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Analysis

Water users associations and irrigation water productivity 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, economically and ecologically beneficial, water savings and increase 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 analyzing the impact of WUA characteristics on the productivity of irrigation water. Explanatory variables in our analysis are derived from 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 productivity. Resource characteristics, i.e. resource size and degree of overlap between the WUA boundaries and natural boundaries, do not significantly affect water productivity in our research area.

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, due to the monsoon-dependent and continental climate in the north, 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 (Calow et al., 2009; NBS, 2012).

Growing demands for 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% 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 million ha in 1979–81 to 61.7 million ha in 2011 (NBS, 2012; World Bank, 2006). 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 2011 (NBS, 2012; World Bank, 2006).

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

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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: (1) There should be adequate and reliable water supply, (2) the WUA should be organized hydraulically (not administratively), (3) leaders should be elected and WUA management and decision making should be with the farmers (without local government interference), (4) water should be charged volumetrically (not according to land area), and (5) 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% 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 collective management of water 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. 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 the performance of user-based water management is needed to underpin such policies. To our knowledge, however, no rigid empirical studies of user-based water management on the basis of 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. A number of studies have discussed the conditions under which user groups will sustainably govern common-pool resources such as irrigation water (e.g., Binswanger-Mkhize et al., 2010; Meinzen-Dick, 2007; Ostrom, 1990a,b; Slangen et al., 2008). 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.

We estimate a random intercept regression model of the impact of various WUA characteristics on two indicators of water productivity, i.e. total crop production value and cropping income, both expressed per m^3 of water. The empirical analysis is based on data collected among 315 households and 21 WUAs in Minle County, Zhangye City, Gansu Province for the year 2009. Zhangye City is located in the middle reaches of the Heihe River basin. The Heihe River basin is one of three large inland river basins in northwest China, together with the Tarim and Shiyang river basins, where a comprehensive ecological water conveyance project has been implemented since the year 2000 to address the severely degraded ecological environment in their lower reaches (Wang et al., 2013). Due to overexploitation of the water resources in the middle reaches of Heihe River since the 1960s, water resources discharged to the lower reaches significantly decreased and led to declining groundwater levels, worsening water quality, reduced vegetation and severe desertification and thereby transforming it into one of China's "sandstorm cradles" (Guo et al., 2009).

The ecological water conveyance project includes ecological water transfer, grazing bans, resettlement of herdsmen, and the development of water-efficient agricultural practices (Wang et al., 2013). It has achieved obvious ecological benefits in terms of groundwater tables, biodiversity and vegetation recovery, According to Guo et al. (2009), however, the geographical scale of these beneficial changes is still limited. In order to fundamentally solve the ecological environment problem in the lower reaches of the Heihe River, they formulate a number of policy recommendations including popularization of water-saving irrigation techniques and reducing the water use volume for agricultural irrigation in the midstream reaches of the basin. By examining the impact of WUA characteristics on water productivity for WUAs located in the middle reaches of the Heihe River basin, this paper intends to contribute to policies that simultaneously increase agricultural output, raise farmers' incomes and improve downstream ecological conditions.

The paper is structured as follows. The next section discusses in more detail 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 the productivity of irrigation water. 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. However, 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 reduce the overuse of irrigation water in the middle reaches, 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%. 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% 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 1600 to 2000 m. Precipitation in this zone is relatively scarce. Zone 2 is located between 2000 and 2200 m, while zone 3 has an elevation ranging from 2200 to 2600 m. 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 seven reservoirs in the Qilianshan Mountains, serving five irrigation areas within Minle County. Five water management bureaus (WMBs), one for each of the five 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 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 organized by the WMBs, payments for water by the WUAs, and so on.

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 productivity. 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]

3.1. 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 productivity 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 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 productivity.
  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

[1] 15 mu equals 1 ha.

[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] 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).

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
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

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 productivity of water use.

3.2. 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 productivity, 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 higher water productivity. 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 receive more respect from 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 productivity 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). The underlying argument is that organizing a community for collective action involves large start-up costs; wealthy elites that have a relatively large economic interest in the resource can afford to invest extra effort in initiating and maintaining collective action as they stand to benefit most from sustainable collective management of the resource (Nagendra, 2011). 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 productivity.
- *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 productivity. 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 productivity. 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 1200 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 productivity.

3.3. 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 two 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 productivity.

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

[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.

- *Level of demand*
  High levels of unmet demand for water may increase the possibilities of conflicts among users, which are expected to be negatively related with successful joint action (Agrawal, 2003; Ostrom, 2009). On the other hand, when users' demand for water is high, they may have more incentives for saving water use. 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 5720 m^3. We expect that WUAs with a lower demand for water have a higher water productivity.

3.4. Governance[6]

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 productivity 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 exist, 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 productivity. 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 productivity 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 productivity is indeterminate.
- *Operational rules*
  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 productivity 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 productivity 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).

3.5. 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.

- *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 productivity 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%.

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

Table 2
Descriptive statistics of dependent variables.

Variables	Unit	No. of observ.	Mean	Std. Dev.	Min	Max
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

4. Model Specification

The econometric model that we use for our empirical analysis explains irrigation water productivity of WUA member households from the WUA characteristics discussed in Section 3. Water productivity is an indicator of the performance of irrigation systems (Keller et al., 1996), and is a measure of partial productivity that indicates how efficiently the system converts water into valuable outputs (Molden et al., 1998). The assessment of water productivity has attracted attention from many researchers (e.g., Clemmens and Molden, 2007; Kassam et al., 2007; Rockstrom and Barron, 2007; Steduto et al., 2007).

The two dependent variables in the model that we will examine are total crop production value and household income from crop production,[7] both expressed per m^3 of water. The first indicator measures water savings achieved by either using water saving irrigation techniques and management methods or by changes in crop choice. These water savings not only affect the total production value of crops, but may also affect the costs of inputs (including irrigation water) that farmers use for growing these crops and hence the profits that farmers make. To examine these consequences, we also run the regression with household cropping income per m^3 of water as dependent variable.

Table 2 shows the descriptive statistics of the two dependent variables. The total value of crops harvested by farmers in the research region equals on average 1.96 RMB per m^3 of irrigation water, while average cropping income amounts to 1.12 RMB per m^3 of water.

Besides WUA characteristics, we include agricultural production inputs and agro-ecological zone dummies as control variables in the model. This gives the following specification for the regression model:

$$WP_{ij} = f\left(W_j, F_{ij}, D_{ij}\right) + \varepsilon_{ij} \quad \text{for } i = 1, \ldots, 315,\ j = 1, \ldots, 21 \tag{1}$$

where:

WP_{ij}	Water productivity for household i in WUA j;
W_j	Set of 12 WUA characteristics for WUA j;
F_{ij}	Set of 10 agricultural production inputs for household i in WUA j;
D_j	Set of two agro-ecological zone dummies for WUA j;
ε_{ij}	Random disturbance terms with standard properties.

Descriptive statistics of the 12 WUA characteristics, and the expected impact of each indicator on water productivity, were discussed in Section 3. In addition, ten agricultural production factors and variable inputs and two agro-ecological zone dummies are included as control factors in the regression equations (Table 3).

Besides cultivated land size, labor input, machines value, irrigation water use and fertilizer and seed use, we also include two indicators of the quality of the land and two human capital indicators in the regression model. All these variables are expected to have a positive impact on crop production value per unit water. Their impact on cropping income

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

Table 3
Descriptive statistics of other explanatory variables.

Variables	Unit	No. of observ.	Mean	Std. Dev.	Min	Max
Agricultural production inputs						
Land	mu	312	19.6	11.1	1.60	71.3
Labor	days	310	145	126	6.0	862
Machines	RMB	310	1026	755	45	4680
Water	m^3	308	8880	6409	544	42,800
Fertilizer	jin	312	3872	2534	360	15,312
Seed	jin	309	1264	773	13	3960
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
Age of head	Years	315	46.4	10.2	23	78
Education of head	Years	314	7.52	3.51	0	15
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

per unit water is indeterminate, except for the two land quality variables, because the costs of using inputs may be larger than the productivity gains they generate.

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 productivity.

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	−
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	−
Agricultural production inputs	
Land	+ (+/−)[a]
Labor	+ (+/−)
Machines	+ (+/−)
Water	+ (+/−)
Fertilizer	+ (+/−)
Seed	+ (+/−)
Fertility of land (1 = good, 0 = otherwise)	+
Slope of land (1 = flat, 0 = otherwise)	+
Age of head	+ (+/−)
Education of head	+ (+/−)
Agro-ecological zones	
D1 (1 = zone 1, 0 = otherwise)	−
D2 (1 = zone 2, 0 = otherwise)	−

[a] Expected sign in cropping income equation is listed between brackets.

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 productivity are summarized in Table 4.

We use a Cobb–Douglas specification for the agricultural production inputs, with (the logarithms of) land size, labor input, machines value, fertilizer use and seed use expressed per unit water, and dummy variables entering the model in a linear way. For reasons of consistency, we enter the WUA characteristics in a similar way into the model, i.e. using logarithmic transformations for all variables except the dummy variables. Four of the non-dummy explanatory variables, namely share of households with per capita land exceeding twice the average, share of poor households, expenses on guards and education of head, have a number of zero observations. We use the method proposed by Battese (1997) for estimating a model with logarithmic transformations of these variables.

5. Regression Results

As is evident from Eq. (1), we use hierarchical data in the models, with variables varying at two different levels (i.e., household and WUA level). A suitable method to estimate linear models in which the explanatory variables vary at two or more different levels is the random intercept model (Cameron and Trivedi, 2009).

Eq. (1) was estimated for the 315 households in our data set using the random intercept method. Table 5 shows the regression results for each of the two dependent variables. Due to missing data for a number of variables, the sample size for the crop production value equals 302. In addition, we had to drop 30 households with negative crop incomes for the estimation of the crop income equation. This gave us 272 observations for estimating that equation.

The results indicate that *resource characteristics* do not significantly affect water productivity. Both the length of the 2nd level canals and the number of those canals within a WUA do not have a statistically significant impact on the productivity of water among farm households in our sample.[8] Hence, the hypothesis that water productivity is notably higher in smaller water resources, because water misuse is easier to monitor, is rejected for our research area.

[8] High correlations between resource characteristics and group characteristics may potentially affect our findings. The correlation coefficient of length of second-level canals and number of households in a WUA, however, is only 0.05. And the correlation coefficient of number of second-level canals and number of WUGs is 0.10. Likewise, no problematic correlations were found for the other explanatory variables in the model. The correlation matrix can be obtained from the first author upon request.

Table 5
Regression results for water productivity, random intercept model.

	ln(Crop production value/Water)	ln(Cropping income/Water)
Resource characteristics		
ln(Length of 2nd level canals)	−0.052	0.132
	(−0.93)	(1.06)
ln(Number of 2nd level canals)	−0.143	0.105
	(−1.40)	(0.45)
Group characteristics		
ln(Number of households)	−0.275***	−0.735***
	(−2.91)	(−3.35)
ln(Age of WUA leader)	−0.251	1.32**
	(−0.99)	(2.24)
ln(Share of households with per capita land > twice the average)	0.303***	0.533***
	(3.90)	(3.12)
ln(Number of water users groups)	0.409***	0.846***
	(3.27)	(2.91)
ln(Share of poor households)	−0.064	−0.126
	(−1.41)	(−1.19)
Relationship between resource and group characteristics		
ln(Share of households with migrant heads)	0.076*	0.098
	(1.87)	(1.08)
ln(Water demand at current price)	−0.161**	−0.026
	(−2.32)	(−0.17)
Governance		
ln(Expenses on guards)	−0.014	−0.010
	(−0.72)	(−0.23)
Involvement of WUA in cropping decision (1 = yes, 0 = no)	0.204***	0.582***
	(2.93)	(3.62)
External environment		
ln(Share of land planted with marketed crops)	−0.094	−0.432*
	(−0.97)	(−1.89)
Agricultural production inputs		
ln(Land/Water)	0.620***	0.920***
	(6.92)	(4.31)
ln(Labor/Water)	0.004	0.064
	(0.12)	(0.97)
ln(Machines/Water)	0.021	0.052
	(0.53)	(0.59)
ln(Water)	−0.012	0.251**
	(−0.30)	(2.54)
ln(Fertilizer/Water)	0.161***	−0.023
	(2.63)	(−0.16)
ln(Seed/Water)	0.081	−0.047
	(1.63)	(−0.42)
ln(Age of head)	0.032	−0.082
	(0.32)	(−0.36)
ln(Education of head)	−0.004	−0.069
	(−0.13)	(−0.94)
Fertility of land	0.076	0.198*
(1 = good, 0 = otherwise)	(1.60)	(1.82)
Slope of land	0.230**	0.008
(1 = flat, 0 = otherwise)	(2.02)	(0.03)
Agro-ecological zones		
D1	−0.271**	−0.192
(1 = zone 1, 0 = otherwise)	(−2.17)	(−0.69)
D2	−0.366***	−0.130
(1 = zone 2, 0 = otherwise)	(−2.93)	(−0.46)
Intercept	5.62***	2.55
	(5.52)	(1.08)
Number of observations	302	272
Number of WUAs	21	21
R^2 (overall)	0.67	0.37
Wald chi^2	539.86***	141.63***

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

On the other hand, several *group characteristics* are found to play a significant role in achieving water savings. Three 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 hypothesis 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. 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 lower water productivity. 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 productivity. All the three variables that have significant impact on crop production per m^3 water are also found to significantly affect cropping income per m^3 water. Besides these, the age of WUA leader has significantly positive impact on the cropping income per unit water, probably because that relative old leader may receive more respect from member households.

The third group of WUA characteristic that we examine consists of two indicators of the *relationship between resource characteristics and group characteristics*. They are both found to significantly affect crop production value but not the cropping income per unit water. The estimated coefficients are positive for the share of migrant household heads and negative for water demand at the current price. The latter finding provides supporting evidence for the hypothesis that higher water demand may lead to more conflicts among users and hence to fewer water savings. But the hypothesis that smaller resource dependence negatively affects joint action in water management is not supported by the result for share of migrant heads in a WUA. In fact, we find that the share of migrant heads has a significant positive impact on crop production value per unit of water (at a 10% testing level), but not on the cropping income per unit water. These findings suggest that households in WUAs with relatively many migrant heads have higher water productivity because they spend relatively more on productive inputs. In other words, using the terminology of the so-called new economics of labor migration (e.g., Taylor and Martin, 2001), we find evidence of a positive income effect that dominates the negative lost-labor effect of migration plus the negative resource dependency effect outlined above.

There are two *governance* variables in our model. Expenses on guards do not significantly affect water productivity in neither of the two estimated equations. Hence, the two counteracting effects of this variable on water productivity seem to more or less balance each other. For WUA involvement in cropping decisions, we find a significantly positive impact on crop production value and cropping income per unit of water. This finding suggests that jointly decided crop choices lead to higher water productivity than crop choices made by individual households within a WUA.

The last WUA characteristic that we consider in our analysis refers to the *external environment*. The hypothesis that external markets indeed put more pressure on water resources and therefore lead to lower water productivity is not supported by our results, because the estimated coefficient for this variable in the crop production value equation is not significantly different from zero. We do find a significant negative impact of the share of land planted with marketed crops on cropping income per unit water. In other words, these results suggest that households that are relatively more involved in marketed crops can afford to buy more productive inputs, but these inputs do not cause a higher total crop production per unit water.

The regression results for the *control variables* confirm that land size is a crucial determinant of agricultural production in China, given the scarcity of cultivated land. Controlling for other determining factors, crop production per unit water is highest in the highest altitude zone (zone 3). Households living in that zone rely more on rainfall, and hence need less irrigation water than farm households living in the other two zones. Cropping income per unit water, however, is not significantly affected. Hence, households living in zone 3 achieve the higher productivity by spending relatively more on productive inputs.

6. Conclusion

This study examines which characteristics of WUAs play a significant role in promoting water productivity among the households belonging to a WUA in northern 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 total crop production value and cropping income per cubic meter of water.

Previous research on WUAs and performance of user-based water management 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 derived from a comprehensive framework developed by Agrawal (2003). The regression results that we obtain indicate that group characteristics, particularly group size and number of sub-groups, are important factors in water productivity. 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 productivity by allowing more crop diversification and by a better tuning of planting and irrigation decisions among member households. Another group characteristic that affects water productivity in our sample is heterogeneity of land endowments, which is found to have a positive effect on water productivity of member households in a WUA.

Several other factors listed in Agrawal's framework are found to affect water productivity in our research area. In particular we find that a high pressure on the water resource caused by a large unmet water demand negatively affects water savings in crop production, while the share of households with migrant heads in a WUA positively affects the productivity of water use. Another noteworthy result is that we do not find evidence that resource characteristics, i.e., resource size and degree of overlap between the WUA boundaries and natural boundaries, affect water productivity in our research area.

Our findings have important implications for the ongoing water management reforms in northern China in general, and in the middle reaches of the Heihe River in particular. Increasing water productivity is of crucial importance for maintaining food self-sufficiency, a major national-level policy goal in China. And it is also needed to meet the growing water demand from non-agricultural sectors, including the environment. Consequently, it may contribute to achieving food self-sufficiency as well as environmental goals, such as improving the ecological environment in the downstream reaches of north-western China's inland rivers, at the same time.

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 productivity, and thereby simultaneously achieving economic and ecological benefits, if these characteristics are taken into account and, wherever possible, manipulated in appropriate directions.

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