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Impact evaluation of the irrigation management reform in northern China

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Abstract

The paper evaluates the reform in the irrigation sector in northern China, in particular, the transfer of irrigation management to Water User Associations or contractors from the village committee. With a set of panel data collected in randomly selected villages in northern China, a fixed effects model at the canal level with instrumental variable estimation is used to control for unobservable heterogeneity and endogeneity problem. The results show that WUAs have increased maintenance expenditures, the timeliness of water deliveries, the percent of irrigated area and the rates of fee collection. There are also improvements in irrigation systems managed by contractors but with magnitudes smaller than in the case of WUAs. WUAs or contracting, however, have limited impacts on water use and crop production. Discussions on reasons for the findings of limited impacts offer some suggestions for the next steps of the irrigation reform and call for continued research efforts to collect more data for further impact evaluations.

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1. Introduction

Since the 1980s, many countries have begun to transfer irrigation management responsibilities from government bureaus to farmer-run organizations (Irrigation management transfer – IMT) or increase farmers’ participation in irrigation management (Participatory Irrigation Management – PIM, Araral, 2010; Garces-Restrepo et al., 2007; Shyamsundar et al., 2005; Vermillion, 1997). Often the core component of the reform is to establish either Water User Associations (WUA) or irrigator associations and to transfer irrigation management to those entities. A large number of studies have documented the impacts of IMT and PIM. The summary of findings by Vermillion (1997) and Garces-Restrepo et al. (2007) show that the record is mixed. There is a consensus among most studies that IMT/PIM improved the timeliness of water delivery. Partly as a result of the improvements in the timeliness of deliveries, the rate of fee collection has increased after the implementation of IMT/PIM (Garces-Restrepo et al., 2007). There are fewer consensus about other outcomes. For example, the quality of maintenance has improved in some countries, such as Sri Lanka and India, but worsened in others, including the Philippines, Indonesia, Bangladesh and several African countries (Vermillion, 1997). Since most IMT/PIM programs in developing countries are targeted at poor rural communities, researchers also have analyzed the impacts on agricultural productivity (measured as the size of irrigated area, cropping intensity or yields) as well as on farm income and rural growth. Again, the findings are mixed. While in many countries IMT/PIM programs have been found to increase crop yields and farm income, in others, particularly in a number of African countries, zero or even negative impacts have been found (Garces-Restrepo et al., 2007; Vermillion, 1997).

China is also in the process of reforming its irrigation sector. The irrigation management reform at the village level is motivated by several factors. One driving force is the increasing water shortages, especially in the agricultural sector (Jiang, 2009; Yang et al., 2003). China's water resource availability is among the lowest worldwide (Jiang, 2009). With the economic growth, the demand for water continues to increase steadily over time, especially in the industrial and residential sectors. The total water use of all sectors has increased by 9.7% from 1997 to 2011 (MWR, 2007 and 2011). Although northern China remains an important agricultural and industrial region, it has only 21% of the country's water endowment (MWR, 2011). The lower levels of precipitation in northern China are also much more seasonal than in the south, with more than 70% concentrated between June and September. In addition, the government has determined that agricultural users will not be given priority for any additional future allocations of water (China, 2002).

The most common form of irrigation water in China is surface water (Huang et al., 2006). Before 1980s, the village committee (i.e., village leaders) took responsibility for the allocation of irrigation water, operation and maintenance (O&M) tasks and fee collection (Huang et al., 2009). While the village leaders made the major decisions, a water manager was hired for a small stipend to carry out daily irrigation-related activities. The water manager coordinated with irrigation district (ID) on the timing of water deliveries and informed farmers of it. Traditionally water fee collection was managed by the village committee. This is because up until the 2003 tax-for-fee reform, water fees were bundled with other village taxes and fees (Lohmar et al., 2008). In addition to water fees, farmers were also required to contribute obligatory labor to community activities such as the construction and maintenance of irrigation infrastructure. Under such circumstances, it was natural that the irrigation infrastructure was owned and managed by

the collective before the 1980s (Lohmar et al., 2008). In this paper, when the village committee is in charge, the village's irrigation system is considered to be run under *Collective Management*.

Changes in the rural area brought on by the economic reforms also motivated the irrigation management reform at the village level. While China's economic reforms led to rapid economic growth, they also generated some unintended consequences in the irrigation sector. The household responsibility system (HRS) implemented nationwide in the 1980s transferred agricultural production from the commune to individual households (Lin, 1992). Although farmers were the users of the irrigation infrastructure, they did not organize themselves to take up the management of the irrigation system because historically it was considered as a typical public good that was provided by the government. The village collectives, however, did not have strong incentives to invest in or maintain the irrigation infrastructure either. This is because the circumstances after the implementation of the HRS put in doubt their ownership of the irrigation infrastructure. For a long time no legislation efforts were made to clarify it. In addition, a series of fiscal reforms have weakened the ability of the village committee to invest in and maintain irrigation infrastructure (Lohmar, et al., 2003). Tax revenues accrued to the village collectives dropped significantly after the 1994 fiscal reform reassigned much larger shares of them to the central government (Wang, 1997). Village leaders lost their authority to levy fees and surcharges on farmers after the 2003 tax-for-fee reform (Oi et al., 2012). In 2006, agricultural tax was completely eliminated nationwide (Oi et al., 2012). In the 2000s, provincial governments have also started to gradually remove the requirement of obligatory labor (Oi et al., 2012). Without much of the capital and labor they previously had, village leaders are much more limited in their capacity to maintain or improve the irrigation system. As a result, problems such as deteriorating

irrigation systems have appeared in many areas due to lack of maintenance and negatively affected agricultural production (Xie, 2007).

To address the looming water shortage problems and the weakened village leadership, the government has focused on promoting WUAs to take over the majority of the irrigation tasks. As villages are the basic hydrologic units within which irrigation is managed, most WUAs were established at the village level. Some WUAs are also established at the level of branch canal and govern several villages. Since the first WUA was established in south China in 1995 with the assistance of the World Bank (2003), the development of WUAs has gone through exploration and experimentation stages (Zhai, 2006). Starting in 2002, a series of policy documents have made clear the government's intention to extend WUAs nationwide (General Office of the State Council of China, 2002; MWR, NDRC, MCAC, 2005). This has led to a rapid expansion of WUAs. By 2009, the Ministry of Water Resources of China (MWR) reported that there were more than 52,700 WUAs nationwide (Li, 2009).

In some provinces of China, contracting also emerged as a way to manage a village's irrigation system (Huang et al., 2009). Contracting is a commonly observed form of management in many different contexts of China's reforms (e.g., in the management of township and village enterprises and grain enterprises, Park and Rozelle, 1998). It is similar to WUAs in that irrigation management is turned over from village leaders to a specified manager. However, instead of irrigation infrastructure of the whole village, often only a lateral canal which services only part of the village is turned over. In some villages, WUAs also contract out the management of one or more canals to contractors (Huang et al., 2009; Huang et al., 2010).

Water is among the most critical factors that limit China's further growth (Jiang, 2009; Yang et al., 2003). Despite the rapid expansion of WUAs nationwide and contracting regionally, not many studies have examined the impact of irrigation management reform in China. One major reason is the lack of data. Wang et al. (2010) are among the few that provided impact analysis but they only focused on a selected sample of WUAs established under World Bank projects. Wang et al. (2013) did an in-depth study of two villages in one county in north China. However, contracting was the only managerial form at the study sites. Zhang et al. (2013) on the other hand, only focused on WUAs in one county in northwest China and examined the impact of the specific characteristics of WUAs on crop production and crop income.

The objective of this paper is to evaluate the reform in the irrigation sector in northern China, in particular, the transfer of irrigation management to WUAs or contractors. We use the approach suggested by previous research (Araral, 2009; Meinzen-Dick, 2007; Poteete and Ostrom, 2008; Vermillion, 1997). First, data come from a random sample of villages. The *China Water Institutions and Management* (CWIM) Panel Survey, which is collected by the author and collaborators, covers Ningxia and Henan provinces from the Yellow River Basin (YRB) and Hebei province in the Hai River Basin, two of the most important river basins in northern China. Unlike most previous studies that selected study sites without randomization, often as case studies (Poteete and Ostrom, 2008), a random sampling strategy is used. Within each province, a stratified random sampling strategy is used to select counties with varying degrees of water scarcity, which happens to be correlated the distance to the source of water supply in sample areas (e.g., Yellow River for sample sites in Ningxia and Henan provinces because they are within the command areas of IDs that draw water from Yellow River). Sample villages were then randomly chosen from a roster of all villages in each of the counties. The systematic random

sampling method is used to ensure each village listed on the roster has equal probability of being selected into the sample. Second, information collected in the CWIM survey allows the inclusion in the empirical analysis a large set of factors other than the irrigation reform that may influence irrigation systems, such as the characteristics of water resources, canals, water users and canal managers. Additionally, the CWIM survey tracks the same sample villages in 2001, 2004 and 2007. The panel nature of the data allows us to control for time invariant unobservable heterogeneity in estimation. The sample size, although moderate, provides a sufficient degree of freedom to allow for the inclusion of those factors. Third, when evaluating the effectiveness of the irrigation management reform, instrumental variable (IV) estimation is used to control for the endogeneity of the presence of WUAs or contracting in villages.

The paper is organized as follows. Section 2 describes the selection of indicators used to measure the impact of irrigation management reform. Section 3 presents the framework and the estimate methods. Section 4 reports results and the final section concludes.

2. Irrigation Management Reform and Indicators Used to Evaluate Its Impacts

The CWIM data reveal that WUAs and contracting are replacing collective management in northern China's villages (Table 1). In 2001, collective management was still the dominant form of management (23 out of 47 villages). By 2007, only 10 villages remained under collective management. The majority of the sample villages have switched to using WUAs or contracting. The accelerated rate of conversion to WUAs observed between 2004 and 2007 is in part stimulated by macro policies (MWR, NDRC, MCAC, 2005). Some sample villages also have mixed institutions. WUAs can also be flexible in how they manage water. Management can be done by WUA board members or it can be contracted out to individual or a group of individuals (MWR, NDRC, MCAC, 2005). In some of those villages, some canals were under the control of

collective management while others were managed by WUAs or contractors. In other villages, canals were jointly managed by contractors and WUAs. For canals under joint management, information on the division of responsibilities (maintenance, water delivery and fee collection) is used to specify the canal as collective management, WUA or contracting, depending on who takes on the relevant management responsibilities. It should be noted that since a large share of the WUAs were formed between 2004 and 2007 and the most recent data used in empirical analysis are from 2007, only the short-run impacts of WUAs are evaluated.

In principle, a WUA is a farmer-based, participatory organization in which farmers organize themselves to elect a board as their representative to manage the village's irrigation system (World Bank, 2003). Like other reforms in China, the state government has allowed great flexibility for local governments in setting up and operating WUAs. The first principle laid out by the government is that WUAs should be set up in a context-specific manner and contingent on the local history of water management and specific problems needed to be resolved (MWR, NDRC, MCAC, 2005). Current water policies do not foster favorable environment for user participation (Araral and Yu, 2013). Partly because of this, although the most widely recognized principle of WUAs is broad-based participation, both Huang et al. (2009) and Huang et al. (2010) have found that at least in northern China, increasing participation was not the focus of the irrigation management reform. More often than not, farmers were not involved in the decision to adopt WUAs or contracting or electing the WUA board members or contractors (Huang et al. 2009; Huang et al., 2010). Evidence also shows that farmers may have low willingness to participate. For example, although 75% of the WUAs in the CWIM sample villages invited farmers to attend their regular meetings in 2007, the median percentage of farmers that actually attended was only 15% (Huang et al., 2010). The explanation offered by the authors was that

given the large number of households in the village and the alternative of off-farm employment, the cost of participation may outweigh the benefit. Using the patterns of farmer participation identified by Meinzen-Dick (1997), the China model is somewhere in between the Asian model (which tends to have smaller units of organization, e.g., at the village level, and allows for the direct participation of all members) and the American Model (which relies heavily on specialized formal irrigation organizations that employ professionals, rather than on face-to-face interaction between all members).

Which indicators to use depend on the purposes of the irrigation management reform. In China's version, the establishment of WUAs serves several purposes (MWR, NDRC, MCAC, 2005; Li, 2009). WUAs resolve the lack of maintenance and poor irrigation services resulted from the ambiguous property rights over irrigation infrastructure after the HRS reform. WUAs are also set up to improve the coordination between villages and IDs. Under collective management, farmers and sometimes village water managers often can neither choose when their irrigation water is delivered nor how much they receive (Lohmar et al., 2008). Although IDs deliver water to villages, IDs only receive payment for water after water fees have been routed through various levels of bureaucracy (from farmers to village; village to township irrigation stations; towns to counties and finally from counties to IDs, Lohmar et al., 2008). Each level of bureaucracy usually charges a fee for the service of handling these payments, further reducing the amount ultimately remitted to the ID. In contrast, most WUAs bypass the traditional village-township-county channels and directly purchase water from the ID on a volumetric basis. It is hoped that this more direct interaction between WUAs and IDs can improve the timeliness of water deliveries.

It is also hoped that WUAs can improve the rate of water fee collection. One of the fundamental problems of the irrigation system is the low water price. Surface water is priced between 30% and 50% of the cost of supply (Zheng, 2002). The low water prices provide IDs with few incentives to deliver water in a timely manner, partly because revenue generated from water fees are not sufficient to maintain delivery infrastructure (Lin, 2003). The poor delivery services then result in farmers refusing to pay their water fees. Farmers are rarely punished for forfeiting their water fees. The poor rate of water fee collection in turn exacerbates the insufficient fund of IDs (Lohmar et al., 2008). Since the operational funding of WUAs and contractors come from water fees collected, they do have incentives to provide satisfactory irrigation services to farmers, which is likely to increase farmers' willingness to pay for water.

Four indicators are constructed to measure the impact of the irrigation management reform. The first indicator, the total maintenance expenditure per meter of the canal (MAINTAINEXP), measures the quality of maintenance. Cleaning canals by cutting weeds or removing silt is the major maintenance activity undertaken in most villages. It can be done in three ways: hire seasonal labor, rent machines or mobilize voluntary labor within the village. The CWIM survey collected information on cash expenditures on maintenance including those for renting machines and hiring seasonal labor. Typically these expenditures are paid from the water fees collected from farmers. Some provincial governments have gradually removed the requirement of obligatory labor (e.g., Hebei province in 2002 and Henan province in 2004), although the village leaders (and WUAs) can still mobilize village labor, it is more or less on a voluntary basis. Although the CWIM survey only collected information on the amount of voluntary labor used in maintaining canals, its cash equivalent was imputed using the wage rate of the hired labor. The total maintenance expenditure is the sum of rent for machines, wage

compensation for hired labor and cash equivalent of the voluntary labor. Although a direct measure of the quality of maintenance is a better indicator, since we control for canal characteristics such as the propensity to silt up and the share of lined canals, the maintenance expenditure is a reasonable indicator.

The second indicator measures the quality of water delivery service. During the survey, farmers were asked to report the total number of times they were scheduled to receive water for irrigation, and the number of times that the scheduled irrigation was delayed or cancelled. From these two pieces of information, PTTIMELY is calculated as the percentage of the times that irrigation was not delayed or cancelled. The third indicator measures the adequacy of water supply. During each survey year, the canal manager was asked to report the maximum area the canal can irrigate (the command area of the canal) and the area that was actually irrigated. The percent of the canal command area that is irrigated (PTIRRI) is calculated as the ratio of these two variables. The fourth indicator measures the effectiveness of water fee collection. The percentage of water fee collected (PTCOLLECT) is calculated as the ratio of the water fees canal managers were able to collect from farmers to the total fees farmers should have paid based on the area that was irrigated in each survey year. The effectiveness of water fee collection is crucial to the financial sustainability of an irrigation scheme. For example, in our sample villages, since O&M costs come from water fees collected, the percentage of water fee collected directly affects the quality of maintenance and thus the quality of the water delivery service.

WUAs are also set up to facilitate other policy goals. One important goal is to promote water savings (MWR, NDRC, MCAC, 2005; Li, 2009). To achieve this, one policy instrument is the monetary water saving incentive provided to water managers in some IDs (Wang et al., 2005). The water saving incentive mechanism works because of the way surface water is measured and

priced (Wang et al., 2005; Lohmar et al., 2008). Most IDs measure water flows at the branch or lateral canal that delivers water to villages. This allows IDs to charge villages a volumetric price for the amount of water delivered. Within the village, there are no water meters along the tertiary and lower canals that deliver water into farmers' fields. So farmers pay for water on per unit of land basis. The level of the water fee farmers pay is determined prior to the irrigation season and is often tied to the level of historical use. If a water manager could generate water savings in an irrigation season and thus need to pay the ID less than the amount of the water fees collected from farmers, the manager could keep the difference as his own profit. The use of water saving incentive is more common among WUAs or contractors. For example, Huang et al. (2010) found that in the CWIM sample villages, although none of villages under collective management used water saving incentives, more than 80% of WUA villages and 31.3% of the contracting villages implemented them in 2007.

Three additional indicators are constructed to measure the impact of irrigation management reform on water use and agricultural production. In each survey year, canal managers (and village leaders) were asked to report the number of irrigations applied and the amount of water used per irrigation for all major grain and cash crops. Total water use is obtained from these two pieces of information and measured in m^3/mu , where mu is the metric for land area in China. Crop yields are reported and measured in kg/mu . The log form both water use and yield is used because plotting the data show they follow the log-normal distribution more closely. The third indicator is crop produced per unit of water applied (kg/m^3). Two crops, wheat and rice, are examined. Another major crop, corn, is excluded because its growing season overlaps with the rainy season and so is often rainfed. Wheat and rice rely heavily on irrigation and so their production is affected by irrigation management reform to a greater extent.

3. Framework to Evaluate Irrigation Management Reform

Types of water management institutions are likely to affect various aspects of an irrigation system because different types of managers are in charge (village leaders, WUAs and individual contractors). The difference in governance under different institutions may also generate differential impacts. For example, the provision of water saving incentives under WUA and contracting may motivate canal managers to exert more efforts to plan necessary maintenance and supervise the operation of sluice gates and the coordination of water deliveries, all targeting at reducing the actual water demanded by farmers. The transparency of management is encouraged by the government in operating WUAs (Li, 2009). Huang et al. (2010) found that in the CWIM sample villages, management under WUAs is more transparent than under collective management or contracting. Almost 90% of the WUAs shared information with farmers in 2007 including the total amount of water fees collected, the volume of water actually delivered by the ID and the actual area irrigated (Huang et al., 2010). In contrast, the operation under collective management was pretty much a black box. Contracting was a bit better but the degree of transparency is far below that of the WUAs. Only a little more than one third of the contractors share as much information as WUAs (Huang et al., 2010). The higher transparency associated with WUAs will likely increase farmers' willingness to pay for water fees.

There is a consensus among scholars that the ability of communities to overcome collective action problems will affect some aspects of the irrigation system (e.g., Tang, 1992). Examples of collective actions in irrigation activities include coordinating cropping schedule and water rotation, contributing money or labor contribution to collective maintenance, monitoring water deliveries and conflict resolution (Meinzen-Dick et al., 2004). In fact, some indicators used to evaluate the irrigation reform have also been used to measure the outcome of collective action

in other countries. For example, the percentage of irrigation fees collected was used as a proxy that measures the extent of monetary free riding among irrigators in the Philippines (Araral, 2009). The quality of maintenance of canals was used as an indicator of cooperation among farmers in India and Mexico (Bardhan, 2000; Dayton-Johnson, 2000). The factors that have been identified in the literature to affect the likelihood of successful collection action should also be included when evaluating the irrigation reform.

3.1. Selection of Explanatory Variables

Following the previous literature (Araral, 2009; Bardhan, 2000; Fujiie et al., 2005; Lam, 1998; Meinzen-Dick, 2007; Meinzen-Dick et al., 2002; Tang, 1992), we group the critical factors into the following categories: governance (WUA, contracting or collective management), characteristics of resource systems (water resource and canal), and characteristics of water users and canal managers/leaders. Table 2 lists all the variable definitions and descriptive statistics.

Three characteristics of water resources are included: water scarcity, the availability of alternative water supply and the importance of water resources as a source of income. Two dummy variables are used to measure water scarcity. SLIGHT equals one if the village leader reported that the village had a water shortage problem but the problem was not severe.

SSEVERE equals one if the village leader reported that the water shortage problem was severe and had affected agricultural activities or even daily life of villagers. The general view in the literature (e.g., Uphoff et al., 1990) is that if water is abundant, farmers have no incentives to undertake collective action such as removing silts and cutting weeds in canals to augment the supply of water. If water shortage is severe, conflicts among water users might become so intense that farmers do not cooperate in maintaining canals or obey allocation rules. Including

both variables allows testing for an inverse U-shaped relationship between water scarcity and outcome variables.

The share of *irrigated* sown area that is irrigated by groundwater (PTGW) is used to measure the availability of alternative water supply. If groundwater resource is readily available, farmers will be less willing to contribute to maintaining canals or paying surface water fees. The share of sown area in rice and wheat (SHRICEWHEAT) is used to proxy the importance of water resource because wheat and rice production rely heavily on irrigation. The share of sown area in horticultural crops is not used because it is very small. If water is important to agricultural production, farmers will make more efforts to maintain canals and coordinate in water deliveries.

Clearly the characteristics of the canals will affect the cost of maintenance and the timeliness of water deliveries. Two variables are included: the share of the total length of canals that was lined (PTLINED), and a dummy that equals one if the canal silts up easily (SILT). Unfortunately the CWIM survey did not collect information that could be used to measure how deteriorated a canal was. However, it is likely that PTLINED and SILT are closely related to the extent of deterioration of canals.

The total number of households within the canal command area (LOGNHH, in log form) and the number of household per meter of canal length (LOGPMNHH, in log form) are used to measure the group size. In all specifications, the squared variables are also included. To avoid multicollinearity problem, the standardized values of LOGNHH and LOGPMNHH (both original and squared terms) are used in regression. The size of the group is among the factors whose effects on the prospects for collective action are most debated (Poteete and Ostrom, 2004). Depending on the specific indicators, the size of group may work in different directions. A manager of a canal serving a larger number of households may get larger total amounts of labor

and cash contributions from farmers for maintaining the canal. However, he will face more difficulty in delivering water and collecting fees.

Four other variables are included to characterize water users. The first two are intended to capture the potential leadership and the ability of farmers to organize among themselves: the share of labor force that graduated from high school (EDU) and income per capita in log form (LOGPCINC). The third and fourth variables are used to capture the extent of market activities: the share of households that have self-business in the village (PTSELF) and the share of migrants in the village labor force (PTMIG). Migrants are defined as village members that worked outside the village for more than one month. The alternative income sources from off-farm activities will reduce farmers' reliance on agricultural production and thus reduce the importance of irrigation, which will reduce the likelihood of collective actions under most circumstances.

Although the analysis controls for some aspects of the heterogeneity among farmers such as access to off-farm employment and time invariant unobserved heterogeneity through fixed effects in estimation, factors that measure economic and social inequality (which are likely to change over time) are not included in our analysis due to the lack of data. However, there are reasons to believe that this may not be a serious limitation. The most important type of economic inequality in irrigation systems is the variation in farm size. In rural China, land is equally allocated across households within a village. Unlike other countries such as India, there is no caste system in rural China. Therefore, economic and social inequality may not play important roles in the study areas.

Since canal managers are the ones that are in charge once the type of management institution is chosen, their characteristics also matter. Years of water management experience of the canal manager (WEXP) is used. In the case of WUAs, WEXP is calculated as the average

years of experience of the chair and all board members. A second variable is included, a dummy that equals one if the canal manager currently is a village leader (VILEAD). This variable is included since there is still a large overlap between the leadership of WUAs and that of the villages. In more than half of the WUAs and for all three sample years, the head of WUA is a village leader and the WUA board was comprised of the village leadership (Huang et al., 2010). This is partly because in most villages, the chair or the board members of WUAs were appointed by either the ID or the village committee.

3.2. Estimation Method

The estimating equation for evaluating the irrigation management reform is expressed as:

$$P_{it} = v_i + \beta_1 WUA_{it} + \beta_2 Contract_{it} + \mathbf{Z}'_{it} \boldsymbol{\delta} + \varepsilon_{it} \quad (1)$$

In equation (1), P_{it} is the indicator for canal i in year t . The subscript t denotes the three survey years 2001, 2004 and 2007. The key variables of interest, water institutions, are defined using two dummy variables: WUA and CONTRACT. In addition, P_{it} is also the function of a set of covariates, $\mathbf{Z}_{it}$, as described in section 3.1. Two year dummies (one for year 2004 and one for year 2007) are included to capture the time effects, which is equivalent to adding time fixed effects. The term, v_i , captures canal level characteristics that are *time invariant*, including all observable and unobservable factors. ε_{it} is the idiosyncratic error term.

A standard ordinary least squares (OLS) model can be employed to estimate equation (1) but may produce biased estimates. Although a large set of explanatory variables are included in equation (1), some unobserved factors may still be omitted in the regressions because data are not available. Bias arises if these omitted factors are correlated with any of the explanatory variables. For example, the extent of deterioration of a canal will affect maintenance expenditure and timeliness of water delivery (two of the dependent variables) and will remain in the error

term if not controlled for. It is also likely to influence villages' choice of switching to WUA or contracting (two of the explanatory variables). Then the omission of such a variable will lead to bias in OLS estimates of parameters in equation (1).

With a set of panel data, the fixed effects model is used to control for unobserved heterogeneity. The version of the fixed effects model used in the paper works as follows. Taking the time average of equation (1) generates equation (2):

$$\overline{P}_i = v_i + \beta_1 \overline{WUA}_i + \beta_2 \overline{Contract}_i + \overline{\mathbf{Z}}_i' \boldsymbol{\delta} + \overline{\varepsilon}_i \quad (2)$$

In equation (2), $\overline{P}_i = \frac{1}{3} \sum_t P_{it}$, where $t = 2001, 2004, 2007$. Other terms are derived in the same fashion. Notice the time average of v_i is itself because it is time invariant. Subtracting equation (2) from (1) generates equation (3):

$$(P_{it} - \overline{P}_i) = \beta_1 (WUA_{it} - \overline{WUA}_i) + \beta_2 (Contract_{it} - \overline{Contract}_i) + (\mathbf{Z}'_{it} - \overline{\mathbf{Z}}_i') \boldsymbol{\delta} + (\varepsilon_{it} - \overline{\varepsilon}_i) \quad (3)$$

The term v_i disappears in equation (3). Estimating equation (3) thus generates consistent estimates of all parameters in equation (1) such as β_1 , β_2 , and $\boldsymbol{\delta}$ without the need to include all possible observed and unobserved factors at the canal-level. One limitation of the fixed effects approach is the loss of the opportunity to include important time invariant variables such as the location (e.g. middle stream or downstream of the ID or the head and tail-enders) of the canals. Another drawback is that time invariant variations in the data are removed in the averaging process in equations (1)-(3). Since less variation is used in estimation, estimates are less precise. That is, standard errors are larger. Choosing between consistent and unbiased estimates and more precise estimates is a typical trade-off researchers face in the panel data setting.

Since the motivation of establishing WUAs is to improve some aspects of irrigation systems (e.g., O&M), the decision to establish WUAs, to a great extent, is determined by the

expected outcome. Therefore, the variable that measures the presence of WUA is endogenous because it is simultaneously determined with the dependent variable that measures the impacts of WUAs. The same argument applies to contracting. Not taking into account the endogeneity of WUA and CONTRACT could lead to biased estimates of β_1 and β_2 . The empirical analysis uses information on the policy of the upper level government to address the endogeneity problem. The average numbers of meetings per year upper level governments held to promote WUA or contracting (NMEETWUA and NMMETCONTR) are candidates of instrumental variables (IV) for WUA and CONTRACT for two reasons. First, the variable NMEETWUA (NMMETCONTR) has a positive and statistically significant effect on villages' choice of WUA (contracting), thus NMEETWUA (NMMETCONTR) is strongly correlated with WUA (contracting). The estimation results reported later support this. Second, except through their effects on WUA and CONTRACT, NMEETWUA and NMMETCONTR have no direct effect on the dependent variable that measures the impacts of the irrigation reform.

In operating the instrumental variable estimation, we follow the method suggested by Wooldridge (2002) for binary endogenous explanatory variables. A discrete choice model, the multinomial logit panel data model with random intercepts, is first estimated with three alternatives, collective management, WUA and contracting. In this process, the exogenous variations in WUA and CONTRACT are purged out through the inclusion of IVs NMEETWUA and NMMETCONTR as the additional explanatory variables. The predicted probability of WUA and CONTRACT are then used in equation (3) to obtain the estimates of β_1 , β_2 , and δ . The estimates are not subject to endogeneity problem because only the exogenous variations in WUA and CONTRACT are used in estimation. When calculating the standard errors of estimated coefficients, the original WUA and Contract variables are used.

In the multinomial logit panel data model, at time t , each village i faces three alternative choices of institutions indexed by j . The base category is collective management ($j = 1$) and the two alternatives are WUA ($j = 2$) and contracting ($j = 3$). The two random intercepts, α_i , one for WUA and one for CONTRACT, capture unobserved canal level effects that are time invariant. One such unobserved heterogeneity could be the incentives upper level governments or village leaders have to push for WUA or contracting, which may be influenced by their other objectives such as agency survival (Araral, 2008). Conditional on observed characteristics $\mathbf{X}_{it}$ (that may vary across villages and over time but not across alternatives) and α_i , the probability that village i chooses institution j in period t is given by $\Pr \text{ob}(j | \mathbf{X}_{it}, \alpha_i) = \frac{\exp(\mathbf{X}'_{it}\boldsymbol{\beta}_j + \alpha_{ij})}{\sum_{k=1}^J \exp(\mathbf{X}'_{it}\boldsymbol{\beta}_k + \alpha_{ik})}$. Since the choice probabilities are conditioned on the random intercept α_i , the sample likelihood is obtained by integrating over the distribution of α_i (Haan and Uhlenborff, 2006):

$$L = \prod_{i=1}^N \int_{-\infty}^{\infty} \prod_{t=1}^T \prod_{j=1}^J \left(\frac{\exp(\mathbf{X}'_{it}\boldsymbol{\beta}_j + \alpha_{ij})}{\sum_{k=1}^J \exp(\mathbf{X}'_{it}\boldsymbol{\beta}_k + \alpha_{ik})} \right)^{d_{ijt}} f(\alpha) d\alpha, \text{ where } d_{ijt} = 1 \text{ if village } i \text{ chooses}$$

alternative j at time t and zero otherwise. The coefficient vector and random intercept associated with the base category, $\boldsymbol{\beta}_1$ and α_{i1} , are normalized to zero for identification of the model. The random intercepts for the two other alternatives: α_{i2} and α_{i3} , are assumed to be identically and independently distributed over the villages and their joint distribution follows a bivariate normal. The model is estimated using maximum simulated likelihood based on Halton sequences for integration (Haan and Uhlenborff, 2006; Train, 2003). Since α_{i2} and α_{i3} are allowed to be correlated, the estimator does not exhibit the independence from irrelevant alternatives (IIA) property (Train, 2003). Variables contained in $\mathbf{X}_{it}$ are similar to those in $\mathbf{Z}_{it}$.

Since the focus of the paper is on surface water management, only sample villages that used surface water are included in the analysis. In the 2001 round, 57 of the sample villages used surface water for irrigation (32 from Ningxia, 19 from Henna and 6 from Hebei). The 2004 panel only included 51 villages from the original 2001 sample, because six villages that had used surface water in 2001 did not use surface water in 2004. In the 2007 survey, three villages that used surface water in 2004 did not irrigate and thus dropped out of the sample. The attrition rate was 10.5% between 2001 and 2004 and 6% between 2004 and 2007. Attrition only occurred in Hebei and Henan provinces. A test of attrition suggested by Verbeek and Nijman (1992) is conducted. The result indicates that the attrition is not systematic (that is, not related to the error term in any of the regressions) and thus will not result in sample selection problems.

The lagged forms of some explanatory variables are used to avoid the potential endogeneity problems due to feedback effects. For example, more timely water delivery and higher yields (dependent variable) may increase income in the same period (explanatory variable). So income in the last period is more appropriate as an explanatory variable. In the 2001 panel, recall data were collected for year 1995. Values of these variables in 1995 are used as the lagged values for 2001. The characteristics of canal network do not change or only change slightly over time, so their current values are used. In the model for maintenance and percent of irrigated, the number of households per meter of canal (PMNHH) is used. In the model for water delivery and water fee, the total number of households (LOGNHH) is used. Since there is no information on the amount of voluntary labor in 2001, only the 2004 and 2007 panels are used in the regression on the maintenance expenditure. In the discrete choice model, variables that measure the characteristics of village leaders are included instead of those of managers. This is because in most villages, the leaders make the decision regarding whether to reform or not and

so their characteristics matter. Three variables are created to characterize the head of the village committee, the party secretary: Age of the party secretary (AGESEC), level of education of the party secretary (EDUSEC), and a job dummy that equals one if the occupation of the party secretary (in addition to being a village leader) was agriculture-related (JOBSEC). The test for serial correlation suggested by Wooldridge (2002) and Drukker (2003) is conducted. The result fails to reject the null hypotheses that there is no serial correlation in the model. The balanced panel is used, that is, only villages that were observed in all three years are included.

4. Results

Results on the discrete choice model that estimates the likelihood of water institutions show that the policy of upper level governments plays an important role in encouraging irrigation management reform (Table 3). The estimated coefficients on the variables that measure the governments' efforts to promote WUAs or contracting (NMEETWUA and NMEETCONTR) are positive and statistically significant (rows 15-16, columns 1-2). So these variables can serve as good IVs. Results on other explanatory variables are also of interest. In the WUA equation, the estimated coefficient on SLIGHT, which indicates that a village had slight water shortage problems, is negative, but the estimated coefficient on SSEVER, which indicates a village had severe shortage problems, is positive (rows 1-2, column 1). Similar results are obtained when alternative specifications are run using two other measures of water shortages, the percent of the maximum area the canal can irrigate (the command area of the canal) that was actually irrigated in the previous survey year and the number of years (in the past five years) of no water or not enough water in the canal. This means that WUAs are more likely to form either when villages do not have water shortage problems or villages experience severe water shortage problems — a nonlinear relationship. It is possible that when water resources are abundant, there is more room

for water savings, thus WUAs are more likely to form to grab the profit opportunities offered by the water saving incentives. At the other end, with severe water shortage problems, there is more need to augment water supply through better water management and therefore villages are more motivated to reform their institutions. It is also likely village leaders are motivated to shift the management responsibilities to WUAs when there are severe water shortages.

When a larger share of the canal in a village is lined with concrete, the village's irrigation system seems more likely to remain under collective management (row 5, column 1). This is consistent with the findings in Huang et al., (2008). The possible reason is that if canals were not lined, managers would have to put in much more time and labor maintaining the canals. Since village leaders usually have many other duties such as managing the village enterprises, they would not have a lot of time for managing canals. Hence, leaders are more motivated to turn an irrigation system over to a WUA when the canal system is of poorer quality. From WUA members' points of view, such an irrigation system might provide more scope for improvement, since there might have been more waste in unlined canals when they were under collective management. Characteristics of water users are also associated with the adoption of WUAs. For example, wealthier villages, those with smaller share of migrants in the labor force, and those with fewer self-employed businesses seem more likely to adopt WUAs (rows 9-11, column 1).

The characteristics of water resources or canals, however, do not affect the likelihood of a village choosing contracting (rows 1-6, column 2). One possible reason is that because WUA is the managerial form the government focuses most on in irrigation management reform, WUAs have been given formal and legal status (MWR, NDRC, MCAC, 2005). The authority of WUAs is recognized by upper-level government and farmers in most villages in terms of mobilizing labor or raising fund for irrigation related matters, which is important in managing irrigation

systems with severe water shortage problems or poor infrastructure. Contractors, on the other hand, have no such authority over farmers because they are just fellow villagers. As a result, characteristics of water resources or canals do not play an important role in the decision to use contracting or not. The only factor that is systematically associated with contracting is the (lagged) share of self-business households (PTSELF). Self-business can be considered as an alternative to contracting in terms of earning profit. In villages with more off-farm employment opportunities, partly reflected by the higher share of households with self-business, the opportunity cost of being a contractor managing canals increases. As a result, fewer agents in the village would want to contract the canals. This explains the negative coefficient on PTSELF.

The main results are reported in Tables 4-6. The instrumental variable regressions with canal and time fixed effects performed well. The predicted probabilities are valid instruments and there is no weak identification. Most explanatory variables have expected signs. For example, the maintenance expenditure is lower if more of the canals are lined (Table 4, row 7, column 1).

The most significant result of our analysis is that WUAs have positive and statistically significant effects on all four indicators (Table 4). Since collective management is the base group, the coefficients on WUA and CONTRACT are interpreted as the difference between the reformed institutions and the traditional collective management. Other things being the same, WUAs spent 12.7 yuan/meter more on maintenance expenditure than collective management (row 1, column 1). In our sample, the average maintenance expenditure in villages with collective management was 9.3 yuan/meter in 2007. Yuan is the currency used in China. In 2007, \$1 is about 7.5 Yuan. All monetary terms in the paper is converted into 2007 yuan using the Consumer Price Indices for rural China. So when irrigation management is transferred to WUAs from the village committee, WUAs increased the maintenance expenditure by about 37%. WUAs

increased the share of timely water deliveries by 25 percentage points and increased the percent of irrigated area by 41 percentage points (row 1, columns 2-3). In villages with collective management, the average share of timely water deliveries was 57.2% and on average only 83% of the canal command area is irrigated. Perhaps because irrigation services are extended to more of farmers' land and provided in a timelier manner, WUAs also increased the rate of water fee collected by 24 percentage points (row 1, column 4). In villages with collective management, only 72% of water fees were collected in 2007.

Contractors also spent more on maintenance than the village committee (row 2). A *t*-test show that the magnitudes of increase are about the same under WUAs and contracting. The profit of contractors comes from a portion of the water fees collected from farmers. If contractors do not provide quality irrigation services (e.g., deliver water in a timely manner), farmers are likely to decline to pay or only pay a partial amount. Maintenance activities such as cleaning canals are essential for the timely delivery of water. Although maintenance expenditures are also paid out of water fees and shrink the profit margins of contractors, insufficient maintenance hurts profit more. Water saving incentives facing some contractors further motivate them to exert more efforts to plan necessary maintenance such as fixing broken canals so that less water can be used to meet farmers' irrigation needs. The profit incentives drive contractors to keep up with maintenance. Contractors also increased the rate of fee collection and the percent of irrigated area but were less successful than WUAs, with only 13 and 28 percentage points increments respectively. The contractors, however, did not improve the timeliness of water deliveries.

WUAs and contractors have much less impact on water use and crop production. Since the dependent variable is in log form, coefficients are interpreted as percentage differences. When the explanatory variable is a dummy variable, the *exact* percentage difference is calculated

as $\exp^{\beta} - 1$, where β is the parameter on the dummy variable (Halvorsen and Palmquist, 1980). In villages managed by WUAs, about 76% less water is applied to irrigate rice relative to villages under collective management (Table 5, row 1, column 1). Rice yield is also lower under WUAs but the difference is much smaller (only 14%). The estimated coefficients on WUA, however, are not statistically significant in either the regression of water use or yield (row 1, column 2). WUAs, however, does increase crop produced per unit of water by almost three folds and the effect is statistically significant (row 1, column 3). The impact of contracting is similar to that of WUAs but the impact is smaller and none of the effects is statistically significant. There is some evidence that both WUA and contractors reduce water use and increase yield in wheat production but the evidence is not strong (Table 6). None of the estimated coefficients is statistically significant.

The weak result on water use is not expected because water saving incentives are used widely under WUAs and contracting and they have shown to reduce water use (Wang et al., 2005). The possible explanation is that the profit managers can earn from saving water is tied to the magnitude of water reduction relative to earlier years. If large water savings were achieved in earlier years, then the room for water saving would be smaller in later years. Then the water saving incentive is less and less effective as time progresses. This may explain why the results using the panel data that span over 7 years do not reveal larger impact of WUAs or contractors on water use. Another explanation is that managers are not able to reduce water supplied to farmers by much, especially in areas already facing severe water shortage problems. Otherwise other management goals, particularly the percent of water fees collection, will be negatively affected.

The weak results on crop yields are likely related to lack of sufficient data for such analysis. It is possible that crop production has less direct relationships with irrigation management (Vermillion, 1997) and so it is difficult to isolate the effects of irrigation reforms on crop yields from a large set of confounding factors such as input uses and technology changes (Garces-Restrepo et al., 2007). The presence of policies that target at poverty reduction will also affect crop yields (Araral, 2009). This is particularly true in China. During the span of the survey period (between 2001 and 2007), there are significant changes in the macro policy environment in rural China. Araral (2010) has observed a decreased attention of China's water policy to the concerns of the poor between 2002 and 2007. Concurrent with the irrigation management reform, a series of policies have been implemented that affect agricultural production and rural welfare. Examples include the tax-for-fee reform enacted in the late 1990s and the eventual elimination of agricultural tax in 2006. The Chinese government has also started to provide nationwide direct subsidies for farmers as essential instruments in increasing rural incomes, including direct payments to grain producers based on planting areas and direct subsidies to purchased farm inputs. Farmers can also apply for subsidies to purchase seeds or agricultural machineries (Yu and Jensen, 2010). The use of year dummies in regressions helps control for the effects of macro policies. However, a regression of crop yield on input uses and technology is subject to endogeneity problem because input levels and technology choices are simultaneously determined with expected yields in agricultural production (Marschak and Andrews, 1944). Unfortunately, information collected in the CWIM survey does not provide good IVs for such regressions.

When examining crop yields and the productivity of water, it is also important to control for the spatial and temporal variability in hydro-climatic factors. Cai et al. (2011) show that in the YRB, both crop yield and water productivity are strongly correlated with both climate factor

(measured by the ratio of potential ET to precipitation) and water factor (measured by the ratio of actual ET to precipitation). Fig. 7. in Cai et al. (2011) also shows that both the climate and water factors vary across space and over time in the YRB. Although the use of canal fixed effects control for any canal-level time invariant factors such as the long-term trend in hydro-climate factors, temporal variations in these factors are not controlled for. This affects the results in at least two ways. First, because hydro-climatic factors such as crop ET are not available at the canal level, the measure crop produced per unit of water is constructed using gross irrigation water. Because of conveyance loss and return flow, gross irrigation water will be higher than crop ET. This means the measure used will under-estimate water productivity (Cai et al., 2011). It is easy to show that when the dependent variable in a regression is smaller than its actual value, the estimated coefficients will often be smaller than their actual sizes (called attenuation bias). Combined with the fact that standard errors are often larger in panel estimation because only time-variant variations in data are used, the attenuation bias may explain why only limited impacts of WUAs and contracting on water productivity are found in the empirical analysis, even though both have improved some aspects of the irrigation system.

Second, the insufficient control for hydro-climatic factors may also explain why different impacts are found on wheat and rice production. In our sample areas, although both rice and wheat are irrigated, rice is irrigated on average 36 times during its growing season while wheat is irrigated only between two and five times. The demand for irrigation management is much higher in rice production and thus changes in irrigation management (conversion to WUA or contracting) could generate significant effects. In contrast, wheat production is influenced more by variations in hydro-climatic factors, which is supported by the finding from Cai et al. (2011) that water productivity of irrigated wheat has a higher spatial variability than that of irrigated rice

in the YRB. Then in addition to attenuation bias, the insignificant impact of WUA or contracting on wheat production may also be because irrigation reform does not provide solutions that could increase the robustness of production to hydro-climatic variability (e.g., water storage). In this sense, irrigation systems (in terms of crop pattern and hydro-climatic variability) matter for the decision to reform irrigation management or not and what the reform should focus on.

Our results can also be used to test the relationship between collective action and water scarcity, exit option and the salience of the resource. Other things held constant, a one percentage point increase in the share of sown area in rice and wheat increases the maintenance expenditure by 0.08 yuan/meter and the percent of fee collected by 0.2 percentage point (Table 4, row 6, columns 1 and 4). The availability of alternative water supply, on the other hand, reduces both maintenance expenditure and farmers' willingness to pay water fees (row 5, columns 1 and 4). Both results are consistent with expectations and the empirical literature (Dietz et al., 2003; Meinzen-Dick et al., 2002). The estimated coefficients on SLIGHT and SSEVERE are not statistically significant (rows 3-4, columns 1-3). In an alternative specification, the number of years (in the past five years) of no water or not enough water in the canal (lagged, LWTYR) is used to measure water scarcity. The estimated coefficient on LWTYR was statistically significant (and negative) only in the model for percent of fee collected. When the squared LWTYR was also added, the estimated coefficients on LWTYR and squared LWTYR were not statistically significant in any model. One explanation for the insignificant effect of water scarcity is that its effects are mitigated by the establishment of WUAs. Results in Table 3 indicate WUAs are more likely to be established in villages with abundant water resource or severe water shortage problems. The result on the rate of water fee collection does not support the inverse U-shaped relationship. Water users are less likely to pay water fees as the degree of

water shortage increases (rows 3-4, column 4). It should be noted that although the location of the canal (head or tail-end) is an important factor, it is not explicitly included here because it is time invariant and is thus captured in the canal fixed effects.

The group size affects maintenance expenditure. The estimated coefficients on the number of household per meter along the canal (LOGPMNHH) and the squared term are both positive and statistically significant (Table 4, rows 9-10, column 1). This is consistent with the argument by Meinzen-Dick et al. (1997). Farmers may benefit from increases in the number of households that lead to better maintenance due to the economy of scale and larger total contribution associated with larger sizes. The group size has the opposite effect on the timeliness of water deliveries and the percent of irrigated area. The estimated coefficients on the number of household along the canal (LOGNHH) and the squared term are both negative and statistically significant (rows 11-12, column 2). This is probably because the difficulty of coordinating water deliveries increases with the group size. Contrary to the finding in Araral (2009), group size does not affect the percent of fee collection. This may be because canal managers have sufficient time to get to each household regardless of the group size since they only collect fees before or after the busy irrigation season. In addition, canal managers are from within the villages. They know when and where to find their fellow villagers to collect the fees. Finally, because land is highly equally distributed among households and water fees are charged on a per unit of land basis in rural China, the amount of irrigation fees each household owes is easy to calculate and does not vary significantly across households in the village. In contrast, in the Philippines, fees are sometimes collected by the staff of the government irrigation agency from outside the villages. Land is not equally distributed and the level of irrigation fee varies by the level of water service (Araral, 2009). The geography and accounting factors lower the cost of fee collection per user in

China relative to the Philippines, which may reduce the influence of group size on the percent of fee collection. Other characteristics of water users also matter. More educated water users or users with higher income are more likely to pay their water fees (rows 13-14, column 4). The share of households with self-business (PTNSELF), affects the rate of fee collection negatively (row 16, column 4). This is consistent with the argument that increasing access to market activities outside agriculture, by providing farmers an “exit option” from collective action, usually reduces users’ cooperation in managing the commons (Meinzen-Dick et al., 2002).

Our results also indicate that the characteristics of canal managers matter. Interestingly, different aspects of the managers are important for different indicator. In villages with WUAs, if a manager is also the village leader, the share of timely water deliveries is lowered by 7.9 percentage points (row 18, column 2). A manager-cum-village-leader may operate the WUA similar to collective management. He may hire a person to carry out daily irrigation-related activities on his behalf. This person is often paid by a fixed wage, which does not give him any incentive to deliver water in the timeliest manner. In terms of maintenance, the experience of the manager matters. A one year increase in the experience will increase maintenance expenditure by 0.46 yuan/meter (row 17, column 1). This indicates that more experienced canal managers put more emphasis on maintaining canals, which is important given the general deteriorating status of canals in many areas. It is a bit surprising that the experience of water manager does not affect the timeliness of water deliveries or the rate of water fee collection.

5. Conclusions

This paper evaluates the impact of the irrigation management reform in northern China that has been going on since 1995. Empirical results show WUAs have been successful in improving the irrigation systems in terms of higher maintenance expenditure, more timely water delivery,

higher irrigated percentage and higher rate of water fee collected. Since these are among the primary goals of the irrigation management reform, we can say that WUAs in China have been largely successful so far. Improvements are also found in irrigation systems managed by contractors, although the improvement is not as substantial as in the case of WUAs. The differential impacts of WUAs and contracting may be attributed to the difference in governance. For example, management under WUAs is more transparent in that more irrigation-related information is shared with farmers. The difference may also arise because contractors, unlike WUAs that have some form and legal status recognized by farmers and local IDs, do not have the same authority as WUAs in terms of mobilizing funds and labor.

WUAs, however, have not succeeded in all aspects. Although promoting water savings is one of the ultimate goals of the reform, there is no strong evidence that WUAs have worked. WUAs only seem to have increased crop produced per unit of water in rice production and no impacts have been found on wheat production. The limited impact of WUAs and contractors on water use is partly attributed to the mechanism of water savings, which shrinks the room for water savings over time. The more fundamental problem, however, is related to water pricing. As long as farmers are still paying for water on per unit of land basis as they do now, farmers have no incentive to use less water. Then WUAs are constrained in how much water they can save. If canal managers reduce water supply significantly, farmers may forfeit water fees due to discontent, which will threaten the financial sustainability of WUAs.

There is still substantial room for more reform efforts. Current policy reforms serve primarily to trim the bureaucracy, provide incentives to improve irrigation service and streamline the path of fee remittances to improve the capacity for local IDs to be self-sufficient. Most surface water systems in China still suffer from a lack of volumetric pricing mechanisms at the

farmer level. Policy efforts by the national government indicate that it is the direction China is moving towards. Starting in 2004, China's leaders have begun to consider reforming the pricing of water as a key policy instrument for dealing with the nation's water scarcity problem to encourage more efficient water use (General Office of the State Council of China, 2004). Starting in 2005, the national government also encouraged many IDs to improve irrigation infrastructure at tertiary levels and below, which are the canals that deliver water into either one farmer's field or the fields of several farmers that are located along the same canal (MWR, 2005). In 2007, pilot projects were implemented in seven provinces and have been expanded to more areas (China Water & Power Press Editorial Team, 2008). The improvements include lining tertiary canals and installing water measurement equipment. Water officials consider this as a step towards charging volumetric price at farmer levels in the future. WUAs could play a role in extending volumetric pricing to more places. WUAs can initiate and organize the projects that improve irrigation infrastructure at tertiary levels and below (China Water & Power Press Editorial Team, 2008). WUAs can be the ones that work with farmers to implement volumetric pricing including measuring the volume of water and setting the water price.

WUAs could also facilitate other reform efforts. WUAs could revive the government's efforts to promote water-saving technologies, which started in the 1990s but did not result in widespread adoption. WUAs could also play a role in other mechanism to improve water allocation efficiency. In water trading between agriculture and other sectors, WUAs can take on the role of representing farmers in the market, which will lower the transaction cost significantly relative to the case of individual farmers being the market participants (Cai, 2008).

Results on some of the factors that affect cooperative behavior in irrigation management are consistent with expectations and the empirical literature. For example, the presence of exit

option, measured using groundwater supply as the alternative water supply or using self-business as one of the off-farm employment opportunities, reduces the likelihood of cooperative behavior such as percent of fee collected. Other results may be more specific to the context of rural China. For example, the results on water scarcity did not mirror those from other countries. This is probably because the effect of water scarcity is mediated by the choice of water institutions of a village.

Although this paper makes the important contribution of quantifying the impact of irrigation management reform, it lacks the details that can explain why WUAs or contracting have succeeded in improving some but not all aspects of irrigation systems. The CWIM survey did not collect sufficient information on the various aspects of the workings of WUAs or contracting (e.g., differences in water allocation rules). As reported by Huang et al. (2010), some aspects of the governance of WUA and contracting (e.g., management transparency and the use of water saving incentives) did vary over years. These variations could lead to different effects of WUAs or contracting in different years. The sample size is not large enough to allow a more detailed analysis that includes an even larger set of factors.

The scope of the paper is also limited in that it does not examine whether changes in irrigation systems has led to other desirable outcomes such as reduced variations in crop yields, diversification into higher value crops and improved household welfare. In order to uncover the correct relationship between the irrigation reform and these outcomes, a rich data set is required to control for the large set of confounding factors. Although canal fixed effects are used to control for *canal level time invariant* factors, canal or village level *time variant* factors also need to be accounted for. For example, spatial and temporal variations in hydro-climatic factors strongly influence variations in crop yields and water productivity. The change in road

conditions in the villages (access to market) will influence farmers' decision to diversify into high value crops such as fruits or vegetables. Such analysis also needs to control for household level time invariant factors such as farmers' skills and time variant factors such as off-farm jobs and remittances (which can be used as capital for investment in higher value crops). A particular factor is whether farmers have adopted new varieties (such as drought tolerant seeds), perhaps in response to seeds subsidies offered by the government (Yu and Jensen, 2010). To examine whether irrigation reform helps reduce variations in crop yields, time series data with long panels are also required to construct a good measure of variation before and after the irrigation reform. There is also a need to collect hydrologic data such as precipitation and crop ET. Integrating economic data such as the CWIM data with hydrologic data will improve the quality of analysis significantly. It will also generate sounder policy implications. Case studies could also be employed for a more in-depth ethnographic study.

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Table 1. Number of sample villages under different water management institutions ^a

2001 \ 2004	Total	Collective management	Water user association	Contracting	Mixed institutions
Collective Management	23	18	0	3	2
Water user association	6	1	2	2	1
Contracting	13	3	0	10	0
Mixed institutions	5 ^b	0	2	2	1
	47	22	4	17	4 ^c

2004 \ 2007	Total	Collective management	Water user association	Contracting	Mixed institutions
Collective Management	22	9	8	3	2
Water user association	4	0	4	0	0
Contracting	17	1	8	3	5
Mixed institutions	4	0	3	0	1
	47	10	23	6	8 ^d

a. This table is adapted from Table 1 in Huang et al. (2010) with one modification: only the balanced panel (the 47 villages that are in all three years) is used here.

b. In three villages, some canals were managed under contracting and others were under the control of collective management. In two villages, WUAs managed some canals and collective management controlled the remaining canals.

c. WUAs managed the canals jointly with contractors in two villages. In another village, WUA managed the canals jointly with the village committee. In the third village, some canals were jointly managed by WUAs and contractors, while others were managed by contractors.

d. In all eight villages canals were jointly managed by contractors and WUAs.

Table 2. Variable definitions and descriptive statistics

Variable Name	Variable description	Mean	Std. Dev.
Indicators to evaluate the irrigation reform			
MAINTAINEXP	Maintenance expenditure per meter of the canal, Yuan/meter ¹	18.7	25.6
PTTIMELY	% of the times that irrigation was not delayed or cancelled	81.1	25.6
PTIRRI	% of maximum irrigatable area that is irrigated	90	21
PTCOLLECT	% of the total amount of water fees payable by farmers that was collected	89.4	20.9
Water management institution			
WUA	Dummy, =1 if canals are managed under WUA		
CONTRACT	Dummy, =1 if canals are managed under contracting		
Characteristics of water resources			
SLIGHT	Dummy = 1 if a village leader reported that the village experienced <i>slight</i> water shortage problems.	0.18	0.39
SSEVER	Dummy = 1 if a village leader reported that the village experienced <i>severe</i> water shortage problems.	0.29	0.46
PTGW	% of <i>irrigated</i> sown area that is irrigated by groundwater	10.31	23.25
SHRICEWHEAT	% of sown area in rice and wheat	51.52	18.55
Characteristics of the canals			
PTLINED	% of the total length of a canal that was lined	27.86	40.13
SILT	Dummy, =1 if the canal silts up easily	0.41	0.5
Characteristics of water users			
LOGNHH	Total number of households within the canal command area, in log form	5.92	0.66
LOGPMNHH	Number of households per meter of canal, in log form	-2.17	0.76
EDU	% of labor force graduated from high school or above	55.87	23.25
LOGPCINC	Income per capita, Yuan, in log form	7.92	0.61
PTMIG	% of the village labor force that are migrants	17.8	19.91
PTSELF	% of households in the village with self-business	12.25	13.01
Characteristics of the canal manager			
WEXP	Years of water management experience	6.57	7
VILEAD	Dummy, =1 if the manager currently is a village leader	0.61	0.49
Characteristics of village leaders			
AGESEC	Age of the party secretary in Years	46.51	8.46
EDUSEC	Level of education of the party secretary in years of schooling	9.84	2.08
JOBSEC	Job dummy, =1 if the main job of the party secretary was agriculture-related	0.47	0.5
Policy of upper level governments			
NMEETWUA	Average number of meetings per year upper level governments had to promote WUA	5.33	5.39
NMEETCONTR	Average number of meetings per year upper level governments had to promote contracting	4.16	5.43

1. Yuan is the currency used in China. \$1≈ 7.5 Yuan in 2007.

2. Values of variables that measure the characteristics of water resources in 2004 are reported. Values of other variables in 2007 are reported.

Table 3. Estimate probabilities of WUA and contracting
(Multinomial logit with random intercepts to control for unobserved heterogeneity)

Base group:		(1)		(2)	
Collective Management		WUA Equation		Contracting Equation	
<i>Characteristics of water resources</i>					
1	SLIGHT, Lagged	-3.769*	(2.107)	-0.192	(0.990)
2	SSEVER, Lagged	3.078*	(1.784)	0.374	(0.843)
3	PTGW, Lagged	-0.088	(0.089)	0.012	(0.021)
4	SHRICEWHEAT, Lagged	0.012	(0.047)	-0.043	(0.028)
<i>Characteristics of the canals</i>					
5	PTLINED	-0.032*	(0.019)	0.016	(0.010)
6	SILT	-1.988	(1.757)	1.335	(0.841)
<i>Characteristics of water users</i>					
7	LOGNHH, Lagged	2.210	(1.493)	-0.770	(0.557)
8	EDU, Lagged	-0.048	(0.034)	0.002	(0.019)
9	LOGPCINC, Lagged	6.954**	(3.075)	0.061	(0.849)
10	PTMIG, Lagged	-0.110**	(0.055)	-0.014	(0.027)
11	PTSELF, Lagged	-0.080*	(0.044)	-0.059*	(0.030)
<i>Characteristics of village leaders</i>					
12	AGESEC	0.014	(0.090)	-0.061	(0.054)
13	EDUSEC	0.207	(0.302)	-0.029	(0.181)
14	JOBSEC	0.658	(1.204)	0.400	(0.744)
<i>Policy of upper level governments</i>					
15	NMEETWUA	0.669**	(0.303)	0.197	(0.175)
16	NMEETCONTR	0.021	(0.204)	0.351**	(0.166)
17	Intercept (Mean)	-63.922**	(29.017)	7.656	(7.095)
18	Intercept (SD)	3.146**	(1.506)	1.909**	(0.785)
19	Covariance between intercepts	3.474	(3.72)		

†Standard errors in parentheses; *, **, *** significant at 10%, 5% and 1%, respectively.

Table 4. Impact of irrigation management reform on irrigation system
(Fixed effects with instrumental variable estimation)

	(1) MAINTAINEXP	(2) PTTIMELY	(3) PTIRRI	(4) PTCOLLECT
Water management institution				
1 WUA	12.697*** (3.079)	25.116* (14.940)	41.393** (17.062)	24.302* (13.121)
2 CONTRACT	11.723** (4.605)	0.679 (11.218)	27.848** (12.169)	13.089* (7.246)
Characteristics of water resources				
3 SLIGHT, Lagged	1.117 (2.102)	5.172 (4.449)	7.347 (4.502)	-3.013 (3.746)
4 SSEVER, Lagged	0.040 (2.211)	0.754 (4.949)	-0.229 (4.246)	-7.339* (4.154)
5 PTGW, Lagged	-0.102*** (0.032)	-0.147 (0.255)	0.239 (0.184)	-0.390** (0.196)
6 SHRICEWHEAT, Lagged	0.080* (0.041)	0.121 (0.169)	0.000 (0.156)	0.210* (0.127)
Characteristics of the canals				
7 PTLINED	-0.037*** (0.011)	-0.085 (0.056)	0.122* (0.064)	-0.011 (0.046)
8 SILT	-0.055 (1.547)	2.938 (3.142)	3.558 (4.892)	3.412 (3.238)
Characteristics of water users				
9 LOGPMNHH	6.992*** (2.143)		-20.887*** (6.233)	
10 LOGPMNHH, Squared	4.234** (1.941)		-22.020*** (5.782)	
11 LOGNHH		-12.162** (5.179)		4.679 (3.468)
12 LOGNHH, Squared		-18.199*** (5.872)		2.127 (3.487)
13 EDU	-0.009 (0.045)	-0.046 (0.068)	0.053 (0.101)	0.173** (0.077)
14 LOGPCINC, Lagged	2.916 (1.779)	-4.823 (4.568)	14.227*** (4.786)	7.619* (3.950)
15 PTMIG	0.039 (0.049)	-0.075 (0.084)	-0.268* (0.156)	0.108 (0.076)
16 PTSELF, Lagged	0.219*** (0.070)	0.144 (0.119)	0.144 (0.135)	-0.197** (0.098)
Characteristics of the canal manager				
17 WEXP	0.458** (0.187)	-0.138 (0.210)	0.423 (0.336)	0.185 (0.232)
18 VILEAD	-0.900 (4.281)	-7.915* (4.345)	9.717** (3.970)	-3.566 (3.458)
19 Canal fixed effects	YES	YES	YES	YES
20 Year fixed effects	YES	YES	YES	YES

†Standard errors in parentheses; *, **, *** significant at 10%, 5% and 1%, respectively.

†Robust standard errors clustered at village levels.

Table 5. Impact of irrigation management reform on rice production
(Fixed effects with instrumental variable estimation)

		(1) Log of Water Use (m ³ /mu) ^a	(2) Log of Yield (kg/mu)	(3) Log of Crop Produced per unit of Water (kg/m ³)
Water management institution				
1	WUA	-1.409 (0.889)	-0.148 (0.504)	1.607* (0.877)
2	CONTRACT	-0.480 (0.500)	-0.309 (0.262)	0.325 (0.583)
Characteristics of water resources				
3	SLIGHT, Lagged	-0.084 (0.281)	0.033 (0.127)	0.171 (0.358)
4	SSEVER, Lagged	0.192 (0.208)	-0.215 (0.136)	-0.394* (0.216)
5	PTGW, Lagged	0.031** (0.014)	0.003 (0.008)	-0.033** (0.015)
6	SHRICEWHEAT, Lagged	0.013 (0.009)	0.004 (0.004)	-0.010 (0.010)
Characteristics of the canals				
7	PTLINED	-0.008 (0.005)	-0.001 (0.003)	0.006 (0.006)
8	SILT	0.173 (0.319)	-0.003 (0.206)	-0.140 (0.310)
Characteristics of water users				
9	LOGPMNHH	-0.116 (0.124)	-0.164* (0.090)	-0.023 (0.106)
10	EDU	-0.016* (0.009)	-0.000 (0.005)	0.018* (0.009)
11	LOGPCINC, Lagged	-0.487* (0.281)	0.055 (0.165)	0.497* (0.285)
12	PTMIG	-0.000 (0.009)	0.001 (0.004)	0.004 (0.009)
13	PTSELF, Lagged	-0.006 (0.009)	-0.007 (0.005)	0.001 (0.010)
Characteristics of the canal manager				
14	WEXP	0.050** (0.022)	0.015 (0.012)	-0.037 (0.029)
15	VILEAD	-0.061 (0.263)	-0.075 (0.108)	-0.024 (0.290)
16	Canal fixed effects	YES	YES	YES
17	Year fixed effects	YES	YES	YES

†Standard errors in parentheses; *, **, *** significant at 10%, 5% and 1%, respectively.

†Robust standard errors clustered at village levels.

Mu is the metric used to measure land area in rural China, 1 hectare = 15 mu.

Table 6. Impact of irrigation management reform on wheat production
(Fixed effects with instrumental variable estimation)

	(1)	(2)	(3)
	Log of Water Use (m ³ /mu) ^a	Log of Yield (kg/mu)	Log of Crop Produced per unit of Water (kg/m ³)
<i>Water management institution</i>			
1 WUA	-0.290 (0.584)	0.092 (0.170)	0.465 (0.516)
2 CONTRACT	-0.779 (0.553)	0.154 (0.116)	0.725 (0.584)
<i>Characteristics of water resources</i>			
3 SLIGHT, Lagged	0.085 (0.136)	0.049 (0.059)	0.016 (0.141)
4 SSEVER, Lagged	-0.325** (0.165)	-0.003 (0.068)	0.182 (0.197)
5 PTGW, Lagged	0.000 (0.005)	0.000 (0.001)	0.004 (0.006)
6 SHRICEWHEAT, Lagged	0.001 (0.008)	0.001 (0.002)	-0.004 (0.007)
<i>Characteristics of the canals</i>			
7 PTLINED	-0.005*** (0.002)	-0.000 (0.001)	0.003 (0.002)
8 SILT	0.061 (0.163)	-0.009 (0.057)	-0.046 (0.172)
<i>Characteristics of water users</i>			
9 LOGPMNHH	-0.009 (0.076)	-0.005 (0.018)	0.053 (0.078)
10 EDU	-0.003 (0.003)	-0.000 (0.001)	0.001 (0.003)
11 LOGPCINC, Lagged	-0.232 (0.163)	0.042 (0.050)	0.303* (0.159)
12 PTMIG	0.005 (0.004)	-0.000 (0.002)	-0.004 (0.005)
13 PTSELF, Lagged	0.001 (0.005)	-0.000 (0.001)	0.000 (0.005)
<i>Characteristics of the canal manager</i>			
14 WEXP	0.004 (0.009)	0.000 (0.005)	-0.001 (0.009)
15 VILEAD	-0.192 (0.177)	0.001 (0.048)	0.213 (0.175)
16 Canal fixed effects	YES	YES	YES
17 Year fixed effects	YES	YES	YES

†Standard errors in parentheses; *, **, *** significant at 10%, 5% and 1%, respectively.

†Robust standard errors clustered at village levels.

Mu is the metric used to measure land area in rural China, 1 hectare = 15 mu.