Water Users Associations and Agricultural Water Use Efficiency in Northern China

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Abstract

Traditional irrigation water management systems in China are increasingly replaced by user-based, participatory management through water users associations (WUAs) with the purpose to promote more efficient water use and higher farm incomes. Existing research shows that significant differences exist in the institutional setup of WUAs in China, and that WUAs have not been universally successful in saving water and improving farm incomes. This paper aims to examine the underlying causes of differences in WUA performance by analysing the impact of WUA characteristics on the efficiency of agricultural water use. Explanatory variables in our analysis are largely based on Agrawal's user-based resource governance framework. Applying a random intercept regression model to data collected among 21 WUAs and 315 households in Minle county in northern China, we find that group characteristics, particularly group size and number of water users groups, and the existing pressure on available water resources are important factors in water use efficiency. We further find that WUA characteristics that positively affect water savings in crop production tend to increase the costs of inputs used in crop production, and thereby reduce or even fully offset the potential positive impact of water savings on farm incomes in our research area.

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1. Introduction

Water scarcity constitutes a major problem in China, as per capita water availability is only a quarter of the world average (Falkenmark et al., 1989; Shalizi, 2006). Within the country, water resources are distributed rather unevenly. Water is a very scarce resource in the north, while water availability in the south is less problematic due to abundant precipitation (World Bank 2001; Yang et al., 2003; Zhang et al., 2008). Moreover, the monsoon-dependent, continental climate in the north makes that rainfall is restricted to a short period of the year in that region. Yet, almost half of the Chinese population lives in the north, and most of the maize, wheat and vegetables is grown there (NBS, 2011; Calow et al., 2009).

Growing demands on water, particularly in the north, are putting more and more pressure on China's ability to produce its own food as agricultural production in China is highly dependent on irrigation water. In northern China, 75 percent of crop output is generated from irrigated land (Yang et al., 2003). The size of the irrigated area has rapidly increased in recent decades, from 45 mln. ha. in 1979-81 to 60 mln. ha. in 2010 (World Bank, 2006; NBS, 2011). The use of water for industrial purposes and domestic consumption, however, is increasingly reducing the amount of water available for agricultural production. As a share of total water use, the use of water in agriculture has steadily declined from around 80% in 1980 to 61.3% in 2010 (World Bank, 2006; NBS, 2011).

Technical innovations as well as water policy and management reforms are required to improve water use efficiency in agriculture to meet growing food demands (Rosegrant and Cai., 2002; Yang et al., 2003). Farmers in northern China increasingly resort to water-saving irrigation systems and cultivation methods, but also greatly increased the use of groundwater for agricultural production (Wang et al., 2007; Zhang et al., 2008). As a result, groundwater tables in the Hai river basin have fallen considerably; evidence on groundwater tables in other parts of northern China is mixed, however (Qu et al., 2011).

The management of water resources was mainly done through collective ownership arrangements since the implementation of the household responsibility system in agriculture at the end of the 1970s / beginning of the 1980s, with village leaders (representing the village council) being responsible for water allocation, canal operation and maintenance and fee collection (Huang et al., 2009). This traditional management system is similar to the system that governed most of China's rural water resources during the people's commune system period.

In recent years, two major types of management reforms can be observed in northern China, namely user-based, participatory management through water users associations (WUAs) and contracting out of irrigation canal management to individuals. Huang et al. (2009) estimate that more than one-quarter of the villages in northern China had replaced traditional management by either WUAs or contracting in 2004. Their study further finds that water availability, length and complexity of the canal system and reform-promoting policies of local governments are the main drivers of water management reforms. In subsequent research comparing the performance of the three management systems, Huang et al. (2010) find that WUAs perform better than traditional management systems in terms of maintenance expenditures, timeliness of water delivery and rates of fee collection; management systems based on contracting also perform better than traditional systems, although not as much as WUA-based systems.

The impact of WUAs on farm production, income and water savings is examined by Wang et al. (2005, 2006, 2010). These studies find that WUAs have not been universally successful in either saving water or improving farm incomes, and link the performance of water management systems to the incentives that these new institutions provide to water managers. Wang et al. (2010) identifies five key principles that, according to World Bank project managers, WUAs should satisfy in order to be successful: There should be adequate and reliable water supply, the WUA should be organized hydraulically (not administratively), leaders should be elected, WUA management and decision making should be with the farmers (without local government interference), water should be charged volumetrically (not according to land area), and the WUA should have the right to collect water fees. Empirical evidence among WUAs in Ningxia, Gansu, Hubei and Hunan Provinces indicates that there are important differences in the extent to which these five key principles are implemented, and that the degree of implementation has important implications for water use efficiency (Wang et al., 2010). Water use in rice, wheat and maize in World Bank-supported WUAs, which mostly operate according to the five principles, is found to be 15-20 percent lower than in traditionally managed villages. In villages where participation by farmers plays only a minor role and water management reforms have been only nominally implemented, the establishment of WUAs has had little effect on water use. The study further finds that crop yields and incomes are not significantly different between World Bank-supported WUAs and other WUAs.

The study by Wang et al. (2010) emphasizes the importance of five key principles promoted by the World Bank for successful user-based water management. It neglects, however, the potential role played by other factors identified in the literature on sustainable governance of common pool resources, such as group size or level of dependence on the resource system. A large group size may negatively affect water use efficiency because it intensifies problems of collective action and free-riding. A high participation in off-farm employment among WUA members, and hence a low reliance on agricultural production, may reduce the incentives of group members for improving agricultural water use efficiency. Policies that narrowly focus on promoting the five key principles may be less successful in stimulating water savings through sustainable user-based water management if such additional factors that may play a role in user-based decision making are not properly taken into account. Empirical research that identifies the relative importance of different factors influencing water use efficiency through user-based water management is needed to underpin such policies. To our knowledge, however, no rigid empirical studies of water use efficiency based on an established framework of common pool resource management have been carried out so far in the case of China.

This study uses the sustainable governance of common-pool resources framework presented by Agrawal (2003) to examine the conditions for successful user-based management of irrigation water in northern China. Data collected among 315 households and 21 WUAs in Minle County, Zhangye City, Gansu Province for the year 2009 is used for this purpose. We use that data set for estimating a random intercept regression model of the impact of various WUA characteristics on three different indicators of water use efficiency, i.e. barley production, total crop production value and cropping income per m^3 of water..

A number of studies have discussed the conditions under which user groups will sustainably govern common-pool resources such as irrigation water (e.g. Ostrom, 1990a, 1990b; Meinzen-Dick, 2007; Slangen et al., 2008; Binswanger-Mkhize et al., 2010). Agrawal (2003) summarizes the conclusions of three influential studies by Baland and Platteau (1996), Ostrom (1990a) and Wade (1988) and further extends the set of determinants distinguished in these studies. We choose to apply Agrawal's framework instead of the more recent framework presented by Ostrom (2007, 2009, 2010), because it includes relationships between resources and user groups and their external environment (markets, technology), which may play an important role in the Chinese context.

The paper is structured as follows. The next section discusses the research area and the method of data collection. In section 3 we discuss how we implement Agrawal's framework, present descriptive statistics of the WUA characteristics that we include in our analysis, and discuss the expected effects of these characteristics on agricultural water use efficiency. Subsequently, in section 4, we specify the regression model that we use for our analysis and present descriptive statistics for the dependent variables and control variables. The regression results of our model are presented in section 5. The final section summarizes the main findings and discusses their implications for the ongoing water management reforms in northern China.

2. Research area and data collection

The data used for our research were collected via a household survey and a WUA survey held in May 2010 in Minle County, Zhangye City, Gansu Province. Zhangye City is an oasis located midstream of the Heihe River, an inland river that flows across Qinghai Province, Gansu Province and Inner Mongolia Autonomous Region. It originates from the Qilianshan Mountains in Qinghai province and ends in Juyanhai Lake in Inner Mongolia. In the midstream of the Heihe River watershed, the land is flat, sunshine is abundant, and annual precipitation is very low while evaporation is high. But due to the availability of irrigation water from the Heihe River, the area has become a major grain and vegetables production base in Gansu province.

According to the MWR (2004), Zhangye City is severely short of water resources, even though it uses up almost all the water of Heihe River. Only 50% of the farmland is well irrigated, and much arable land has been abandoned due to water shortage. Agriculture accounts for approximately 95% of all water use and almost all water in the Heihe River is extracted for irrigation use. As a result, too little water flows into Juyanhai Lake; the lake dried out in 1992, turning an area of 200 km^2 around the lake into a desert (MWR, 2004; Zhang et al., 2009).

To deal with these problems, the Ministry of Water Resources (MWR) initiated a pilot project called ‘Building a Water-saving Society in Zhangye City’ in 2002. The project, the first project of its type in the country, was designed to save water through government investments in a water-saving irrigation system and in meters for measuring water use and through establishing a water use rights (WUR) system with tradable water quotas. The first two measures decreased irrigation water use somewhat, but trading of WUR did not become popular (Zhang et al., 2009).

Minle County, one of the six counties in Zhangye City, is located between the foothills of the Qilian Mountains and the lower lying Hexi corridor. Its total cultivated land area equals

860,000 mu[1], with irrigated land constituting 67 percent. Major crops in Minle County include barley, wheat, maize, sesame, rapeseed, garlic and potato. Surface water is the major water resource for irrigated agriculture in the area. Due to the high costs of pumping water from the wells, the use of groundwater is less than 5 percent of total water use in irrigated agriculture (source: Water Bureau of Minle County).

Agricultural land in Minle County is usually divided into three zones with different planting conditions and water requirements. Zone 1 has an elevation ranging from 1,600 to 2,000 meters. Precipitation in this zone is relatively scarce. Zone 2 is located between 2,000 and 2,200 meters, while zone 3 has an elevation ranging from 2,200 to 2,600 meters. By far the largest zone is the second one, with 500,000 mu of cultivated land, followed by the first and third zones, with 190,000 and 170,000 mu respectively. Due to the relatively high rainfall in zone 3, it relies less on irrigation than the other two zones.

The water used for surface irrigation is stored in six reservoirs in the Qilianshan mountains. Five of these reservoirs serve their own irrigation area within Minle County, while one reservoir serves two irrigation areas. A county-level water management bureau (WMB) is responsible for the water allocation institutions within the region. Seven lower-level WMBs, one for each of the seven irrigation areas, arrange the water allocations to WUAs within their own irrigation area. WUAs are responsible for arranging the water distribution to households belonging to their own WUA. WUA are sub-divided into water users groups (WUGs), consisting of households having plots along the same channel. Since the plots of different households within a WUG are irrigated at the same time, households belonging to a WUG need to coordinate their planting decisions and water demands.

Irrigation is carried out by flooding adjacent farmland at the same time, organized from lowest to highest altitudes, with villages in the first zone receiving more irrigation rounds (generally three) per year than the villages in the other two zones (generally one or two rounds). Standard water quantities per mu are assigned for each irrigation round, but these

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[1] 15 mu equals one hectare.

quantities are only realized in years of abundant rainfall. Water is allocated according to a quota system based on the size of the so-called WUR land of the farmers. Not all the irrigated land is classified as WUR land. Its size depends on the labor provided by a village to the construction of the reservoir and some other factors (like WUR land obtained through auctions).

The household survey and WUA survey data used in this study were collected in May 2010 by staff and students from Gansu Academy of Social Sciences in Lanzhou, Gansu Agricultural University in Lanzhou, and Nanjing Agricultural University. The data cover information for the year 2009. Household interviews were done in the same 21 villages where a similar household survey was held in May 2008[2] (see Wachong Castro et al., 2010 for a description of the sampling method). This resulted in a household-level dataset containing 315 observations. Because some crucial information needed for the analysis in this study is missing in the data set for 2007, we only use the data set for 2009. It contains information about crop production, use of water and other inputs, WUA participation, water and other prices, land tenure and land use, and so on.

For the WUA survey, we interviewed leaders of WUAs in the same 21 villages. The WUA survey covers information about water allocation, water trading and water exchange between WUAs, water-saving and canal maintenance activities, WUA management, income and expenditures of WUAs, and so on.

To obtain more background information, the WMBs of the seven irrigation areas in Minle County were interviewed by the first author in August 2010. Questions asked during these interviews include the water allocation to WUAs within each irrigation area, the contents and participants of water management meetings organised by the WMBs, payments for water by the WUAs, and so on.

[2] In the survey carried out in May 2010, we interviewed 265 households that were also interviewed two years before. The other 50 households could not be found, and were replaced by other randomly selected households within the same village.

3. Characteristics of the examined WUAs

In this section, we use Agrawal's theoretical framework (Agrawal, 2003) to examine the characteristics of the 21 surveyed WUAs in Minle County and to develop hypotheses on their expected effects on sustainable irrigation water management. In doing so, we focus on one major aspect of sustainable water management, namely water use efficiency. The discussion in this section will follow the same grouping of characteristics as in Agrawal's framework, but is limited to the characteristics for which information is available and show a sufficient degree of variation in our data set.[3]

Characteristics of the resource

We take the following two resource characteristics identified by Agrawal (2003) into account in our analysis.

- *Resource size*

We use the length of 2nd level canals within a WUA as an indicator of the size of water resources. In our research area, 1st level canals feed water from the reservoir to 2nd level canals. WUAs distribute the water from the 2nd level canals that they manage over the 3rd and 4th level canals. Farmers' fields are usually located alongside the 4th level canals. The length of the 2nd level canals varies from 0.3 to 20 km for the WUAs in our sample, with an average length of 5.68 km (see Table 1). We expect that water use efficiency is higher in WUAs with a smaller size, as measured by the length of their 2nd level canals, because use and misuse of water is easier to monitor in such WUAs.

- *Resource boundaries*

Well-defined resource boundaries make it easier to exclude outsiders from using the resource. The boundaries of all the 21 WUAs that we use in the regression analysis correspond to the boundaries of administrative villages. All resource boundaries therefore

[3] Variables dropped due to a very small degree of variation include the share of ethnic minorities among the member households (as an indicator of shared norms) and (former) village leadership of the WUA leader (as an indicator of appropriate leadership).

seem to be well-defined in our sample. As a consequence we do not include an indicator for this resource characteristic in our analysis of water use efficiency.

Village boundaries, however, often do not correspond to the natural boundaries of the water resource. Some WUAs are located along one 2nd level canal, while others are located along two, or even three or four, 2nd level canals (see Table 1). We use the number of 2nd level canals in a WUA as an indicator of the degree of overlap between the WUA boundaries and the natural boundaries, and expect that WUAs with fewer 2nd level canals have a higher efficiency of water use.

[Table 1]

Group characteristics

Five group characteristics, that are expected to facilitate institutional success in the sustainable governance of common pool resources in Agrawal's framework, are included in our empirical analysis.

- *Group size*

We use the number of households within a WUA as an indicator of group size. It varies from 37 to 630 in our sample, with a mean size of 276 households (see Table 1). We expect that WUAs with fewer households have higher water use efficiency, because small groups can overcome problems of collective action and free-riding more easily.

- *Group leadership*

Appropriate leadership facilitates efficient rules setting, and therefore is expected to stimulate more efficient water use. We use the age of the WUA leader as an indicator of group leadership. It ranges from 35 to 59 in our sample, with a mean value of 46. A relative old leader may have more respect among member households, and therefore be able to establish more efficient rules. On the other hand, younger leaders may be more familiar with changing external circumstances. Hence, the impact of the age of the leader on water use efficiency may be positive or negative.

- *Heterogeneity of endowments*

Heterogeneity of endowments is expected to have a positive effect on resource management, through enhancing the possibility of collective action (Baland and Platteau, 1996). Because use of irrigation water is closely linked to land endowments, we use the proportion of households with per capita land more than twice the average[4] as an indicator of endowment heterogeneity. Its value varies from 0 to 40% in our sample, with an average value of 5.8%. We expect a positive relationship between this variable and water use efficiency.

- *Homogeneity of interests*

WUAs with members having a relatively high degree of homogeneity of identities and interests are more likely to have common concerns. In our analysis, joint interests in agricultural production and water savings are likely to be an important factor in water use efficiency. These interests are expected to be very similar within WUGs, but may differ considerably between WUGs. We therefore use the number of WUGs within a WUA as an indicator of the homogeneity of interests (in agriculture and water savings), and expect that it is negatively related to water use efficiency. The value of this variable varies from 3 to 20, with a mean value of 8.29 (see Table 1).

- *Poverty level*

Poor households are expected to be more interested in achieving individual rather than common goals. We use the proportion of households with an income lower than 1,200 RMB per capita per year, which is the poverty line of Gansu Province in 2009, as an indicator of the level of poverty in a WUA. Using this definition, the share of poor households ranges between 0 and 90% for the WUAs in our sample, with an average value of 28.8%. We expect that WUAs with relatively low poverty shares have higher water use efficiency.

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[4] The average of households within the same village.

Relationship between resource and group characteristics

A third category identified in Agrawal's framework reflects the relationship between resource characteristics and group characteristics. We use three indicators of such relationships in our analysis.

- *Resource dependence*

In successful cases of self-organization, users are either dependent on the resource system for a substantial portion of their livelihoods or attach high value to the sustainability of the resource. Otherwise, the costs of organizing and maintaining a self-governing system may not be worth the effort (Ostrom, 2009). We use the share of households in a WUA with heads that migrate at least six months per year as an indicator of the degree of dependence of the resource. Its value varies from 0.8 to 75.2%, with a mean value of 35.2%.[5] We expect that WUAs with a higher share of migrating household heads have lower water use efficiency.

- *Fairness of benefit allocation*

The perceived fairness in the allocation of benefits from common resources may affect participants' motivation in pursuing common rather than individual goals. In our case, the way in which water is distributed over the available irrigated land is likely to play an important role in perceptions of fairness. As discussed in section 2, the proportion of WUR land in total irrigated land is a crucial factor in the allocation of water resources in Minle County. We expect that the allocation of water resources will be considered as less fair when the proportion of WUR land in total irrigated land is low as compared to its average value for all WUAs within the same irrigation district,. The value of this indicator[6] varies from -46% to +39%, with a mean value of +1.56% (see Table 1). We expect that it has a positive impact on water use efficiency.

[5] These values are based on the answers provided by the leaders of WUAs. The variation in actual migration rates of household heads may be less extreme than these answers suggest.

[6] $\frac{area\ of\ WUR\ land\ in\ the\ WUA}{total\ area\ of\ irrigated\ land\ in\ the\ WUA} - \frac{area\ of\ WUR\ land\ in\ all\ WUAs\ in\ the\ same\ irrigation\ district}{total\ area\ of\ irrigated\ land\ in\ all\ WUAs\ in\ the\ same\ irrigation\ district}$

- *Level of demand*

High levels of user demand may increase the possibilities of conflicts among users, and are therefore expected to be negatively related with successful joint action. In the survey, a question was included that asked the amount of water that the WUA was willing to buy, if there were no constraints, at the current water price level. The resulting water demand level divided by the number of households within a WUA is used as the indicator of the level of demand in our analysis. Its value varies from 200 to 14,400 m^3 for the WUAs in our sample, with a mean value of 5,720 m^3. We expect that WUAs with a lower demand for water have a higher water use efficiency.

Governance [7]

Our data set contains information on two variables that reflect the governance and institutional arrangements within WUAs.

- *Monitoring processes*

Adequate monitoring of water use is essential for a proper functioning of WUAs and for increasing water use efficiency levels. The use of surface water for irrigation is measured in a similar way throughout Minle county as part of the water-saving pilot project in Zhangye City (see section 2). Important differences exists, however, in expenses on guards that prevent water stealing. Prevention of water stealing may affect successful joint action in irrigation water use and therefore also result in higher water use efficiency. Expenses on guards vary from 0 to 1.24 RMB per mu for the WUAs in our sample, with a mean value of 0.22 RMB (see Table 1). Guards may increase water use efficiency by reducing water stealing, but expenses on guards may be higher in WUAs where more water stealing occurs. Hence, the expected impact of this variable on water use efficiency is indeterminate.

- *Operational rules*

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[7] The terminology used for this set of characteristics resembles more closely the terminology in Ostrom (2009).

A bottom-up approach to rules setting and enforcement is seen as an important factor in sustainable joint resource management. In Agrawal's framework this means that governments should not interfere in the way WUAs operate. In a similar vein, we may argue that WUA interference in households' decisions may negatively affect water use efficiency of member households. On the other hand, WUA decisions are taken jointly by member households instead of an outside authority with limited knowledge of local conditions. Hence, it is unclear a priori whether WUA involvement in cropping decisions has a positive or a negative impact on water use efficiency of its member households. We use a dummy variable that reflects whether or not the WUA is involved in cropping decisions made by households as an indicator of WUA interference. Of the households in our sample, 33% report WUA involvement in their cropping decisions (see Table 1).

External environment

A distinguishing feature of Agrawal's framework is the emphasis placed on the impact of the external environment on successful management of the commons. We distinguish two different factors in this respect.

- *Articulation with external markets*

External markets form an important external stress factor on resource systems. The level of articulation with external markets is therefore expected to affect water use efficiency negatively. We use the proportion of land planted with marketed crops as an indicator of this factor. Its value varies from 0 to 28.3% in our dataset, with an average value of 8.16%.

- *External aid*

Appropriate levels of external aid are needed in cases where local residents may not undertake conservation activities without such compensations. In our analysis, we use the amount of government subsidies received by the WUA per household as an indicator of external support. Its value varies from 0 to 165 RMB in our sample, with a mean value of 8.75 RMB. WUAs that receive more subsidies per household are expected to have a higher water use efficiency.

4. Model specification

The econometric model that we use for our empirical analysis explains irrigation water use efficiency of WUA member households from the WUA characteristics discussed in section 3. Other explanatory variables in the model include household and farm characteristics and agro-ecological zone dummies.

We selected three different variables as dependent variables in the model, namely household barley production, total crop production value and household income from crop production[8], all expressed per m^3 of water. We examine water use efficiency in barley, because barley is the crop that is most widely planted by the households in the research area. Water savings achieved by switching between crops, however, are not reflected in the results for this indicator. We therefore include the total value of crop production per m^3 of water as an alternative measure of water use efficiency. A disadvantage of this measure, compared to the first indicator, is its sensitivity to differences in crop prices received by households. Moreover, water savings realised by switching to more water-efficient crops and those achieved by increased application of water-saving techniques in non-barley crops cannot be distinguished when we use this dependent variable. Using water saving techniques or management methods and changes in crop choice may not only affect the production value of crops, but also the costs of inputs (including irrigation water) that farmers use for growing these crops and hence the profits that farmers make from crop production. To examine these consequences, we use household cropping income per m^3 of water as the third dependent variable in our regression analysis.

[Table 2]

[8] Income is calculated as revenues, incl. the value of own food consumption, minus costs of input use, incl. water fees paid by households.

Table 2 shows the descriptive statistics of the three dependent variables. Farmers in the research region harvest on average 0.32 kg barley per m^3 of irrigation water, and obtain an average crop production value of 1.96 RMB and an average cropping income of 1.12 RMB per m^3 of water. The variations in gross revenues and incomes are much larger than the variation in barley yields (its standard deviation equals only one-sixth of the mean value) for the households in our sample.

The regression model used for estimating the factors affecting water use efficiency is as follows:

$$E_{ij} = \delta_0 + \sum_{k=1}^{14} \delta_k W_{kj} + \sum_{l=1}^{4} \delta_l H_{lij} + \sum_{m=1}^{2} \delta_m D_{mj} + \varepsilon_{ij} \quad (1)$$

Where:

E_{ij} = Water use efficiency for household i (i = 1, …, 315) in WUA j (j= 1, ...,21);

W_{kj} = Value of WUA characteristic k (k= 1, ..., 14) in WUA j (j= 1, ...,21);

H_{lij} = Value of household and farm characteristic l (l= 1, ..., 4) for household i (i = 1, …, 315) in WUA j (j= 1, ...,21);

D_{mj}= agro-ecological zone dummies (m=1, 2) for WUA j (j= 1, ...,21);

δ_0 , δ_k , δ_l , δ_m = Coefficients to be estimated;

ε_{ij} = Disturbance terms with standard properties.

The model includes 14 characteristics of WUAs that may affect water use efficiency at the household level. Descriptive statistics of these indicators, and the expected impact of each indicator on water use efficiency, are discussed in Section 3. In addition, four household and farm variables that are likely to affect water use efficiency and two agro-ecological zone dummies are added as control factors to the regression equations.

[Table 3]

The age and education level of the household head reflect the level of schooling and experience of the head of the household, who is regarded as the main decision maker on agricultural production. Older and more educated heads are expected to have a higher efficiency of water use. On the other hand, they may also have more power in negotiating water distribution within their WUAs. Hence, the expected impact is indeterminate for both variables. The average age of the household head is 46.4 years in our sample, while the level of schooling equals 7.5 years on average (see Table 3).

We use two indicators of the quality of the land in our analysis. More fertile land and relatively flat land are expected to need less water than less fertile and sloping land. Hence, the two dummy variables reflecting whether land fertility is good or not and whether the land is flat or not are expected to be positively related to water use efficiency. Land fertility is qualified as good by 58 percent of the households in our sample, while 96 percent of the households mention that their land is flat (see Table 3). The survey data that we use for our analysis also contains information on the water price per m^3 paid by farm households. Its value shows very little variation over households.[9] Hence, we do not include the water price as an explanatory variable in our model.

Finally, two dummy variables are included in the regression equation to control for the differences in agro-ecological conditions between the three zones in Minle County (see section 2). Crops planted at higher altitudes need less irrigation water. Hence, the dummies for zone 1 and zone 2 are both expected to have a negative impact on water use efficiency. Most households (62 percent) that were interviewed in our survey live in zone 2, while 23 and 15 percent live in zones 1 and 3, respectively (see Table 3).

As explained above, we use hierarchical data in the models, with variables varying at two different levels (i.e. household and WUA level). The random intercept model model that we apply in our analysis is considered a suitable method to estimate linear models in which the explanatory variables vary at two or more different levels (Cameron and Trivedi, 2009).

[Table 4]

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[9] The mean value of water prices in our sample is 0.88 RMB per m^3, with a standard deviation of 0.01 RMB per m^3.

The expected signs of the impact of each of the WUA characteristics (discussed in section 3) and control variables (discussed in the current section) on water use efficiency are summarised in Table 4.

5. Regression results

Equation (1) was estimated for the 315 households in our data set. Table 5 shows the regression results for each of the three dependent variables. Due to missing data for a number of variables, the sample size for the crop production value and cropping income models is 302, while the sample size for the barley production model equals 267.

[Table 5]

The results indicate that *resource characteristics* do indeed affect water use efficiency. The length of the 2nd level canals has a significant negative impact on all three dependent variables. This finding provides support for the hypothesis that water use efficiency is notably higher in smaller water resources because water misuse is easier to monitor. We do not find evidence, however, that the degree of overlap between WUA boundaries and natural boundaries (as measured by the number of 2nd level canals in a WUA) plays an important role.

Several *group characteristics* are found to play a significant role in achieving water savings. Four out of the five examined group characteristics have a strongly significant impact of a household's crop production value per cubic meter of water. The number of households in a WUA has a significant negative impact, thereby providing supportive evidence for the hypothesis that a large group size may exacerbate problems of collective action and free riding in joint water management. Our results further support the hypotheses that heterogeneity of endowments, as measured by the percentage of households with per capita land more than twice the average, is an important precondition for successful collective action and that poverty may be an important obstacle in achieving common (environmental) goals. Heterogeneity of interests, as measured by the number of WUGs in a WUA, has a significant positive impact on crop production per m^3 water value in our regression results. In theory, groups having heterogeneous interests are expected to have a lower water use efficiency. The number of WUGs in a WUA may not be an adequate indicator of the heterogeneity of interests, because households in our case study region generally belong to more than one WUG. In fact, households in WUAs with a relatively large number of WUGs may have more options for crop diversification and have a better tuning of planting and irrigation decisions among member households, and thereby obtain a relatively high water use efficiency.

Only one of the group characteristics, share of poor households, has a significant (negative) impact on barley production per m^3 water. This implies that the water savings induced by the other group characteristics are mainly achieved through the use of water-saving techniques in other crops or through switching towards crops with a higher value per unit of water.

Our third dependent variable, cropping income per unit water, is significantly affected by heterogeneity of (land) endowments but not by the other four group characteristics. And even for endowment heterogeneity the estimated coefficient in the income model is less than half the estimated coefficient in the crop production value model. In other words, the group characteristics that induce higher (lower) water use efficiency tend to increase (decrease) the costs of input use at the same time. For example, households in WUAs with a large share of poor households have significantly lower crop production per unit water, but also spend less on inputs for crop production, such as fertilizer, per unit water[10] - due to credit constraints,

[10] The correlation coefficient of the share of poor households in a WUA with fertilizer, machine and seed use per m3 of water is -0.10, -0.09 and -0.05, respectively. Expenditures on fertilizer constitute on average 50 percent of the input expenditures for the households in our sample, while expenditures on machines make up 21 percent and expenditures on seed 20 percent.

risk aversion, or other factors. This lower use of inputs may in fact, at least partly, explain why crop production per unit water is lower for such households.

The next group of explanatory variables in our three models consists of indicators of the *relationship between resource characteristics and group characteristics*. All three listed indicators significantly affect crop production value per unit water in our regression results. The estimated coefficients are negative for the share of migrant household heads, positive for the relative share of WUR land in irrigated land and negative for water demand at the current price, respectively. These findings provide supporting evidence for the hypotheses that smaller resource dependence negatively affects joint action in water management, that perceived fairness in the allocation of water resources positively affects water use efficiency, and that higher water demand may lead to more conflicts among users and hence to fewer water savings.

In the barley equation, only the estimated coefficient for the perceived fairness indicator is significantly different from zero. This again indicates that a large share of the water savings is achieved in other crops than barley or through switching between crops. In the cropping income equation, only the water demand variable has a significant negative coefficient but its (absolute) size is considerably smaller than the coefficient estimated in the crop production value equation. Like before, this finding suggests that water savings are achieved at the expense at higher costs for the use of other inputs.

There are two *governance* variables in our model. Expenses on guards do not significantly affect water use efficiency in any of the three estimated equations. Hence the two counteracting effects of this variable on water use efficiency seem to more or less balance each other. For WUA involvement in cropping decisions, we find a significantly positive impact on crop production value per unit of water. This finding suggests that jointly decided crop choices lead to higher water use efficiency than crop choices made by individual households within a WUA. The results for this variable in the barley production and cropping income equations indicate that joint decision making does not affect water savings in barley, the most popular crop in the region, and that higher input costs counterbalance the income gains that can be obtained from higher water use efficiency in crop production.

The last two WUA characteristics that we consider in our analysis are indicators related to the *external environment*. The significant negative coefficients estimated for land planted with marketed crops in the barley production and total crop production value equations suggests that external markets indeed put more pressure on water resources, leading to lower barley production and total crop production value per unit water. The effect on cropping income per unit water is again not significantly different from zero, indicating that the lower output per unit water is at least partly compensated by lower costs of input use. Our regression results for the amount of government subsides received by a WUA per member household indicate that such subsidies negatively affect the water use efficiency in crop production. The information on subsidies in our survey data set refers to government subsidies in general, not to subsidies targeting water savings, and are positive for only two of the 21 WUAs in our sample. Hence, care should be taken in drawing far-reaching conclusions from this result.

The household and farm characteristics that we include as *control variables* in our regressions also show some interesting results. The age of the household head does not significantly affect any of our water use efficiency indicators, but the education level of the household head does. The negative sign estimated for the latter variable in the cropping production value equation suggests that households with more educated heads have a relatively low water use efficiency. A greater capability to negotiate favourable amounts of water within a WUA may explain this result. Of the two land quality variables in our analysis, only the slope of the land seems to matter for water use efficiency. Households with relatively flat land obtain significantly higher cropping incomes per unit water than households with sloping land.

[Table 6]

Table 6 shows the elasticities that correspond to the estimated coefficients for the WUA characteristics, calculated at the sample means. Only the coefficients that are statistically significant (at a 10 percent testing level) are included in the table. The small elasticities obtained for the variables affecting water use efficiency in barley production confirm that water savings are obtained either through using water-saving techniques in other crops or through switching towards crops that have a higher value per unit water. Total crop production value per unit of water is found to be very sensitive to group characteristics, particularly the number of households that constitute a WUA (elasticity: -0.61) and the number of WUGs within a WUA (elasticity: 0.96). High pressure on the resource due to a large water demand at the current price (elasticity: -0.45) or a high degree of articulation with external markets (elasticity: -0.54) is also found to play an important role, and to a lesser extent also resource size (elasticity: -0.36) and degree of dependence on the resource (elasticity: -0.27). The calculated elasticities for cropping income per unit water, shown in the last column of the table, confirm that gains in cropping value per unit water are partly or fully counterbalanced by the higher costs of inputs used in growing these crops.

6. Conclusion

This study examines which characteristics of WUAs play a significant role in promoting water use efficiency among the households belonging to a WUA in nortern China. Data collected among 315 households and 21 WUAs in Minle County, Gansu Province for the year 2009 are used to estimate a random intercept model explaining barley production, total crop production value, and total cropping income per cubic meter of water.

Previous research on WUAs and water use efficiency in northern China has concentrated on the five so-called key principles, identified and promoted by World Bank project managers, that WUAs should satisfy. These are: adequate and reliable water supply, hydraulically (not administratively) organized WUAs, elected leaders and no government interference in WUA management and decision making, water payments based on used quantities, and water fees collection rights with the WUA. Our research broadens the analysis by examining a range of potentially important factors identified in the literature on sustainable common pool resource management.

Model specification in our study is largely based on a comprehensive framework developed by Agarwal (2003). The regression results that we obtain for the crop production value equation indicate that group characteristics, particularly group size and number of sub-groups, are important factors in water use efficiency. Large groups tend to have greater difficulties in overcoming problems of collective action and free-riding. A large number of sub-groups, i.e. water users groups (WUGs), within a WUA can promote water use efficiency by allowing more crop diversification and by a better tuning of planting and irrigation decisions among member households. Other group characteristics that affect water use efficiency in our sample are heterogeneity of land endowments and share of poor households in a WUA. The former factor has a positive effect on water use efficiency of member households in a WUA, while the latter factor has a negative impact.

Several other factors listed in Agrawal's framework are found to affect water use efficiency in our research area. In particular we find that a high pressure on the water resource caused by a large unmet water demand or a high degree of articulation with external markets negatively affects water savings in crop production. We also find evidence that resource size, as measured by the length of the 2nd level canals in our research, contributes to lower water use efficiency because misuse of water is more difficult to monitor. And we find evidence s that the degree of dependence on the resource, as measured by the share of households with migrant heads in a WUA, affects the efficiency of water use.

These results refer to findings that we obtain in the equation for total crop value per unit water. The regression results of the barley production equation indicate that WUA characteristics play a very limited role in obtaining water savings in this crop, that is grown by a large majority most farmers in the region. In other words, WUA characteristics that affect water savings in our research area mainly do so by encouraging water-saving techniques on other crops or the cultivation of crops with a higher value per unit water than barley.

Our regression results for the third equation indicate that resource size, heterogeneity of land endowments and unmet water demand significantly affect the amount of cropping income obtained per unit of water. Estimated elasticities for these three variables are slightly smaller in (absolute) value than their elasticities in the cropping value equation. The findings for this equation imply that WUA characteristics that positively affect water savings in crop production tend to increase the costs of inputs used in crop production, and thereby reduce or even fully offset the potential positive impact of water savings on farm incomes in our research area.

Our findings have important implications for the ongoing water management reforms in northern China. Increasing water use efficiency is of crucial importance for maintaining food self-sufficiency, a major national-level policy goal in China, while water demand from non-agricultural sectors is rapidly growing. WUAs established on the basis of the five key principles identified and promoted by World Bank project managers may play an important role in this respect, as convincingly shown by Wang et al. (2010). Our findings show that a number of factors that are commonly identified in the literature on sustainable management of common pool resources also need to be taken into account if WUAs are to be successful in promoting higher water use efficiencies. In particular we find that WUAs with a relatively small number of member households, a large number of WUGs, and a low pressure on the available water resources are more likely to achieve relatively high water use efficiencies. Water management reforms in northern China are more likely to be successful in stimulating water use efficiency and possibly even farm income levels, if these characteristics are taken into account and, wherever possible, manipulated in appropriate directions.

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Table 1: Descriptive statistics of WUA characteristics

Indicators	Unit	Mean	Std. Dev.	Min	Max
Resource characteristics					
Length of 2nd level canals	km	5.68	5.61	0.3	20
Number of 2nd level canals		2.05	0.86	1	4
Group characteristics					
Number of households		276	190	37	630
Age of WUA leader	Years	46.3	6.76	35	59
Share of households with per capita land > twice the average	%	5.80	11.1	0	40
Number of WUGs		8.29	4.71	3	20
Share of poor households	%	28.8	25.1	0	90
Relationship between resource and group characteristics					
Share of households with migrant heads	%	35.2	22.8	0.83	75.2
Relative share of WUR land in irrigated land	%	1.56	20.2	-46.0	38.6
Water demand at current water price level	10,000 m^3/hh	0.572	0.426	0.02	1.44
Governance					
Expenses on guards per mu of WUR land	RMB/mu	0.22	0.34	0	1.24
Involvement of WUA in cropping decision	1=yes, 0=no	0.33	0.48	0	1
External environment					
Percentage of land planted with marketed crops	%	8.16	6.47	0	28.3
Subsidies received from government per household	RMB/hh	8.75	36.0	0	165

Table 2: Descriptive statistics of dependent variables

Variables	Unit	No. of observ.	Mean	Std. Dev.	Min	Max
Barley production per m^3 of water	kg/m^3	267	0.32	0.05	0.05	0.60
Crop production value per m^3 of water	RMB/m^3	302	1.96	1.57	0.29	13.5
Cropping income per m^3 of water	RMB/m^3	302	1.12	1.49	-4.76	11.2

Table 3: Descriptive statistics of other explanatory variables

Variables	Unit	No. of observ.	Mean	Std. Dev.	Min	Max
Household characteristics						
Age of head	Years	315	46.4	10.2	23	78
Education of head	Years	314	7.52	3.51	0	15
Farm variables						
Fertility of land	1=good, 0=otherwise	312	0.58	0.49	0	1
Slope of land	1=flat, 0=otherwise	312	0.96	0.20	0	1
Agro-ecological zones						
D1	1=zone 1 0=otherwise	315	0.23	0.42	0	1
D2	1=zone 2 0=otherwise	315	0.62	0.49	0	1

Table 4: Expected effects of explanatory variables

Variable	Expected effect
Resource characteristics	
Length of 2nd level canals	–
Number of 2nd level canals	–
Group characteristics	–
Number of households	–
Age of WUA leader	+/–
Households with per capita land more than twice the average	+
Number of water users groups	–
Share of poor households	–
Relationship between resource and group characteristics	
Share of households with migrant heads	–
Relative share of WUR land in irrigated land	+
Water demand at current water price level	–
Governance	
Expenses on guards per mu of WUR land	+/-
Involvement of WUA in cropping decision (1=yes, 0=no)	+/–
External environment	
Share of land planted with marketed crops	–
Government subsidies	+
Household Characteristics	
Age of head	+/-
Education of head	+/-
Farm variables	
Fertility of land (1=good, 0=otherwise)	+
Slope of land (1=flat, 0=otherwise)	+
Agro-ecological zones	
D1 (1=zone 1, 0=otherwise)	–
D2 (1=zone 2, 0=otherwise)	–

Table 5: Regression results for water use efficiency, random intercept model

	Barley production per m³ of water (kg/m³)	Crop production value per m³ of water (RMB/m³)	Cropping income per m³ of water (RMB/m³)
Resource characteristics			
Length of 2nd level canals	-0.002 * (-1.77)	-0.126 *** (-4.27)	-0.068 ** (-2.20)
Number of 2nd level canals	-0.002 (-0.17)	-0.374 (-1.37)	-0.270 (-0.93)
Group characteristics			
Number of households	-0.00002 (-0.24)	-0.004 *** (-2.60)	-0.0003 (-0.17)
Age of WUA leader	0.001 (1.08)	0.007 (0.33)	-0.009 (-0.40)
Share of households with per capita land > twice the average	0.001 (0.96)	0.105 *** (4.49)	0.049 ** (1.99)
Number of water users groups	0.003 (1.16)	0.227 *** (3.79)	0.080 (1.27)
Share of poor households	-0.001 *** (-3.12)	-0.024 *** (-3.11)	-0.007 (-0.92)
Relationship between resource and group characteristics			
Share of households with migrant heads	-0.0002 (-0.55)	-0.015 * (-1.83)	-0.006 (-0.64)
Relative share of WUR land in irrigated land	0.001 *** (2.57)	0.016 ** (2.09)	0.011 (1.32)
Water demand at current price	0.003 (0.18)	-1.53 *** (-3.64)	-0.827 * (-1.86)
Governance			
Expenses on guards	-0.000 (-0.09)	0.001 (1.51)	0.0005 (0.83)
Involvement of WUA in cropping decision (1=yes, 0=no)	0.013 (1.41)	0.448 ** (1.99)	0.085 (0.36)
External environment			
Share of land planted with marketed crops	-0.003 * (-1.80)	-0.129 *** (-2.86)	-0.062 (-1.29)
Government subsidies	-0.0004 (-1.25)	-0.017 ** (-2.35)	-0.008 (-0.98)
Household characteristics			
Age of head	0.0003 (0.81)	0.001 (0.10)	0.001 (0.14)
Education of head	0.0003 (0.32)	-0.056 ** (-2.34)	-0.028 (-1.12)
Farm variables			
Fertility of land (1=good, 0=otherwise)	0.010 (1.32)	0.212 (1.14)	-0.179 (-0.92)
Slope of land (1=flat, 0=otherwise)	-0.028 (-1.34)	0.569 (1.32)	0.806 * (1.77)
Agro-ecological zones			
D1 (1=zone 1, 0=otherwise)	-0.023 (-1.23)	-0.586 (-1.22)	-0.631 (-1.24)
D2 (1=zone 2, 0=otherwise)	-0.021 (-1.29)	-1.29 *** (-3.16)	-0.883 ** (-2.04)
Intercept	0.356 ***	5.65 ***	3.24 ***

	(7.98)	(5.51)	(2.99)
Number of observations	267	302	302
Number of WUAs	21	21	21
R^2 (overall)	0.19	0.32	0.16
Wald chi2	59.5 ***	134.0 ***	52.0 ***

Notes: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. z-statistics are in parentheses.

Table 6: Estimated elasticities

	Barley production per m^3 of water (kg/m^3)	Crop production value per m^3 of water (RMB/m^3)	Cropping income per m^3 of water (RMB/m^3)
Resource characteristics			
Length of 2nd level canals	-0.04	-0.36	-0.35
Number of 2nd level canals			
Group characteristics			
Number of households		-0.61	
Age of WUA leader			
Share of households with per capita land > twice the average		0.31	0.26
Number of water users groups		0.96	
Share of poor households	-0.08	-0.35	
Relationship between resource and group characteristics			
Share of households with migrant heads		-0.27	
Relative share of WUR land in irrigated land	0.00	0.01	
Water demand at current price		-0.45	-0.42
Governance			
Expenses on guards			
Involvement of WUA in cropping decision (1=yes, 0=no)		0.08	
External environment			
Share of land planted with marketed crops	-0.08	-0.54	
Government subsidies		-0.08	