels of collective action for irrigation management. In this study, we introduce an objective indicator representing the level of collective action for irrigation management.

4. Data, hypothesis, and definition of variables

4.1 Unit of analysis and data

In this study, we use the information of community-level data obtained from *the Rural Community Card, World Census of Agriculture and Forestry 2000*. These are comprehensive data collected from a survey implemented once in five years by the Ministry of Agriculture, Forestry, and Fisheries (MAFF) to collect information on agriculture and forests in all rural communities. Our unit of analysis is the rural community, which is the smallest social unit in rural villages since rural communities in Japan correspond to WUAs. These data report detailed information on 139,176 rural communities in the year 2000, including data on the agricultural production and the activities of the rural community, such as the management of irrigation, communal farm roads, and facilities. Since further information on irrigation management is not available before 1990, we use the data from 1990 and 2000, including information on the activities of rural communities for the irrigation management. Following Takahashi (2012), we excluded 5 out of 47 prefectures, and this study focuses on the data of 42 prefectures. We exclude rural communities in Hokkaido and Okinawa due to differences in climatic conditions, and in Tokyo, Kanagawa, and Osaka due to the strong effect of urbanization in these areas. In addition, we exclude rural communities in which no paddy field and irrigation facilities are present. Therefore, the final dataset used in this study covers 104,523 communities in 42 prefectures.

4.2 Hypothesis and definition of independent variables

In this subsection, we assess the validity of a set of hypotheses. Table 2 reports the summary statistics, definition of variables, and expected sign of the hypotheses.

(1) Water scarcity

The existing empirical literature showed that water scarcity has a curvilinear effect on the collective action for irrigation management. Collective action for irrigation management can respond to moderate water scarcity. In Japan, water is abundant in most rural communities except during the season of the rice transplanting. However, there is a variation in rainfall patterns across prefectures and demand for water across regions. We add a *prefecture dummy* to account for fixed effects at the prefecture level to deal with this phenomenon.

(2) Access to the market

We use the time distance of a densely inhabited district from a community as an indicator of its access to the market. Density Inhabited Districts (DID) are high population density areas within municipal boundaries, considered as the basic units in the National Census in Japan. We introduced three distinct dummy variables: *Distance to DID (more than 1.5 hr.)* is equal to 1 if the time distance to a densely inhabited district (old city/town/village) is more than 1.5 hours, and 0 otherwise. *Distance to DID (less than 1 hr.)* is equal to 1 if that distance is less than one hour, and 0 otherwise, while *Distance to DID (1 to 1.5 hr.)* is equal to 1 if the time distance is from 1 to 1.5 hours, and 0 otherwise.

(3) Size of the group using the irrigation system

We use *the number of farm households* in a community as an indicator of the group size of WUAs and the *area of paddy field* in a community as an indicator of the size of WUAs as measured by the irrigation service area. We include both the *number of farm households* and its square to capture the possible U-shaped relationship between the likelihood of collective action and group size. In our sample, the number of farm households in a community varies from a minimum of 5 to a maximum of 386 in 2000. The average size of the communities is 25 farm households, with an area of paddy field of 21 ha in 2000.

(4) Heterogeneity of the user group

We create a diversity indicator to measure the community's social and economic heterogeneity. *Diversity among community's farmers* captures the degree of social heterogeneity. Following Alesina et al. (1999), we construct *diversity among community's farmers a*s follows:

$$diversity\ among\ community's\ farmers = 1 - \sum_i Farmer_i^2,$$

where $Farmer_i$ denotes the ratio of farmers i to the total population in the community and i indicates self-sufficient farm households, full-time farm households, type-1 part-time farmers (when the income earned from activities other than farming is higher), and type-2 part-time farmers (the income earned from farming is greater than other income), respectively. If this index is close to one, the community comprises various types of farmers. If this index is close to zero, farmers in the community are homogeneous.

Diversity of farmer's landholdings indicates the degree of economic heterogeneity. We use this indicator instead of the distribution of the farming income, which is not disclosed in the data. We construct *diversity of landholdings a*s follows:

$$diversity\ of\ landholdings = 1 - \sum_i Lnadholdings_i^2,$$

where $landholdings_i$ denotes the ratio of operating farmland, i corresponds to the land (in ha) of the farmer to total farmland in the community, and may correspond to less than 1.0 ha, 1.0~3.0 ha, 3.0~5.0 ha, 5.0~10.0 ha, 10.0~20.0 ha, 20.0~30.0 ha, and more than 30 ha. We include both these indicators of heterogeneity and their square to capture the possible U-shaped relationship between the likelihood of collective action and heterogeneity.

In addition, we use the *ratio of non-farm households* and the *ratio of elderly farmers* to measure heterogeneity. In Japan, irrigation management used to be carried out collectively by all households residing in the community; most members of a community were farmers, and non-farmers also received some benefits for their livelihoods from the irrigation management. As a result of the advancing urbanization, the number of non-farmers in rural communities increased significantly, making it harder to maintain a high level of collective action for the irrigation management. Therefore, we use the r*atio of non-farmers* to control for the heterogeneity derived from increasing urbanization. Moreover, communities in rural areas face a population aging crisis, as much as other areas in the country. Wang et al. (2016) and Li et al. (2012) found that an elderly group is less interested in participating in collective irrigation. Therefore, we introduce the *ratio of elderly farmers*, which is the ratio of the population engaged in farming above 65 years old over the total population of a community, to control for the heterogeneity induced by aging. Therefore, we capture several types of heterogeneity: social, economic, and the heterogeneity caused by the ratios of non-farmers and elderly farmers.

(5) Dependence on irrigation systems

We use the *ratio of paddy field* as a proxy indicator of the dependence on irrigation. The *ratio of paddy field* measures the area of paddy field divided by the total area of farmland in a community. The higher the ratio of paddy field, the greater the dependence on irrigation.

(6) Social capital

Because social capital is intangible, various proxy variables have been used in the existing studies to capture it. In this study, we use *age of community* (or user group) (Fujiie et al., 2005; Araral, 2009), *number of meetings* (Labonne and Chase, 2011), and *ratio of consolidated farmland* as proxies for social capital. *Age of community* is a dummy variable that takes value 1 if a community is established before 1975, and 0 otherwise. Ideally, we would use the number of years after the establishment of the community as a proxy, but this information is not available in our dataset. *Number of meetings* refers to the total number of meetings held by farmers in a year. The higher age of a community and the larger number of meetings are proportionality related to the accumulation of social capital in that community.

In addition, we introduce the *ratio of consolidated farmland*. To improve labor and land productivity, farmland consolidation, including merging and reshaping small plots of farmland into one large plot, is often carried out. These projects are usually based on proposals received from farmers in rural communities. If more than two-thirds of landowners in the project area agree, the project will be implemented by the central or prefectural government, as a public project. Thus, if the social capital in a community is low, that community will usually not agree on the implementation of any projects. The communities in which these projects are implemented have accumulated social capital, and the coordination among farmers is relatively easy.

(7) Additional Variables

We include three dummy variables (flatland, urban, hilly, and mountainous) for the location of a community to control for diverse agricultural conditions. We also include an indicator for farmland use peculiar to the rural area in Japan, accounting for the *ratio of rented-in area* and *ratio of abandoned farmland* (Table 2). In addition, a *year dummy* is included to control for the time dimension.

4.3 Measurement of dependent variables

We use an observable objective indicator to denote the different level of collective action for irrigation management. We focus on how irrigation management, such as cutting the weeds and removing silt, is implemented. We assign an ordered dummy variable for different irrigation management systems: “3” indicates management carried on by all households residing in the community, “2” refers to management only performed by farm households, “1” indicates management performed by hired hands, and “0” denotes a non-functionality (non-functional community).

This ranking is based on a direct indicator of collective action. The level of collective action for irrigation maintenance carried on by all households is the highest: all members of the community are required to participate in the operations and maintenance of the irrigation facilities. Next, the irrigation management carried on by farm households is characterized by a lower level of collective action due to the exclusion of non-farm households. These two irrigation management systems are examples of collective action for irrigation management organized by the members of a community. In the case of irrigation management carried on by fired hands and non-functionality, the collective action of community members is not required. Especially, the ranking of non-functionality is the lowest because the collective action for irrigation management is not carried on or controlled by a community.

We examine the transition of irrigation management systems using the sample described in the previous subsection. Figure 1 shows the distribution of the different irrigation management systems adopted by rural communities in 1990 and 2000. The number of communities adopting each irrigation management systems is 35,695 (all households), 46,867 (farm households), 796 (hired hands), and 21,165 (non-functionality) in 1990. In 2000, the number of communities adopting each irrigation management systems are 34,008 (all households), 50,613 (farm households), 421 (hired hands), and 19,481 (non-functionality). Between 1990 and 2000, the number of communities adopting irrigation management carried on by farm households increased, while the number communities adopting other irrigation management systems decreased. As shown in Figure 2, the share of communities adopting an irrigation system managed by all households or farm households is 79.0% (all households: 34.2%; farm households: 44.8%) in 1990 and 80.9 % (all households: 32.5%; farm households: 48.4%) in 2000. Furthermore, the share of communities characterized by non-functionality is 20.2 % in 1990 and 18.6% in 2000. As shown in Figures 1 and 2, the choice of the irrigation management system by a community seems stable during the period of analysis.

On the other hand, Table 1 indicates the transition of irrigation management systems from 1990 to 2000. It is apparent that communities have changed their irrigation management systems over the period of analysis. For example, looking at communities with irrigation management carried on by all households in 1990 (N = 35,695), about half of these communities (N = 18,625, 52.2%) shows the same system of irrigation management in 2000. The remaining communities have changed irrigation management system (farm households, hired Hands, and non-functionality): 36.0% have changed from an irrigation system managed by all households to one relying on farm households only in 2000, 0.5% have changed to a system managed by hired hands, and 11.5% have shifted to non-functionality. Furthermore, the ratio of communities moving to an irrigation system managed by farm households is the highest: 36% in the case of communities adopting irrigation systems managed by all households, 46.5 % by hired hands, 42.8% characterized by non-functionality. Overall, we can observe the dynamics of the irrigation management systems adopted by a community and concentrate on the irrigation system managed by farm households only.

Focusing on communities that maintained the same irrigation management system, 60.4% were managed by farm households, 4.0% by hired hands, and 36.2% were characterized by non-functionality in 1990. In communities that have not changed irrigation management system in the period of analysis, the ratio of communities adopting an irrigation system managed by farm households is the highest (60.4%) and seems stable compared to other irrigation management systems.

Table 2 shows the changes in the characteristics of communities over the period of analysis. We can observe a remarkable shift in the size of the groups (numbers of farm households), heterogeneity (ratio of non-farmers and ratio of elderly farmers), and social capital (number of meeting and ratio of consolidated farmland). These changes might influence the shifts observed in the irrigation management systems. For example, the change from an of irrigation management system managed by all households to one only relying on farm households (36.0%) implies a decreased level of collective action. The heterogeneity caused by the increase of the ratio of non-farm households and the aging of farmers might make it difficult to coordinate a collective action that involves non-farmers. On the other hand, communities with irrigation management systems (hired hands and non-functionality) not characterized by the collective action have remarkably changed to irrigation management systems (all households and farm households) characterized by collective action. Overall, the level of collective action has increased. The accumulation of social capital through the implementation of farmland consolidation and the increasing number of meetings as well as the reduction of coordination costs obtained decreasing the number of farmers are likely to facilitate the collective action for irrigation management.

A conventional cross-sectional dataset cannot capture such changes in the irrigation management system and characteristics of WUAs. Therefore, we use panel data to capture this transition through an empirical model.

5. Results and discussion

5.1 Estimation models

In the empirical model, we assess level of collective action for irrigation management on a categorical scale. We estimate the proposed model using panel data. We introduce random-effects in an ordered probit model, which allows identifying the actual values of the dependent variables. The model can be written as:

$$y_{i,t}^{*} = \beta x_{i,t} + \alpha_i + \varepsilon_{i,t}$$

and

$$y_{i,t} = k \ if \ k_{K-1} < y_{i,t}^{*} \leq k_K, k = 1, \cdots, K,$$

where $y_{i,t}^{*}$ is an indicator of the level of collective action for irrigation management and captures the unobservable latent continuous response. Only the category chosen by the community i at each point in time t can be observed. $x_{i,t}$ is a set of time-varying independent variables. β is the parameter to be estimated. α_i represents an individual-specific and time-invariant random component, depending on the unobserved heterogeneity. The errors, $\varepsilon_{i,t}$, have a standard normal distribution with mean equal to zero and variance equal to one and are assumed to be independent of α_i. K is the number of outcomes. Furthermore, we report the results of the ordered probit model with and without random effects taking into account the impact of both the observed and unobserved heterogeneity.

5.2 Determinants of the level of collective action for irrigation management

Table 3 shows the results of the ordered probit model with (column 1) and without (column 2-4) random effects to address how the effect of the independent variable change when we add unobserved heterogeneity into model. The estimates from column (1) to (4) have the expected signs and are statistically significant, except for *Age of community* in column (3) and (4). Most coefficients on independent variables are larger in column (2) – (4), in which the specifications add random effects. Running the model without random effects may induce the underestimation of the effect of the independent variables on the level of collective action for irrigation management.

The results in column (2) control for the characteristics of the irrigation systems and those in column (3) control for the characteristics of the user group. In column (4), we add both the characteristics of the irrigation systems and the user group to confirm the specification of the model. The coefficients in column (2) – (3) are stable and less likely to suffer from specification problems. Based on the results reported in column (4), in the next section, we discuss the impact of the characteristics of the irrigation systems and the user group (a community, as a WUA) on the collective action for irrigation management at the WUA-level.

5.2.1 The characteristics of the irrigation systems

The coefficient on the distance to the market (*Distance to DID*) is negative and significant, showing that a community that is far from the market or has no exit options is characterized by a lower level of collective action for irrigation management. This finding is consistent with the results of Meinzen-dick and Raju (2002) and Wang et al. (2016), which use the same indicator for the access to the market. This may be because there are less profitable commercial opportunities for these communities (Meinzen-dick and Raju, 2002), and returns to irrigated farming decrease in remote areas. Furthermore, a community that is further away from the market tends to maintain social ties among the members of the community.

5.2.2 The characteristics of the user group

(1) Size of the group

The coefficient on *the number of farm households* is positive and significant, and the coefficient on its squared term is negative and significant at a 1% level. The result on group size and *the number of farm households* implies that group size and level of collective action are associated through an inverted U-shaped relationship. The level first increases as the number of farm households increase, up to 106 farm households, and decreases after this point. The average *number of farm households* is 25 in 2000. Therefore, in most communities used in this analysis, the level of collective action for irrigation management increases with the number of farm households. In Japanese communities, the level in the irrigation management decreased with the declining number of farm households. Some people are required to maintain the irrigation systems and to assure that the benefit arising from the economies of scale is higher than the coordination costs. In this respect, our empirical result is consistent with the findings of Takeda (2015) for Japan.

The coefficient on the *area of paddy field* is negative and significant. As the area of paddy field increases, the cost of organizing a collective action on a vast territory increases as well (Fujiie et al., 2005). This result is consistent with the findings of case studies for Indonesia (Fujiie et al., 2005) and India (Bardhan, 2000) and with the general opinion that collective action is more difficult as group size increases.

(2) Heterogeneity of user group

The coefficient on the *diversity of farmer's landholdings* is positive and significant and the coefficient on its squared term is negative and significant. It means that economic heterogeneity has an inverted U-shaped relationship with level of collective action. The level first increases with economic heterogeneity up to 0.35, and, then, it decreases. The inverted U-shaped relationship between economic heterogeneity and collective action is consistent with the study of Bardhan (2000) on India and Dayton-Johnson (2000) on Mexico. A group characterized by heterogeneity of landholdings will be more successful than a group with an extreme heterogeneity of asset structure, or with homogeneous assets, in enhancing the cooperation level of collective action for irrigation management.

The coefficient on the *diversity among community's farmers* is negative and significant and the coefficient on its squared term is positive and significant. Social heterogeneity and the levels are associated through a U-shaped relationship. Heterogeneity in the social background makes the collective action for irrigation management more difficult when the homogeneity of farm households is high. This finding is consistent with the previous literature (Bardhan, 2000; Dayton-Johnson, 2000; Meinzen-dick and Raju, 2002; Ito, 2012). Social and economic heterogeneity have non-linear effects on the level of collective action for irrigation management. The direction of the effect is different at each level of heterogeneity because the impact of social and economic heterogeneity on the benefit of collective action complements the effect derived from a variety of farm households. Social heterogeneity has a larger impact than economic heterogeneity on the collective action for irrigation management (Baland and Platteau, 1996).

The coefficients on the *ratio of non-farmers* and *ratio of elderly farmers* are negative and statistically significant. These results imply that an elder group is less interested in irrigation management, which is consistent with the findings of Wang et al. (2016) for China. In addition, the availability of an exit option to non-farming employment weakens the incentives for collective action. This finding is in line with the results of the existing studies (Fujiie et al., 2005; Ito, 2012).

(3) Dependence on irrigation systems

The positive coefficient on the *ratio of paddy field* confirms the hypothesis that a community with a high paddy field ratio is more likely to achieve higher level of collective action for irrigation management. This implies that these communities have an incentive to agree on collective action requiring a higher cooperation because irrigation is essential for their livelihood. This finding is consistent with the empirical results of Gorton et al. (2009) for Mcedonia and Araral (2009) for the Philippines.

(4) Social capital

The coefficients on the *number of meetings* and *ratio of consolidated farmland* are positive and statistically significant, as expected. These variables are used as indicators of social capital. The implementation of consolidated farmland projects induces coordination and transaction costs. The accumulation of social capital is crucial in the implementation of consolidated farmland to decrease such costs. A community with high social capital is likely to choose a higher cooperation level of collective action for irrigation management. In addition, holding meetings requires considerable amounts of social capital. Meetings are expected to increase the likelihood of collective action for irrigation management by strengthening social interactions or traditional social ties.

5.3 Simulation analysis

In this subsection, we discuss the relationship between the characteristics of WUAs and the probability of adopting different types of irrigation management systems (Figure 3). The likelihood of choosing an irrigation system only managed by farm households is the highest with respect to all explanatory variables and is stable regarding changes in the characteristics of WUAs. We argue that this management system is stably selected because irrigation water is essential to paddy farmers. This result is consistent with the higher ratio of communities maintaining irrigation systems managed by farm households in the 10 years under analysis, as shown in Figure 1 and Figure. 2. However, the probability of selecting irrigation system managed by all households and the absence of an irrigation management carried on by a community changes according to variations in the characteristics of WUAs. Focusing on irrigation systems managed by farm households and the absence of irrigation management, we address the relationship between the probability of selecting different types of irrigation management systems and the characteristics of WUAs.

First, the relationship between the number of farm households (Fig.3a), area of paddy field (Fig.3b), diversity of farmer's landholdings (Fig.3c) and the probability of selecting an irrigation system managed by all households shows an inverted U-shape. The relationship between these characteristics of WUAs and the absence of an irrigation management is U-shaped. Below a certain threshold in the number of farm households, area of paddy field, and diversity of farmer's landholdings, the probability of absence of irrigation management decreases, and the likelihood of irrigation systems managed by farm household increases. However, beyond a certain threshold, the trend changes in the opposite direction. Second, the higher the ratio of paddy field (Fig.3g) as a proxy indicator of the dependence on irrigation systems, number of meetings (Fig.3h) and ratio of consolidated farmland (Fig.3i) as a proxy indicator of social capital, the higher the probability of irrigation systems managed by all households. These indicators show that physical infrastructure, such as the ratio of paddy field, and "soft" measures, such as social capital, help promote the collective action for irrigation management by WUAs and seem to play a fundamental role. Third, as the diversity of community's farmers, ratio of non-farmers, and ratio of elderly farmers increase, the probability of irrigation systems managed by all households decreases, while the probability of non-functionality increases.

6. Conclusions

This study provides empirical evidence on some characteristics of WUAs that affect the success of collective action for irrigation management. We used panel data from 100,000 rural communities in Japan observed between 1990 and 2000. The main contribution of this study is the use of a large-scale panel data set (N = 201,046) to assess the theory of collective action for irrigation management. Moreover, we try to address some methodological issues observed in previous empirical studies (Poteete and Ostrom, 2004, 2008; Araral, 2009), such as the informational limits of cross-sectional data, the choice of subjective indicators as dependent variables, and the censoring bias. Although a subjective indicator has been used as a dependent variable to evaluate the performance of communal irrigation management in existing empirical studies, in this study, we use an objective indicator of irrigation management system to denote different levels of collective action for irrigation management.

The result of the econometric analysis verifies the hypotheses of the existing empirical literature and confirms the robustness of the theory of collective action in the context of irrigation management. Our findings suggest that the level of collective action for irrigation management depends on the distance from the market, on the area and ratio of paddy field, the ratio of non-farmers, the ratio of elderly farmers, the number of meetings, and the ratio of consolidated farmland—a proxy for social capital. We also find that the number of farm households, the diversity of farmer's landholdings, and the diversity among community's farmers have a curvilinear effect on the collective action for irrigation management. The relationship between these variables and likelihood of collective action is ambiguous in the existing literature. An inverted U-shaped relationship between collective action for irrigation management and the number of farm households and the diversity of farmer's landholdings seems to exist, as well as a U-shaped relationship between the level and the diversity among community's farmers. This means that user groups with a moderate heterogeneity of landholdings will be more successful than groups with an extreme heterogeneity of asset structure, or with homogeneous assets, in enhancing the level of collective action for irrigation management.

These findings have implications for the irrigation management carried on by WUAs. The rapid depopulation, aging of farmers, and urbanization may help explain the deteriorating state of the irrigation management. The Japanese case can be seen as an example for developing countries, which may experience a similar change in their rural environment due to economic development. To be able to perform collective irrigation management, it is necessary to maintain both physical infrastructures, such as the ratio of paddy field, and "soft" measures, such as social capital. In addition, policies aimed at suppressing deteriorating collective action for irrigation management need to enhance social ties in a community, as the characteristics of irrigation systems and user groups can hardly change in the short run.

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Table 1 The transition of irrigation management systems

(Unit: Number, %)

		2000				Total in 1990
		All households	Farm households	Hired hands	Non-functionality	
1990	All households	18,625 (52.2)	12,863 (36.0)	111 (0.3)	4,096 (11.5)	35,695 (100.0)
	Farm households	10,792 (23.0)	28,328 (60.4)	196 (0.4)	7,551 (16.1)	46,867 (100.0)
	Hired hands	215 (27.0)	370 (46.5)	32 (4.0)	179 (22.5)	796 (100.0)
	Non-functionality	4,376 (20.7)	9,052 (42.8)	82 (0.4)	7,655 (36.2)	21,165 (100.0)
Total in 2000		34,008 (32.5)	50,613 (48.4)	421 (0.4)	19,481 (18.6)	104,523 (100.0)

Source: The Rural Community Card, World Census of Agriculture and Forestry, Ministry of Agriculture, Forestry, and Fisheries (MAFF) , 2000.

Table 2 Summary statistics, variables definition and expected sign

Variables	Definition	1990 Mean	1990 Std. Dev.	2000 Mean	2000 Std. Dev.	Expected sign
Dependent variables						
Level of collective action	Ordered dummy variable (3: management carried on by all households residing in the community; 2: management carried on by only farm households; 1: management carried on by employees; 0: non-functionality of the community)					
The characteristics of the irrigation systems						
Distance to DID (less than 1 hr.)	Dummy = 1 if the time distance to DID (densely inhibited district by old city/town/village) is less than 1 hour, and 0 otherwise.	0.725				
Distance to DID (1 to 1.5 hr.)	Dummy = 1 if the time distance to DID (densely inhibited district by old city/town/village) is between 1 and 1.5 hours, and 0 otherwise.	0.228				−
Distance to DID (more than 1.5 hr.)	Dummy = 1 if the time distance to DID (densely inhibited district by old city/town/village) is more than 1.5 hour, and 0 otherwise.	0.047				−
The characteristics of the use group						
Numbers of farm households	Total number of farm households.	31	23.01	25	19.52	+/−
Area of paddy field	Area of paddy field (ha).	22.901	27.05	21.287	26.43	+/−
Diversity of farmer's landholdings	See text.	0.586	0.14	0.578	0.16	+/−
Diversity among community's farmers	See text.	0.515	0.15	0.525	0.14	+/−
Ratio of non-farmers	Number of non-farm households /total number of farm households.	46.575	27.86	57.047	26.51	−
Ratio of elderly farmers	Population engaged in farming above 65 years old / total population engaged in farming.	20.658	5.66	30.236	8.45	−
Ratio of paddy field	Area of paddy field /area of farmland.	74.157	24.00	74.953	24.22	+
Age of community	Dummy = 1 if a community is established before 1975, and 0 otherwise.	0.996				+
Number of meeting	Total number of meetings held by farmers.	6	5.22	9	6.73	+
Ratio of consolidated farmland	Area of consolidated farmland/area of farmland.	46.044	44.61	57.220	44.14	+
Additional Variables						
Ratio of area rented-in	Area of farmland rented-in/area of farmland.	9.457	9.06	14.199	12.43	
Ratio of abandoned farmland	Area of abandoned farmland/area of farmland.	5.347	8.09	8.870	10.41	
Agricultural area (flatland)	Dummy = 1 if the classification of the agricultural area is flatland agricultural area, and 0 otherwise.	0.208				
Agricultural area (urban)	Dummy = 1 if the classification of the agricultural area is urban agricultural area, and 0 otherwise.	0.294				
Agricultural area (hilly and mountainous)	Dummy = 1 if the classification of the agricultural area is hilly and mountainous Areas, and 0 otherwise.	0.498				
Prefecture dummy	Dummy variables of each prefectures.					
Year dummy	Dummy = 1 if data is in 2000, and 0 otherwise.					
Observations				209,046		

Table 3 Determinants of the cooperation level for the irrigation management

Dependent variable: level of collective action for irrigation management	Ordered Probit Model		Random Effects Ordered Probit Model					
	(1)		(2)		(3)		(4)	
	coefficient	z-value	coefficient	z-value	coefficient	z-value	coefficient	z-value
The characteristics of the irrigation systems								
Distance to DID (1 to 1.5 hr.)	-0.128 ***	-18.64	-0.141 ***	-15.87			-0.153 ***	-17.14
Distance to DID (more than 1.5 hr.)	-0.124 ***	-9.39	-0.146 ***	-8.53			-0.150 ***	-8.77
The characteristics of the user group								
Number of farm households	0.004 ***	13.13			0.005 ***	12.28	0.005 ***	11.73
Number of farm households (squared)	-2.0E-05 ***	-8.41			-2.3E-05 ***	-7.78	-2.2E-05 ***	-7.58
Area of paddy field	-0.001 ***	-10.04			-0.001 ***	-8.44	-0.001 ***	-8.42
Diversity of farmer's landholdings	0.139 **	2.22			0.132 *	1.75	0.131 *	1.74
Diversity of farmer's landholdings (squared)	-0.193 ***	-2.81			-0.182 **	-2.18	-0.188 **	-2.26
Diversity among community's farmers	-0.483 ***	-5.92			-0.533 ***	-5.45	-0.510 ***	-5.22
Diversity among community's farmers (squared)	0.472 ***	5.3			0.522 ***	4.89	0.499 ***	4.68
Ratio of non-farmers	-0.003 ***	-30.76			-0.004 ***	-25.92	-0.004 ***	-28.13
Ratio of elderly farmers	-0.004 ***	-8.48			-0.004 ***	-8.49	-0.003 ***	-6.54
Ratio of paddy field	0.003 ***	22.72			0.004 ***	21.45	0.004 ***	20.85
Age of community	0.072 *	1.72			0.081	1.54	0.086	1.65
Number of meetings	0.007 ***	15.45			0.007 ***	14.85	0.007 ***	14.78
Ratio of consolidated farmland	0.000 ***	7.31			0.001 ***	6.30	0.001 ***	6.14
Additional Variables								
Ratio of area rented-in	0.004 ***	15.4	0.004 ***	12.28	0.004 ***	12.84	0.004 ***	13.33
Ratio of abandoned farmland	-0.003 ***	-8.58	-0.006 ***	-15.53	-0.003 ***	-8.01	-0.003 ***	-8.09
Agricultural area (urban)	-0.092 ***	-11.83	-0.222 ***	-23.00	-0.101 ***	-9.93	-0.111 ***	-10.92
Agricultural area (hilly and mountainous)	-0.118 ***	-16.82	-0.143 ***	-16.12	-0.178 ***	-19.99	-0.141 ***	-15.5
Random effects	*NO*		*YES*		*YES*		*YES*	
Prefecture dummy	*YES*		*YES*		*YES*		*YES*	
Year dummy	*YES*		*YES*		*YES*		*YES*	
cut1	-0.479 ***		-0.678 ***		-0.501 ***		-0.545 ***	
cut2	-0.457 ***		-0.652 ***		-0.475 ***		-0.519 ***	
cut3	0.902 ***		0.944 ***		1.121 ***		1.076 ***	
Likelihood-ratio test: $\chi^2(1)$			5547.51 ***		5134.66 ***		5072.72 ***	
Log likelihood	-212519.52		-211003.34		-210147.79		-209983.16	
Observations	209,046		209,046		209,046		209,046	

Note: *significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.
The reported likelihood-ratio test statistics show that there is enough variability across communities to favor a random-effects ordered probit regression over an ordered probit. Z-value is estimated by using robust standard error.

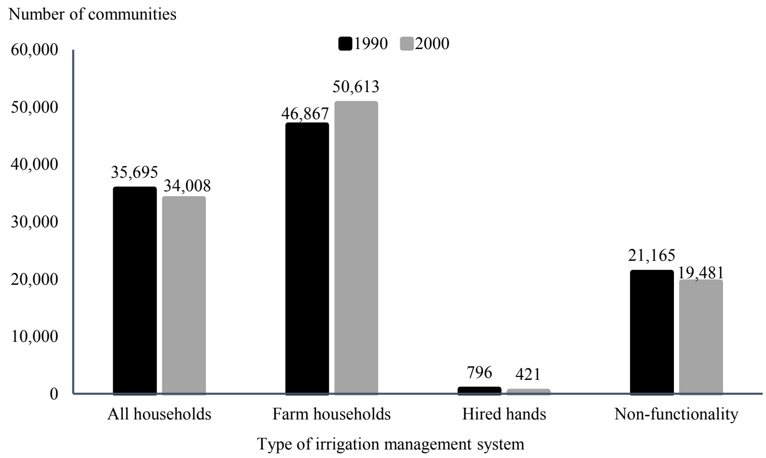


Figure 1 Irrigation management system in 1990 and 2000

Source: The Rural Community Card, World Census of Agriculture and Forestry, Ministry of Agriculture, Forestry, and Fisheries (MAFF) , 2000.

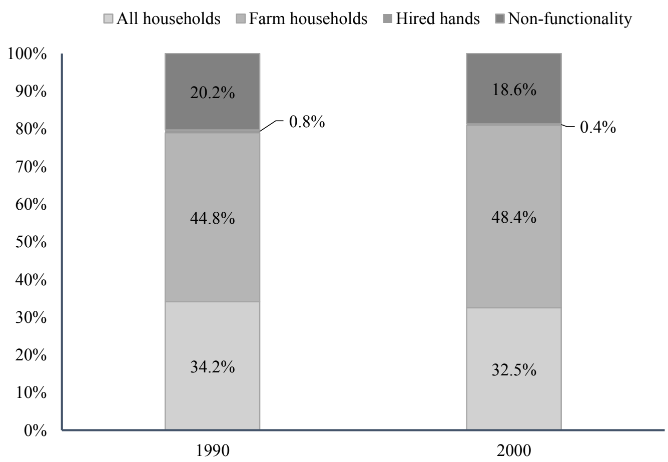
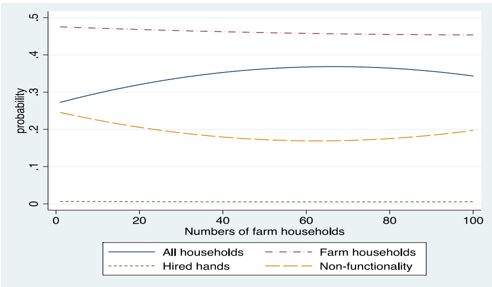
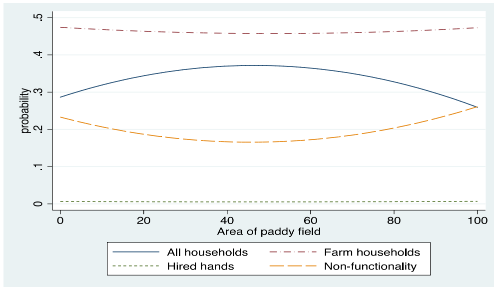


Figure 2 Rate of type of irrigation management system in 1990 and 2000

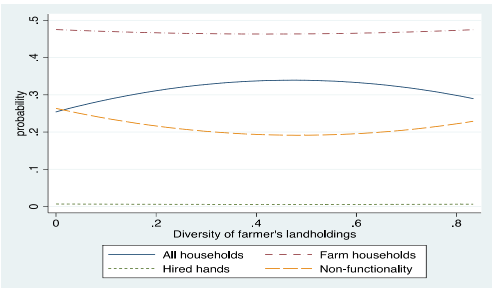
Source: The Rural Community Card, World Census of Agriculture and Forestry, Ministry of Agriculture, Forestry, and Fisheries (MAFF) , 2000.



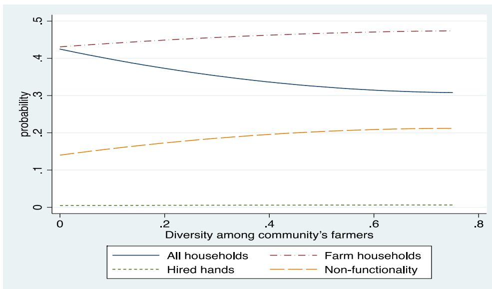
(a)Number of farm households



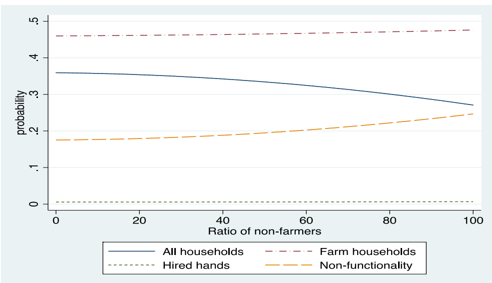
(b)Area of paddy field



(c)Diversity of farmer's landholdings

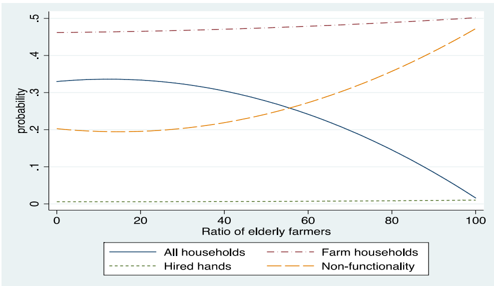


(d)Diversity among community's farmers

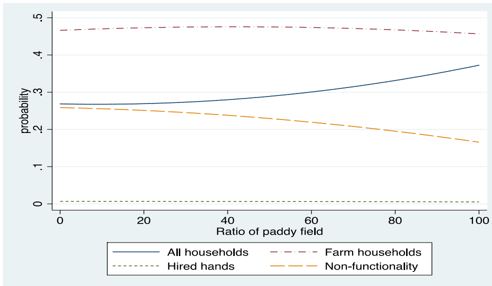


(e)Ratio of non-farmers

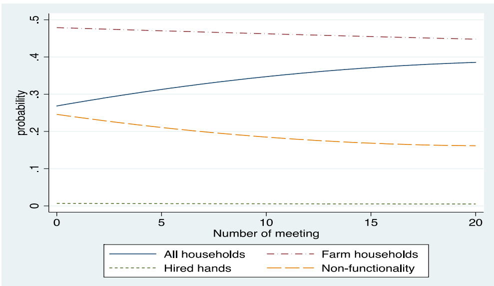
Figure 3 Relationship between the choice probability of the irrigation management method and the characteristics of the user group



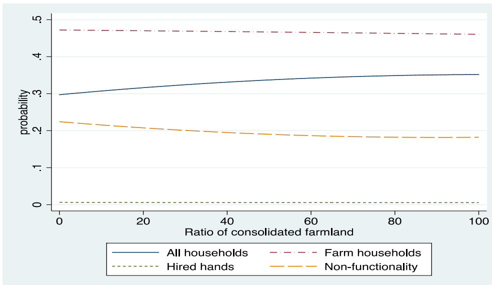
(f)Ratio of elderly farmers



(g)Ratio of paddy field



(h)Number of meeting



(i)Ratio of consolidated farmland

Figure 3 (continued) Relationship between the choice probability of the irrigation management method and the characteristics of the user group