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The Effects of Volumetric Pricing Policy on Farmers' Water Management Institutions and Their Water Use: The Case of Water User Organization in an Irrigation System in Hubei, China

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Abstract

We use original water user group (WUG) data from a reservoir irrigation system in China to examine the effect of water pricing policies on farmers' water saving behaviors. The introduction of volumetric water pricing at the group level, to replace area-based pricing, induces institutional change to prevent each member's overuse of water when the volumetric price levels are moderate. Depending on the initial conditions, the multiple pathways of change lead to new institutional arrangements, with all of them contributing to water savings. However, when the price is set high enough, many farmers exit a WUG for private irrigation. This tendency is associated with an increased probability that the remaining members do not undertake institutional change and that they do not end up saving water. This may be due to the increased management difficulties among the remaining members whose fields are separated by former members who have now opted out for private irrigation across the WUG. As a result, we do not find evidence that the reservoir water is saved at high volumetric price levels.

JEL classification: O12, O17, Q25

Key words: institutional change, collective action, surface irrigation, social capital

International concerns regarding the increasing scarcity of fresh water and food production sustainability have been growing (Molden 2007). As a rapidly growing economy with expanding demand for water and food, China exemplifies this global picture in many aspects. Although the situation looks more severe in

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northern China, southern China also suffers from increasing water scarcity and faces a rapid increase in water demand for urban and industrial use (Loeve et al. 2004). Since the region's paddy production has been considered the largest water consumer, how to save irrigation water has been the major policy issue.

The major effort to promote water conservation in the agricultural sector began in the 1990s with considerable regional variation in intervention tactics (Lohmar et al. 2007). In 2002, twenty provinces implemented a reform on taxes and fees called *fei gai shui*. Before the reform, a water fee was included in the land tax, which is equivalent to area-based pricing (i.e., zero marginal cost for irrigation water). Hence, there was no economic incentive to save water. The reform called for separate water fees and increased independent management for each reservoir. In reaction to this change, many reservoirs began volumetric water pricing and expected this pricing to have a significant impact on farmers' water saving behaviors.

However, volumetric pricing's effectiveness is primarily an empirical question for two reasons. First, some people argue that the demand for irrigation water is inelastic, and farmers thus do not change their behaviors significantly, even under high water prices (Yang et al. 2003). Second, in a surface irrigation system, which is the major mode for paddy production, effective collective action among water users is needed to save water. This is because a feasible pricing method measures the volume at a canal's intake, and the total fee is charged to the water user group (WUG) rather than to individual farmers. The total fee is then divided among the WUG members by cultivated area. Therefore, the group has an incentive to save water, while individual farmers *within* a group may overuse water unless they are closely supervised. Institutional change must play an important role in preventing this free-rider problem within a WUG. Under this setting, a key research issue is exploring how the volumetric pricing contributes to the institutional change and water savings. However, only a few attempts have been made to explore this issue (Vos and Vincent 2011; Dono et al. 2010; Huang et al. 2010).

The purpose of this study is to fill this research gap by providing micro-level evidence of institutional change and water saving behaviors under volumetric pricing in rice farmers' water user groups (WUGs), using data collected in 2008 from the Zhanghe Irrigation System in Hubei, China. Several distinctive features of the study site make this dataset suitable for our analysis. First, the marginal cost of irrigation water varies widely, including zero marginal cost, which allows for different water saving motivations. As we explain later, this variation can be regarded as a de facto natural experiment from the WUG perspective, which provides an ideal setting for our research. Second, we observe multiple paths of institutional change, including the case of maintaining the status quo even under volumetric pricing. Our data provide us with an opportunity to examine both institutional change and persistence. Third, our sample of WUGs is scattered over a large irrigation scheme and varies widely in terms of initial conditions. This variation allows us to examine how initial conditions affect the direction of institutional change.

Our three major findings are summarized as follows. First, a modest increase in a volumetric price of reservoir water induces institutional change to prevent each member's overuse of water. Therefore, for institutional change to occur, the correct signal of resource scarcity must be transmitted to resource users, and the price can play an important role in signaling scarcity. Second, paths of change have multiple directions, depending on initial conditions (e.g., infrastructure conditions, land distribution equality, social capital, and the availability of alternative water sources). For example, redrawing the institutional boundary (the formation of new smaller group) is chosen when the bonding social capital among a smaller group's possible members is high, while a change in institutional design (the appointment of a water manager) emerges when simple topography enables the manager to effectively supervise water distribution. Either change contributes to water savings. Third, when the volumetric price is set high enough, many farmers leave a WUG and start using private irrigation. This tendency is found to be associated with a higher probability that the remaining farmers do not undertake institutional change (i.e., uphold informal management of WUG) and that they do not save water. This may be due to the increased management difficulties (e.g., coordination of water allocation, supervision of water distribution, and maintenance of irrigation infrastructure) among the dispersed remaining farmers after the exit of many members. As a result, in spite of many farmers' substitution of private irrigation for reservoir irrigation, we do not find evidence that the reservoir water is saved at high water price levels.

Our study contributes to two related areas of research: institutional change and common pool resource (CPR) management. As Pande and Udry (2005) noted, only a limited number of micro-level studies are available compared with the growing number of macro-level or historical studies on institutional change. Topics that micro-level studies have explored include the evolution of land rights institutions (McMillan et al. 2012; Otsuka and Place 2001; Pande and Udry 2005), the change in agricultural labor contracts after the Green Revolution (Hayami and Kikuchi 1981), and the emergence of forest user groups (Tachibana et al. 2001). A common finding among these studies is that as resource scarcity increases, stakeholders (resource users, group leaders, etc.) reform their institutions to facilitate more efficient resource utilization.[1] Our finding adds to this group, insisting on the importance of price but, at the same time, indicating its possible adverse effect on institutional change. Second, similar to existing studies' findings, we confirm the importance of social capital, homogeneity, resource characteristics, and an exit option (in our case, individual irrigation) for the evolution and survival of successful institutions (Ostrom 1990, 2000, 2010). We would like to emphasize the importance of an exit option as a factor that underlies the decline of collective management. This point will become increasingly important because exit options in rural areas are becoming more widely available under the economy's rapid industrialization and globalization.

I. The Study Site and Data

The Zhanghe Irrigation System (ZIS) is located to the north of the Yangtze River in Hubei Province in central China (figure 1). This system is typical of large-scale Chinese irrigation systems and is the province's most important base of commodity grain production (Dong et al. 2004; Mushtaq et al. 2006). The total area is 554,000 ha, of which approximately 160,000 ha are irrigated. About 80% of the irrigated area lies in the hilly region and the local topography is rolling in many parts. This geographical feature makes farmers' field activities, including irrigation practices, less observable to each other beyond their immediate neighbors. With the utilization of irrigation and adequate rainfall, ZIS farmers cultivate rice as their main crop during the mid-season (May to September). Rapeseed and winter wheat are commonly cultivated during the winter.

The main water source in the ZIS is the Zhanghe Reservoir, which was built on a tributary of the Yangtze River (figure 2). The reservoir was designed for irrigation, domestic water supply, industrial use, and hydropower generation. A sharp increase in water demand for nonagricultural purposes has increased agricultural water scarcity; the water share allocated to agriculture has dropped from 80% to 25% over the past 25 years (Moya et al. 2004).

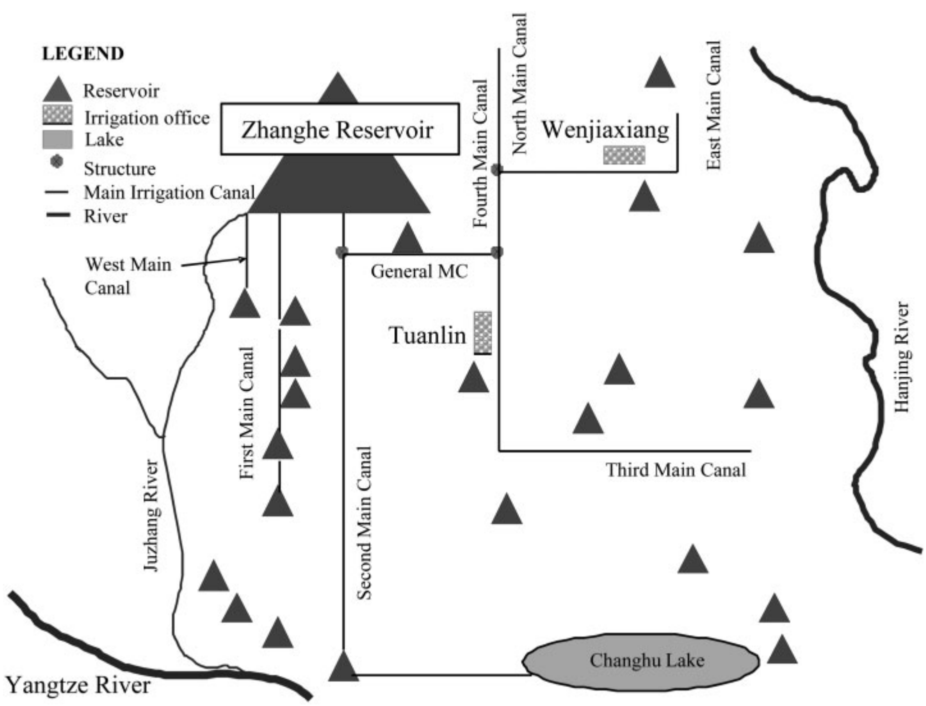
In addition to the main reservoir, many medium-sized reservoirs (the small triangles in figure 2) and hundreds of small ponds supply irrigation water to farmers. The medium-sized reservoirs are owned by different local authorities and are managed independently from the ZIS. Most of the small ponds are owned and operated by individual farmers or a few farmers.

In 2008, the International Rice Research Institute and Wuhan University conducted a survey right after the harvesting of rice. Two neighboring townships in the ZIS, Tuanlin and Wenjiaxiang, were selected for this study (figure 2). Note that the irrigation water demand is the residual demand after rainfall and thus depends on the amount and timing of rain. Therefore, we selected two sites within a relatively close area with similar rainfall patterns that are confirmed by meteorological stations at each site (see figure S1 for rainfall data for each site in the supplemental appendix, available at http://wber.oxfordjournals.org/).

1 Hayami and Ruttan (1985) conceptualize this mechanism as a theory of induced institutional innovation.

Figure 1. The Location of the Zhanghe Irrigation System

Figure 2. The Structure of Zhanghe Irrigation System



The WUGs, which are formed on the basis of irrigation water boundaries, are autonomous local institutions that are responsible for the management of surface irrigation. One village typically includes several WUGs, each consisting of twenty to forty farmers. We randomly sampled sixty-seven WUGs from the study site that were stratified on the basis of size and pricing method and then randomly sampled at least two farming households from each WUG, which generated a total sample of 135 households.[2] The household interview gathered detailed data on irrigation activities, input and output data for rice production, rice plot characteristics, and household demographic data. All sampled farmers primarily derive their income from rice cultivation. The WUG-level interview with the key informants, including a village head, helped collect data on the irrigation infrastructure and social capital endowments. The key informants referred to official statistics when they were available. To capture each WUG's topography, we generated geographical information systems (GIS) data from satellite images.[3]

II. Policy Change in the ZIS

In reaction to the implementation of *fei gai shui* in 2002, reservoirs under different local authorities began charging water fees to WUGs in different ways. Some reservoirs have used area-based pricing, while others started volumetric pricing with an average price of 0.061 (Yuan/m^3) and a standard deviation of 0.037, ranging from 0 to 0.15.[4]

Our price variable has two important features. First, from the WUG's perspective, the changes in the pricing system and price level are de facto exogenous. Although the official stance is to base water-pricing policies on each reservoir's water scarcity, the actual pricing has been strongly influenced by local authorities' logic, legitimacy, and political factors, which produce variation that is independent of the conditions that directly affect farmers' production (Liao et al. 2008; Lohmar et al. 2007).[5] Therefore, unless similar WUGs are concentrated in a group of reservoirs with similar price levels, we can consider this policy change a de facto natural experiment. A balance test (table 1) and an OLS regression analysis (table 2) to explain the relationship between the reservoir's volumetric price level and the WUG's characteristics support this claim by showing no statistical significance at conventional levels.[6,7]

2 Regarding WUG sampling, we believe that there is little attrition after the reform (*fei gai shui*) because we were able to interview the WUGs that no longer used reservoir water and relied solely on private irrigation. Even in this case, the names of WUGs remained, and we were able to include them in our sample. Regarding the household level sample, one farmer was removed in the data cleaning process because this farmer showed a level of water use that was about 8 times higher than the average.

3 A digital elevation model (DEM) for the study area was acquired from an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) image through the Warehouse Inventory Search Tool (WIST). ASTER is a remote sensory device on board the Terra satellite (http://asterweb.jpl.nasa.gov/gdem.asp, http://en.wikipedia.org/wiki/ Advanced_Spaceborne_Thermal_Emission_and_Reflection_Radiometer). WIST can be found online (https://wist.echo.nasa.gov/wist-bin/api/ims.cgi?mode=MAINSRCH&JS=1). For more details on the data source, see Rala et al. (2009).

4 Some authorities, including the ZIS, adopted a two-part tariff that consisted of fixed fee to acquire the right to utilize water and a variable fee that was based on the consumed volume. However, in practice, the fixed fee was seldom collected due to limited administrative capacity, and no WUGs in our sample paid this fee.

5 The provincial water resource bureau and the provincial price bureau determine the price of Zhanghe Reservoir. The local city or county water resource bureau and price bureau determine the prices of mid-sized reservoirs. Townships and villages manage the small reservoirs and determine prices.

6 The characteristics examined here are those used in the analyses on the WUGs' institutional changes. Because the dependent variable is a WUG-level reservoir water price, the WUG averages are used for individual characteristics.

7 Of the 67 WUGs, 54 have a single reservoir; 10 rely on two reservoirs; and 3 use three reservoirs. In case of multiple reservoir use, we computed an average volumetric price that was weighted by water use. Even in the case of multiple reservoir use, WUGs use one reservoir for their dominant source and the other(s) as supplementary sources.

Table 1. Balance Test of Reservoir Water's Price Level and the Characteristics of the Water User Groups

WUG characteristics	Reservoir water price level: Area-based pricing (MC = 0) (n = 7)	Low volumetric price (n = 20)	Medium volumetric price (n = 20)	High volumetric price (n = 20)	*F*-statistics[a]
Group size					
No. of parcels	106	112	105	124	0.67 [0.54]
Homogeneity					
Gini coefficient of parcel size	0.23	0.28	0.27	0.23	0.64 [0.59]
Infrastructure condition					
Simplicity of water flow direction	0.11	0.12	0.15	0.12	0.66 [0.57]
Earth canal length	1.33	0.48	1.31	1.10	1.06 [0.37]
Exit options					
No. of ponds per member (pre-reform)	0.63	0.56	0.68	0.90	1.45 [0.23]
No. of pumps per member (pre-reform)	0.61	0.91	0.89	0.83	0.68 [0.57]
Surrounding parcel characteristics					
No. of surrounding parcels	2.79	2.76	2.74	2.71	0.02 [0.99]
No. of surrounding parcels squared	8.32	8.17	8.47	7.98	0.04 [0.98]
Years knowing the owners of surrounding parcels	38.00	32.73	34.84	35.60	0.55 [0.65]
Proportion of surrounding parcels whose owners send their children to the same school	0.51	0.39	0.33	0.35	0.41 [0.74]
Management skills and water demand					
Average schooling years of working member	8.36	8.97	9.23	8.59	1.54 [0.21]
Parcel size of paddy	0.15	0.14	0.13	0.13	0.43 [0.73]
Sandy/high seepage soil dummy	0.07	0.17	0.09	0.03	1.76 [0.16]

[a]H_0: Means of four price-level groups are all equal.
Note: *p*-values in brackets.
Source: Authors' analysis based on data sources discussed in the text.

Second, once the authorities set the water price, they do not frequently change the level.[8] This point is particularly important when we discuss the incentive mechanism of area-based pricing. If the authorities frequently increased the level of area-based price in reaction to WUGs' overuse of water in the previous season, one farmer's overuse would be partly shouldered by others in the form of an increase in price to all the members; hence, this pricing method would also create a free-rider problem. However, we confirm that this problem does not always surface in our case. Therefore, the free-rider problem and the demand for institutional change arise only among the WUGs in our study site that operate under volumetric pricing.

III. Institutional Change in the ZIS

How have WUGs reacted to the exogenous change in water price? Before explaining the change, we summarize the roles of the WUG. It handles the water transactions between the farmers and reservoirs. The farmers request water from the reservoir through their WUG; the water is then supplied, and the fee is charged to the WUG. Note that the fee is adjusted to the actual amount of water, rather than being fixed at the requested amount. Through its collection system, the WUG collects fees from the group

8 One of the reasons for this rigidness stems from the complication of the bureaucratic process. The provincial water resource bureau and provincial price bureau set the price of large reservoirs, and this price takes a long time to be approved. The smaller reservoirs follow the provincial ones in terms of price revision timing.

Table 2. The Results of Regression Analyses to Explain the Reservoir Water's Price Level by the Characteristics of the Water User Group

Variables	Dep var: volumetric price of reservoir water*1000[a] OLS
Group size	
No. of parcels	0.126 (1.157)
Homogeneity	
Gini coefficient of parcel size	−52.36 (-1.310)
Infrastructure condition	
Simplicity of water flow direction	62.59 (0.778)
Earth canal length	−1.973 (-0.604)
Exit options	
No. of ponds per member (pre-reform)	8.107 (0.871)
No. of pumps per member (pre-reform)	7.834 (0.636)
Surrounding parcel characteristics	
No. of surrounding parcels	8.068 (0.261)
No. of surrounding parcels squared	−1.614 (-0.284)
Years knowing owners of surrounding parcels	−0.0418 (-0.0698)
Proportion of surrounding parcels whose owners send their children to the same school	−5.439 (-0.393)
Management skills and water demand	
Average schooling years of working members	−1.762 (-0.398)
Parcel size of paddy	−139.8 (-1.408)
Sandy/high seepage soil dummy	−41.18 (-1.580)
Constant	74.51 (1.227)
Observations	67

[a]value is zero in case of area-based pricing.

Note: *t*-statistics are in parentheses.

Source: Authors' analysis based on data sources discussed in the text.

members and then pays the reservoir water fee. It also takes care of the maintenance of irrigation facilities and water distribution within the group.

Before the reform, village heads were responsible for all aspects of irrigation management. However, in most cases, their main task was fee collection, while group members individually handled maintenance and water distribution with informal coordination among them, which can be considered informal collective management.

After the reform, changes occurred to this informal collective system. Based on our field observations, the changes can be classified into four categories: (1) no change (or upholding of the informal management), (2) the formal appointment of water managers, (3) the formation of a new smaller groups, each of which is a much smaller sub-set of farmers from neighboring plots only, and (4) individual irrigation using water from ponds.

Formal water managers are chosen from WUG members, and large WUGs tend to appoint multiple managers. Some WUGs provide a manager salary from member contributions.[9] Manager

9 In our study site, the salary is fixed per season or per year and is not related to water management performance. In northern China, there are cases in which the reward is related to the manager's performance. Nevertheless, feeling the obligation in a small group, the managers face reasonable incentives to improve water conservation, even in our study site.

responsibilities include contacting a reservoir for water delivery, coordinating and supervising canal maintenance and water distribution among members, and collecting fees. Note that management tasks are not completely outsourced to the managers; members also participate in these activities, particularly in canal maintenance and water distribution. The managers function as collective management facilitators. This change can be considered an institutional design change. However, in the case of new group formation, neither a formal manager nor a leader is appointed, as the group is small enough to allow efficient communication among members. Hence, management continues to be informally coordinated among group members but within a much smaller group. The new group's management is independent of the original WUG, and each new group can exclusively receive irrigation water. Therefore, a new group is an independent and autonomous WUG. We can regard this change as an institutional boundary change.

Although they represent different solutions, the motivation behind these changes is the same: to prevent the free-rider problem. This is very important issue in the study site because the rolling landscape (even within the WUGs) makes farmers' behavior not so observable each other. Institutional changes toward (2) or (3) can contribute to water savings by improving monitoring effectiveness. Note, however, that in order to obtain this benefit, the farmers have to shoulder the transaction costs of starting and operating a new institution. Under the institution with the manager, in addition to the salary to the manager (if any), members have to devote a significant amount of time to the selection and appointment of managers and the coordination of an irrigation schedule, supervision, and maintenance with the manager. Under the new group formation, negotiation among would-be members is needed to form a new group. Then, the chosen members must spend time negotiating water management. These transaction costs can be regarded as the fixed costs of each institution. The level of the costs varies among the WUGs, depending on the factors such as group size, social capital endowment, equality, and infrastructure conditions that affect the smoothness of coordination among the members.

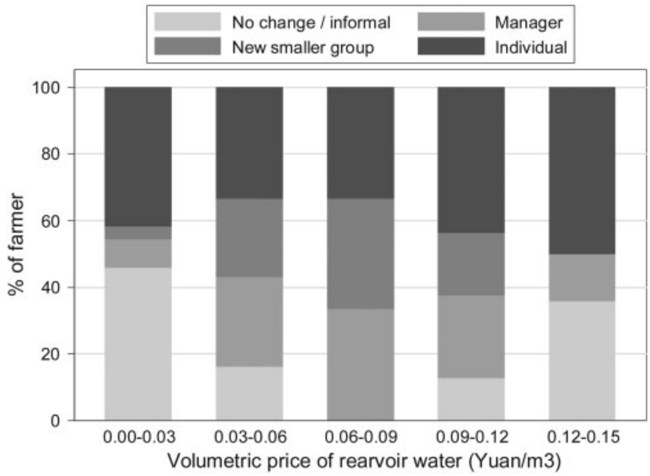
In addition to (2) and (3), we also observed that significant numbers of farmers have stopped utilizing reservoir water and rely on their own water sources (e.g., private ponds and pumped water from streams or drainages). The area's most common mode of individual irrigation is to use existing ponds or dig new ponds close to their paddy fields and apply water by gravity or pumping. Some farmers even convert a part of their paddy field to a pond, forgoing the benefit of rice farming. In this manner, the fixed cost of individual irrigation varies by farmer.

The importance of private irrigation differs among farmers. Some farmers use reservoir water as a main source and supplement with individual irrigation. Other farmers have completely exited from reservoir water irrigation and solely use private irrigation. In our analysis, we classify the latter case as individual irrigation. Note that individual irrigation can coexist within any of the three types of institutions, that is, (1), (2), and (3), in that some individuals can leave a WUG for private irrigation, but the remaining farmers may maintain it. In an extreme case, the WUG is dissolved completely, and all farmers manage irrigation individually.

It is worth noting the variations in the decision-making units. Choosing individual irrigation is a farmer's individual decision. Choosing new group formation largely results from an individual farmer's initiative in consideration of a few neighbors. These individual decisions can be made in any WUG, as long as the individuals choose to make such decisions. Meanwhile, appointing a manager or maintaining the informal management is a group decision.

Figure 3 shows the proportion of farmers under each water management institution by the volumetric price level of reservoir water (which is set zero for area-based pricing). In the group of the lowest price level, including the case of area-based pricing, the farmers who choose no change account for the largest proportion (46%). This is a natural outcome because the farmers have little incentive to implement a strict management for water savings. As the price goes up moderately, the proportion of manager appointment and that of new smaller group formation increase. When the price goes up further (beyond the 4th price

Figure 3. The Proportion of Farmers in the Four Types of Irrigation Institutions by the Volumetric Price of Reservoir Water



Source: Authors' Analysis Based on Data Sources Discussed in the Text.

range category), the attractiveness of the exit from reservoir water use increases, and the proportion of individual irrigation then increases. Interestingly, the proportion of no change (or informal management) also increases in replacement of the other two water-saving institutions (i.e., manager appointment and new smaller group). The figure generally shows a U-shaped relationship of the volumetric price level with no change and weakly so with individual irrigation, while there is an inverted U-shaped relationship with manager appointment and with new smaller group.

IV. A Model

Why do institutional changes show the unique patterns observed above? We construct a simple model by paying attention to differences in fixed costs (*FC*) and profit (π) under different institutions. Let us start with the case of individual irrigation. This mode of irrigation requires different levels of fixed costs from low *FC* (e.g., the users of existing ponds) to high *FC* (e.g., those who have to excavate new ponds), depending on the farmers' hydrological conditions. As the volumetric price level increases, individual irrigation becomes feasible for one farmer after another in the order of low *FC* farmers to high *FC* farmers. This leads to a decrease in the number of reservoir water users in a WUG.

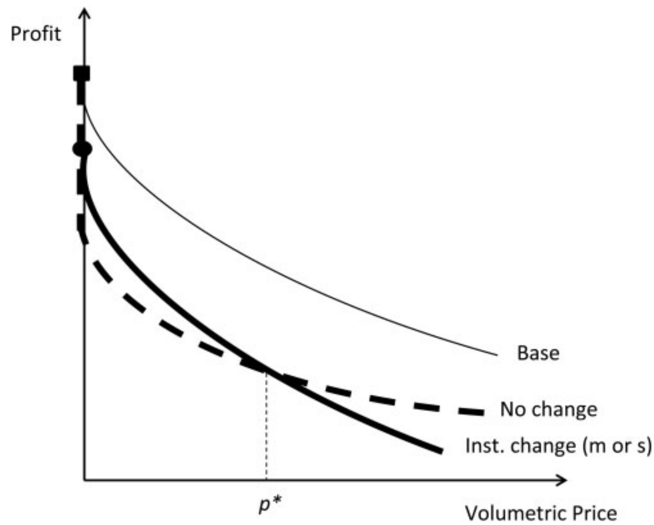
Now, we turn to the behavior of reservoir water users. As a base of comparison, we set up a profit function of a reservoir water user under volumetric pricing as follows:

$$\pi_{base} = f(x) - px,$$

where *f(.)* is a production function, x is a farmer's reservoir water use, and p is the water price. For simplicity, we assume that only irrigation water is used for rice production, with the use of one unit of land under normalized rice price. Based on an agronomic fact, we assume that the production will not increase beyond a threshold level of water application, so that the optimal water use and profit can be determined even when the volumetric price level is zero. The model assumes that a farmer pays the water fee according to his/her actual use, which means that this base case shows a hypothetical profit if there was no free-rider problem even without supervising institution. The profit under a new institution (either manager appointment or new smaller group formation) and under no change may be expressed as follows:

$$\pi_{change} = f(x) - px - FC(n),$$

Figure 4. Profit and Volumetric Price Level under Different Institutional Settings



$$\pi_{no\_change} = f(x) - \frac{p\sum x}{n},$$

where *FC* is the fixed cost that each member must shoulder for the set-up and operation of the new institution, and n is the number of reservoir water users in a WUG. In the case of institutional change, the cost term (i.e., px) is the same as the base case because the irrigation fee is charged to each farmer according to the amount he/she actually uses under strict supervision and water control. We assume that *FC* is a function of n (details will be explained later). Meanwhile, in the case of no change, the users share the total cost charged to a WUG among them ($p\sum x/n$), so that the "effective" water price is (p/n). In this case, the fixed cost does not arise as there is no coordination amongst farmers.

The profit under no change becomes lower than that in the base case because of the inefficient overuse of water (note that the profit maximization condition with Nash behavior under no change is $f'(.) = p/n$). Note, however, that the difference in profit becomes smaller as the volumetric price increases because the number of reservoir water users decreases as volumetric price increases, which leads to an increase in the "effective" water price. Formally, we can show that $\partial\pi_n^*/\partial n < 0$, where π_n^* indicates maximized profit under no change.[10]

This feature is depicted in figure 4, which shows the relationship between volumetric price level and profit under different institutional arrangements, in comparison with the base case. The base case (a thin solid curve) simply shows a declining profit with an increase in water price. The profit under no change

10 From the first-order condition $f'(.) = p/n$, the factor demand function can be expressed as $x*(p/n)$. Because of the symmetry of the group member, it holds that all farmers' $x*(.)$ are equal and that $\Sigma x* = nx*$. Hence, $\pi^* = f(x^*(.)) - px^*(.)$. A comparative static shows that

$$\frac{\partial\pi*}{\partial n} = \frac{1}{n^2}[-x*'(.)p(f'(.) - p)] < 0,$$

where $x*'(.)$ is negative, as is the slope of an ordinary factor demand function, and $(f'(.) = p)$ is also negative given the profit maximizing condition. The profit at $n = 1$ corresponds to the profit under the base case.

is shown by a dashed curve. When price level is zero, the profit under the base case and that under the no-change case become identical (the square symbol on the vertical axis). The difference in profit, indicated by the vertical gap between the two curves, appears once the price level becomes positive, but it becomes smaller as the price increases because the price increase leads to the exit of farmers and, hence, an increase in the "effective" water price for remaining members.

The profit under the new institution (either manager appointment or new smaller group formation) is shown by a thick solid curve in figure 4. The curve starts at a circle symbol located below the base case as the new institution entails a fixed cost. The shape of the curve depends on how FC changes with n. We assume that the fixed cost per person increases when n decreases (i.e., $\partial FC/\partial n < 0$), and thus, $\partial \pi_c^*/\partial n > 0$, where π_c^* indicates maximized profit under the new institution. A rationale behind this assumption is that, after the exit of many members for individual irrigation, it becomes difficult for the remaining farmers to coordinate among themselves as they must now manage their parcels that coexist with the parcels of private irrigation users. In the case of the formation of a new smaller group, it is difficult to find appropriate members and, thus, to form a new group of an appropriate size with an appropriate water boundary. In the case of manager appointment, the effect is mixed. In one way, the reduction in the number of stakeholders eases coordination among them, as Olson (1965) argues. However, we have to note that our case is different from cases where group size is small from the start. In the context of the water users group, the exit of farmers can make coordination and management among remaining farmers difficult because their parcels are separated by the parcels of farmers using private irrigation. For example, there is a case that the monitoring of water distribution for the check of possible overuse at a farmer *i's* plot is done by the manger together with the farmer *i* and *i*'s parcel neighbors, but the effectiveness of this check would decline once the neighboring farmers exited for private irrigation. The neighboring farmers also provide peer pressure to follow an appropriate level of water use, even when the manager is not around. Once they exited, the manager would have to supervise more intensively, which leads to an increase in FC. Hence, although it is an empirical question in nature, it seems reasonable for us to assume that FC per person increases with the exit of original members. If this assumption holds, the gap in profit between the base case and the case of institutional change becomes wider as the volumetric price increases (figure 4). The profit under institutional change becomes lower than that under no change at price level p^*.

In summary, figure 4 indicates that the case of no change first disappears with the introduction of low volumetric price and then resurges later at high volumetric price levels. We would like to make two remarks to fit this model better to the actual patterns observed in figure 3. First, if institutions are rigid, the case of no change may not disappear easily upon the introduction of volumetric pricing. This may explain why no-change cases remain in the 2nd price level category. Second, and contrary to our predictions, figure 3 shows that the proportion of individual irrigation decreases when the price level changes from the 1st category to the 2nd category. Note that, in reality, the area-based price is charged when the volumetric price level is zero. Hence, it may be possible that the farmers who used to employ individual irrigation under area-based pricing switch to reservoir water when the volumetric price level is set at such low levels.

Note that our simple model does not imply that institutional choice is made sequentially from the choice of individual irrigation to the choice of other institutions. The attractiveness of individual irrigation depends also on the effectiveness of the other institutions. For example, a farmer in a WUG, which is effectively managed by a manager at low transaction costs, must have lower incentive to shift to individual irrigation. In this manner, the choice among different institutions is made simultaneously in practice.

V. Outcomes under Different Water Management Institutions

Table 3 presents the average water prices and water use of sample farmers by water management institution. Note that non-price restriction on water use (e.g., a quota) does not exist in any pricing method.

Table 3. Water Price and Water Use by Water Institution

	Institution				
	(1) Area-based no change	(2) Volumetric no change	(3) Manager appointment	(4) New smaller group formation	(5) Individual
WUG-level variable					
Volumetric price of reservoir water (Yuan/m^3)	—	0.080 (0.035)	0.063 (0.030)	0.061 (0.025)	0.066 (0.039)
Area-based fixed price of reservoir water (Yuan/ha)	290.5 (209.1)	—	—	—	27.9 (113.2)
Farm-level variable					
Total water use (mm)	235 (138)	197 (85)	163* (114)	114*** (81)	175 (133)
Reservoir water use (mm)	232 (140)	144* (80)	102*** (82)	89*** (66)	—
Individual water use (mm)	3 (9)	54** (67)	61* (102)	25 (67)	175*** (133)
No. of obs. (farmers)	11	17	31	25	51

Notes: Standard deviations are in parentheses.

*Indicate *t*-test for the mean difference in water use from (1) Area-based no change, *$p < 0.1$, ** $p < 0.05$, ***$p < 0.01$.

Source: Authors' analysis based on data sources discussed in the text.

Note also that, since the no-change cases are observed either under area-based pricing or under volumetric pricing, we further divide the no change cases into two categories. The table indicates that the no-change case under the volumetric pricing has the highest average volumetric price of all (0.080), reflecting the existence of this case in the 4th and 5th price categories in figure 3. The case of individual irrigation is observed in the wide price range (including the case of zero volumetric pricing under area-based pricing). Hence, this case shows the moderate level of average price (0.066) with a high standard deviation (0.039). The fixed price has a positive value (27.9) because the individual irrigation exists even under the area-based pricing.

The lower part of the table shows total water use (mm), reservoir water use (mm), and individual water use (mm), where the water use is measured in terms of cumulative net water depth (mm) applied to a farmer's paddy field. Our major focus is on the change in the reservoir water use with the reservoir volumetric price. The table shows that farmers reduce reservoir water use in any institutions under volumetric pricing. However, it is worth noting that the farmers under the no-change case save water least (144 mm, significantly different from the area-based case (232 mm) at 10%), in spite of the highest average volumetric price level. Meanwhile, a more significant reduction is observed under the manager appointment case (102 mm, significant at 1%) and the new smaller group case (89 mm, significant at 1%). By definition, the reservoir water use by the farmers under individual irrigation is zero. The individual water use by individual irrigation farmers is not so small (175 mm), probably because this case includes the farmers with an inherently low cost for individual irrigation.

If the reservoir water use by the farmers that undertake no change under volumetric pricing is large enough, it may cancel out the other farmers' substitution effect of individual irrigation for reservoir water. The following sections statistically examine this possibility, controlling for other key covariates of collective management and water use, as suggested by the existing literature.

VI. The Determinants of Institutional Change

Modeling institutional change in our case is not straightforward because decisions are made at group and individual levels, and these decisions influence one another (e.g., choice between individual irrigation and manager appointment). Hence, in a structural model, the group-level equation has the individual-level decision, and the individual-level equation has the group-level decision. In our case, an empirical difficulty is finding appropriate identification variables that are unique in each equation because each equation's primary objective is the same (i.e., water savings), and the relevant variables in one equation must thus come in the other equation. Because of this difficulty, our empirical strategy is to estimate a reduced-form equation of institutional choice at each level.

Variable Construction

Our key explanatory variables for reduced-form equations are the volumetric price of reservoir water and its squared term. We also control for other determinants, as suggested by the synthesis of Agrawal (2001) and recent studies on collective action and common pool resource management.[11] They are classified into six categories: (1) group size, (2) homogeneity, (3) infrastructure condition, (4) exit options, (5) surrounding parcel characteristics, and (6) management skill and water demand. The descriptive statistics of the variables are summarized in the online appendix table S1 for individual level analysis and table S2 for group level analysis.

The group size is measured by the number of parcels in the WUG.[12] In our framework, the impact of the initial condition of this variable on institutional choice is an empirical question because an increase in group size may increase the possibility of free riding but it may also increase a coordination difficulty for the avoidance of the free riding. We control for the initial condition of these effects. The impact of homogeneity is also an empirical question. On the one hand, it reduces the transaction cost of coordination and improves the success of collective management. On the other hand, the owners of large farms who can enjoy the so-called lion's share may push for collective management (Deaton-Johnson 2000; Bardhan 2000). Land distribution is an important aspect of homogeneity in the context of irrigation management, as it determines the benefit distribution. To capture this effect, we employ the Gini coefficient of parcel size.

The infrastructure condition is represented by two variables. First, we measure the simplicity of water flow direction. When the flow directions are relatively simple, a manager can easily monitor water volume and effectively implement a water distribution schedule with WUG members. We expect that the motivation to remain in a WUG and to then hire a manager will rise with this variable. Utilizing GIS data, we develop a variable that is the proportion of the area with the same water flow direction as a single continuous area over the entire irrigated area of the WUG.[13]

The second infrastructure-related variable is the length of the earthen part of the irrigation canal. In a surface irrigation system, seepage takes place along the canal, and seepage increases as the length of the earthen canal increases; however, seepage is negligible along a lined canal, regardless of its length. Seepage loss occurs when the soil in an earthen canal is dry and becomes minimal once the water starts flowing along the canal and the soil becomes saturated. Hence, the loss occurs only at the beginning of the irrigation practice as a fixed startup cost of the irrigation that follows. This fact introduces economies of scale and provides an incentive to remain in the group, rather than moving toward individual or small group irrigation. Hence, we expect seepage to have a positive impact on remaining in the WUG.

11 Agrawal's (2001) synthesis relies on three major contributions in this area, i.e., Wade (1988), Ostrom (1990), and Baland and Platteau (1996), and is supplemented by other studies. Recent studies include Bardhan (2000), Deaton-Johnson (2000), Ray and Williams (2002), and Khwaja (2009).

12 This variable shows a high correlation with other size aspects, such as the number of WUG members and the WUG area.

13 As a first step, we estimate the direction of water flow at each pixel in the WUG's GIS map (see examples of two WUGs shown in figures S2 and S3 in the online appendix). Using that information, the largest single area is measured as the aggregated size of the continuous pixels that have the same flow direction. Figure S2 is an example of a simple water flow direction group (index value = 0.23). The largest single area (brown tiles or pixels in the center) relative to the group size is large. Meanwhile, figure S3 is an example of a complicated water flow direction group (index value = 0.07). See Rala et al. (2009) for more details about the data-processing algorithm.

To measure WUG exit options, we introduce the number of ponds or pumps per farmer in the WUG.[14] Because these variables can change as a result of institutional choice, we utilize their levels before *fei gai shui* to avoid simultaneity bias.

The exit to a new smaller group is determined based on the characteristics of the farmers in the surrounding plots, as a new group's management will be easier when strong personal ties exist or when high-bonding social capital is endowed among would-be members. We use the following variables: the number of surrounding parcels and its squared term, the average number of years that farmers have known the owners of surrounding plots, and the proportion of surrounding plots whose owners send their children to the same school.[15] Because these variables characterize nearby farmers, they even vary within a WUG and function as individual-level variables in our analysis.[16] Note that the variables explained above (i.e., volumetric price, group size, homogeneity, infrastructure condition, and exit options) are WUG-level variables.

As other individual-level factors that are related to irrigation management, we employ the average schooling years of working members to control for water management skills, the parcel size of paddy to control for water demand, and the dummy of sandy or high seepage soil types for the paddy parcel to also control for water demand.[17]

Econometrically, we apply a multinomial probit model for the individual level analysis, as every individual farmer has three options: to start individual irrigation, to form a new smaller group with surrounding farmers, or to remain with the WUG (base category). We use 135 individual-level observations, of which 51 farmers start individual irrigation, 25 form a new group, and 59 remain (table S1 in the online appendix for the descriptive statistics of each category). For group-level estimation, we apply two types of probit models to estimate the determinants of manager appointment against the no change. The first model uses a full sample of 67 WUGs, of which 16 WUGs appoint the manager (table S2 in the online appendix for the descriptive statistics of each category). However, the full sample includes the WUGs that were completely dissolved already (due to farmers' exits) and had no decision maker. As our primary interest is the WUG's decision regarding its institutional design, we estimate a second model with a sample of 33 WUGs that had remaining members.

Regression Results

Table 4 presents the average marginal effects computed from the multinomial probit regression of an individual-level analysis. The original results are shown in the online appendix table S3. The first important finding is that the influence of the volumetric price has a U-shaped relationship with the choice of individual irrigation. However, as the statistical significance of the level term is not strong (p-value 12%), we cannot deny the possibility of an exponential increase in individual irrigation, which presumably reflects the fact that only a few farmers switched from individual irrigation to reservoir water at low volumetric price. Second, an inverted U-shaped relationship with the choice of new smaller group formation is clearly detected. Third, a U-shaped relationship is suggested for the choice of remaining at the WUG, but the statistical significance of the squared term is weak (p-value 15%). This result indicates the possibility of a downward linear impact, which may reflect the fact that this choice is the residual

14 We employ these WUG-level variables rather than the household-level ownership of ponds and pumps because even non-owners can purchase water from ponds and/or rent pumps.

15 The rationales to employ the latter variable are that social ties may be more easily established through school events and that generational similarity makes the establishment of social ties easier. Among different schooling levels, variations are observed only at the middle-school level in our sample data.

16 We include the squared term of the number of surrounding parcels to find out an optimal group size for a new smaller group.

17 The parcel size is included in case the scale matters for per hectare water demand.

Table 4. The Average Marginal Effects from Multinomial Probit Regression of an Individual Farmer's Exit Choice Model

Variables	(1) Individual	(2) New smaller group	(3) Stay in WUG
Volumetric price of reservoir water	−5.983	13.07***	−7.088*
	(−1.548)	(2.950)	(−1.941)
Volumetric price of reservoir water squared	48.99*	−87.56***	38.57
	(1.763)	(−3.056)	(1.433)
Group size			
No. of parcels	−0.000524	0.00120	−0.000678
	(−0.528)	(1.433)	(−0.694)
Homogeneity			
Gini coefficient of parcel size	0.262	0.340	−0.602*
	(0.756)	(1.224)	(−1.810)
Infrastructure condition			
Simplicity of water flow direction	−0.0570	−0.682	0.739
	(−0.0712)	(−1.093)	(0.946)
Earth canal length	−0.0228	−0.0247	0.0475
	(−0.677)	(−0.985)	(1.444)
Exit options			
No. of ponds per member (pre-reform)	0.238***	−0.0211	−0.217**
	(2.827)	(−0.306)	(−2.512)
No. of pumps per member (pre-reform)	0.0137	0.157*	−0.170*
	(0.127)	(1.938)	(−1.685)
Surrounding parcel characteristics			
No. of surrounding parcels	−0.0357	0.254**	−0.218*
	(−0.304)	(2.336)	(−1.786)
No. of surrounding parcels squared	0.000830	−0.0395**	0.0387*
	(0.0403)	(−2.092)	(1.786)
Years knowing owners of surrounding parcels	0.00297	−0.00267	−0.000307
	(0.836)	(−0.917)	(−0.0854)
Proportion of surrounding parcels whose owners send their children to the same school	−0.0227	0.159***	−0.137
	(−0.244)	(2.698)	(−1.541)
Management skill and water demand			
Average schooling years of working members	0.0208	0.0274	−0.0481**
	(0.836)	(1.613)	(−2.058)
Parcel size of paddy	0.0975	0.185	−0.282
	(0.189)	(0.529)	(−0.575)
Sandy/high seepage soil dummy	0.352**	−0.105	−0.247
	(2.414)	(−0.823)	(−1.586)
Threshold value: the price level that gives the max/min probability of the dependent variable	0.061	0.075	0.091
Observations		135	

Note: WUG-level cluster robust *z*-statistics are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' analysis based on data sources discussed in the text.

of the combination of the exponential increase of individual irrigation and the inverted U-shaped trend of the choice of new group formation. The threshold values of the volumetric price that give either the maximum or minimum probability of a dependent variable are shown at the bottom of the table; the slopes invert around the mean or slightly above the mean of the volumetric price (mean = 0.061).

Equally important, the results clearly demonstrate that the change also depends on other factors, and they influence in ways that are consistent with our expectations when the coefficients are significant or

Table 5. The Average Marginal Effects from the Probit Regression of a WUG's Manager Appointment Model

Variables	(1) Full sample model	(2) Sub-sample model
Volumetric price of reservoir water	7.482	15.26***
	(1.497)	(2.635)
Volumetric price of reservoir water squared	−52.16	−83.36*
	(−1.529)	(−1.876)
Group size		
No. of parcels	0.000600	0.00198
	(0.525)	(1.246)
Homogeneity		
Gini coefficient of parcel size	−0.0638	0.123
	(−0.165)	(0.225)
Infrastructure condition		
Simplicity of water flow direction	0.980	3.570**
	(1.232)	(2.381)
Earth canal length	−0.00299	−0.0852
	(−0.0982)	(−1.558)
Exit options		
No. of ponds per member (pre-reform)	−0.0477	0.564**
	(−0.433)	(2.266)
No. of pumps per member (pre-reform)	−0.0405	−0.138
	(−0.345)	(−0.723)
Threshold value: the price level that gives the max probability of the dependent variable	0.072	0.092
Observations	67	33

Note: z-statistics are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' analysis based on data sources discussed in the text.

weakly significant. Regarding an empirical question about the impact of the Gini coefficient, our case shows a negative and significant impact on staying in the WUG, which implies that higher transaction costs among WUG members reduce the probability of staying in the WUG. The length of the earth canal has a positive impact on the choice to remain in the WUG, although the statistical significance is weak (p-value 15%). As a proxy of the cost of individual irrigation, the number of ponds before the reform has a positive and significant impact on the choice of individual irrigation, as expected. The characteristics of the surrounding parcels are key determinants for choosing a new smaller group formation. An influential characteristic is the bond that is formed through school-related activities, which implies the importance of bonding social capital. An inverted U-shaped impact of the number of surrounding parcels indicates that the number of would-be members cannot be too small or too large. A positive and significant coefficient of the sandy or high seepage soil dummy for the choice of individual irrigation indicates that, when an individual has a much higher demand for water, he/she prefers to do individual irrigation rather than trying to coordinate with others.

Table 5 shows the average marginal effects computed from the probit regression of a WUG-level decision about manager appointment against no change. The original results are reported in the online appendix table S4. Again, a key finding is an inverted U-shaped relationship between the volumetric price and the choice of manager appointment, although the coefficients of the full sample model are weakly significant (p-values 13% for the level term and 12% for the squared term). The threshold value of the volumetric price for the maximum probability is 0.072 or 0.092.

After we limit our sample to the WUGs with remaining members (33 observations), we have a clearer picture of their decision-making mechanism. The simplicity of water flow direction is highly significant, indicating its correlation with the effectiveness of a manager's initiative for successful management. This result seems to be consistent with the findings of Ray and Williams (2002), who found that the spatial asymmetry of water distribution makes solutions difficult. Khwaja (2009) found that good project design (e.g., simple design) improves management success, even when social capital endowment is low. Our result, which highlights the importance of simplicity, also supports his argument.

A puzzling result is a positive coefficient for the number of ponds for the manager appointment choice. This variable presumably captures some aspects of topographical simplicity that the flow direction variable does not capture.

VII. The Determinants of Water Use

We run five regression models that explain the reservoir water use measured in the same manner as in table 3. Note that our full sample includes those who completely exited for individual irrigation; their reservoir water use is zero. The first model uses a full sample and employs the same reduced-form structure as the previous individual-level analysis. In the second model, we relax the assumption of a quadratic function and check more carefully whether water use increases after the threshold value. For this, we estimate a spline regression model, setting the threshold value indicated by the first model as a knot. This model approximates a nonlinear impact of price in a more flexible manner by allowing different slopes for two connected lines at the knot. The third model uses a sub-sample ($n = 84$) of reservoir water users, in order to examine the possibility of overuse at high price levels by the remaining farmers. The fourth model is a spline regression version of the third model. We run the fifth model by replacing the price variables with institutional dummies because the reduced form cannot directly indicate the impact of institution on reservoir water use. In this model, we set the no change case under area-based pricing as the base category, so that the estimated coefficients show the magnitude of water savings. We run this model for the subsample of reservoir water users because reservoir water use by individual irrigation users is zero by definition. Needless to say, the institutional choice is an endogenous variable, and, hence, the fifth model just provides a supplementary idea on an association between institutional choice and water use.

The OLS regression results of the first model display a U-shaped relationship, which gives the minimum water use at the volumetric price of 0.075 (table 6). However, the second model indicates that the slope becomes statistically insignificant after the threshold value. Our results are ambiguous about the effect of volumetric price at high price levels. The third model shows a U-shaped relationship. The fourth model supports this result by showing that a negative slope before the threshold and a positive slope after the threshold are both statistically significant. The coefficients of dummies in the fifth model indicate that the case of no change under volumetric pricing is the least successful in water savings, implying that a U-shaped relationship among the reservoir water users is associated with the prevalence of no-change cases at high water price levels. Putting all results together, we may argue that at high water price levels, a price increase does not contribute to water savings because savings of those who exit for individual irrigation are canceled out by the overuse by the remaining reservoir water users. The remaining farmers do so presumably because they are in the WUG under no institutional change.

The other significant variables basically show common results among the five models. The number of ponds per member (pre-reform) is a proxy of the cost of individual irrigation water, and a negative and highly significant coefficient is consistent with a regular substitution effect. This result is also consistent with table 4, which shows that this variable increases the likelihood of individual irrigation. The negative effect of the proportion of surrounding parcels whose owners send their children to the same school must capture the water-saving impact of choosing a new smaller group formation, as this variable

Table 6. The Results from the OLS Regression of Water Use Determinants

Variables	Farm-level reservoir water use (mm)				
	(1) Full sample	(2) Full sample (spline regression)	(3) Reservoir water users	(4) Reservoir water users (spline regression)	(5) Reservoir water users
Volumetric price of reservoir water*1000	−1.940*	—	−3.481***	—	—
	(−1.968)		(−4.026)		
Volumetric price of reservoir water*1000 squared	0.0129*	—	0.0253***	—	—
	(1.943)		(4.269)		
Volumetric price of reservoir water*1000 (<threshold value)	—	−1.000*	—	−1.870***	—
		(−1.688)		(−3.400)	
Volumetric price of reservoir water*1000 (> = threshold value)	—	0.839	—	1.635***	—
		(1.437)		(3.688)	
Volumetric pricing & no change[a]	—	—	—	—	−117.7***
					(−3.323)
Manager appointment[a]	—	—	—	—	−126.9***
					(−4.065)
New smaller group[a]	—	—	—	—	−146.1***
					(−4.086)
Group size					
No. of parcels	−0.283*	−0.301*	−0.462**	−0.496***	−0.316*
	(−1.683)	(−1.734)	(−2.593)	(−2.693)	(−1.779)
Homogeneity					
Gini coefficient of parcel size	29.74	26.04	149.5***	136.8***	136.9***
	(0.442)	(0.389)	(3.097)	(2.755)	(2.843)
Infrastructure condition					
Simplicity of water flow direction	−124.7	−133.0	−213.1	−224.0	−302.5*
	(−1.027)	(−1.061)	(−1.132)	(−1.088)	(−1.712)
Earth canal length	11.91***	12.25***	18.54***	19.12***	16.60***
	(2.883)	(2.837)	(4.219)	(4.199)	(3.723)
Exit options					
No. of ponds per member (pre-reform)	−54.34***	−53.91***	−93.77***	−89.10***	−100.6***
	(−3.788)	(−3.898)	(−3.568)	(−3.379)	(−3.858)
No. of pumps per member (pre-reform)	−14.07	−16.23	−0.191	−5.502	6.118
	(−0.733)	(−0.853)	(−0.0112)	(−0.320)	(0.309)
Surrounding parcel characteristics					
No. of surrounding parcels	−58.08*	−59.80*	−69.37	−75.62*	−62.05
	(−1.689)	(−1.705)	(−1.576)	(−1.702)	(−1.481)
No. of surrounding parcels squared	11.62*	11.97*	12.96	14.06	11.68
	(1.682)	(1.689)	(1.490)	(1.588)	(1.412)
Years knowing owners of surrounding parcels	0.914	0.954	1.104	1.246	0.617
	(1.124)	(1.152)	(1.218)	(1.390)	(0.741)
Proportion of surrounding parcels whose owners send their children to the same school	−28.41*	−27.26*	−43.53**	−42.01**	−44.50**
	(−1.791)	(−1.688)	(−2.379)	(−2.250)	(−2.360)
Management skill and water demand					
Average schooling years of working members	−0.103	−0.313	8.171	8.359	8.531*
	(−0.0236)	(−0.0716)	(1.646)	(1.648)	(1.846)
Parcel size of paddy	35.01	35.56	201.4*	183.3	154.9
	(0.338)	(0.343)	(1.835)	(1.623)	(1.420)
Sandy/high seepage soil dummy	−24.84	−26.61	52.17	55.55	41.54
	(−0.695)	(−0.738)	(0.744)	(0.764)	(0.572)
Constant	242.0***	238.9***	237.6**	238.9**	278.3***
	(2.811)	(2.803)	(2.599)	(2.659)	(2.863)

Table 6. (continued)

Variables	Farm-level reservoir water use (mm) (1) Full sample	(2) Full sample (spline regression)	(3) Reservoir water users	(4) Reservoir water users (spline regression)	(5) Reservoir water users
Threshold value: the price level that gives the min value of the dependent variable	0.075	—	0.068	—	—
Observations	135	135	84	84	84
R-squared	0.241	0.230	0.443	0.423	0.465

Note: WUG-level cluster robust *t*-statistics are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. a) Base category: area-based pricing and no change.
Source: Authors' analysis based on data sources discussed in the text.

increases the likelihood of that institution. The number of surrounding parcels and its squared term have the same water saving impact through the choice of a new smaller group formation. There are some puzzling results, including a positive impact of the earthen canal length and a negative impact of group size. Since they are not strongly statistically significant in the institutional choice regressions, they might capture some topographical or hydrological conditions that may directly affect reservoir water demand. Another puzzling result is the positive impact of the parcel size Gini coefficient among reservoir water users because this variable significantly reduces the likelihood of staying in a WUG and appears to increase the likelihood of a new smaller group formation.

VIII. Concluding Remarks

This article has provided micro-level evidence of the importance of the price signal as a guide for institutional change for reservoir water savings. At the same time, we also have shown that when the price is high enough, a further price increase does not contribute to reservoir water savings. If this failure in water savings is rooted in the free-riding problem in the WUGs under no institutional change as our data imply, it entails social costs. The evaluation of social costs would be a worthwhile topic for further research.

In addition to price, we find that the initial conditions affect the paths of change; if the conditions are not supportive, the chance of upholding informal management increases. Our regression results suggest the following interventions for smooth institutional changes. First, to facilitate the formal appointment of a water manager, simpler topography would make water management easier. However, from a practical perspective, the cost to change the landscape may be too high to implement. Second, improving social capital among nearby farmers would make the formation of a new smaller group more attractive. However, with China's rapid economic growth and the resulting dissolution of rural communities, improving social capital may be a cumbersome option. An investigation of intervention costs and water savings benefits could be another topic for future research. Although work is still needed, our view from micro-level data, in the context of the Chinese case, is nevertheless a useful complement to views from macro-level and historical data, providing more detailed mechanisms of institutional change and expanding our insights for future research.

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