Water, food and markets

Household-level impact of irrigation water policies and institutions in northern China

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1. Introduction

1.1 Background

Water is increasingly becoming a limiting factor for sustainable economic growth and development in many countries. Its allocation has significant impacts on overall economic efficiency, particularly with growing physical scarcity in certain regions (Dinar, 2012). A growing world population and climate change are posing severe challenges to available water resources (Yang et al., 2003; UNWATER, 2007), and the use of water for industrial purposes and domestic consumption is putting more and more pressure on the amount of water available for agricultural production. Because of climatic conditions, rainfed agriculture is very limited, and irrigation plays an important role in the agricultural sector in many countries (Dinar, 2012). Worldwide, irrigated land has increased from 50 mln ha (million hectares) in 1900 to 267 mln ha today, with much of this increase in developing countries (Gleick, 2000).

Water scarcity may become an important constraint on future food production growth, particularly in developing countries (Rosegrant and Cai, 2002; Dinar, 2012). Policies and institutions, which are capable of coping with the rapidly increasing demand for water resources, are crucial for successful adaption of efficient, equitable and sustainable resource use (Binswanger-Mkhize et al., 2010). Governments in different parts of the world apply various types of water policies and institutions aiming at achieving objectives, such as income equality, higher food production, environmental sustainability, and resource conservation. Appropriately implemented policies and institutions can affect decision-making processes and motivate water users to conserve and use water more efficiently for irrigation and other uses (Dinar, 2012).

In China per capita water availability is only one quarter of the world average (Falkenmark et al., 1989). In addition, water resources are distributed unevenly across Chinese regions. Water scarcity is most intense in the north, while water availability in the south is relatively less problematic due to abundant precipitation (World Bank, 2001; Yang et al., 2003; Zhang et al., 2008). Current water availability in the north (757 m^3 per person) is almost 25 percent below the water scarcity threshold, while water availability in the south (3,208 m^3 per person) is relatively abundant (Qu et al., 2011). 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 are grown there (Yang et al., 2003). As much as 75% of crop output in north China is generated from irrigated land (Yang et al., 2003).

During the last few decades, Chinese irrigation water institutions have undergone a number of important changes. Before the agrarian reforms in China in the late 1970s, irrigation water resources were managed primarily through collective ownership arrangements. Since then, a variety of institutional arrangements have been established to govern irrigation water. They involve the introduction of market-oriented instruments as well as institutional innovations such as water pricing, the introduction of water users associations (WUAs) (Qu et al., 2011), and contracting out of irrigation canal management to individuals (Wang et al., 2010).

Evaluation of the impacts of policies and institutions on environmental and economic outcomes in the context of agricultural water resource management is important for effective water policy decision making, planning and management (OECD, 2010). While the economic impacts of policies and institutions regarding irrigation water use have gained increasing attention in the existing international literature, most economic analyses focus on the effects of different pricing schemes on farmers' choice of crops, income redistribution, and water use efficiency (Tsur and Dinar, 1997; Johansson, 2000; Johansson et al., 2002; Dinar and Mody, 2004; Tsur et al., 2004; Liao et al., 2008). Quantitative analyses of structural policies and institutional change in irrigation water management (e.g. WUAs, water markets) are scanty due to limited data availability.

The case of north China may provide a fertile soil for research on irrigation policies and institutions, given the fast growth rates of the Chinese economy, the limited availability of water and land resources, and the process of economic and institutional transformation that the country is going through. Research is needed in particular at the household level, given that it is the basic level at which cropping and water use decisions are taken. Moreover, agricultural water management policies and institutions are developed at different layers of governments and may have inconsistent effects on farmers' decisions that often are difficult to disentangle.

1.2 Objective and research questions

The general objective of this study is to empirically investigate household-level effects of some major recent institutional changes and policies affecting irrigation water use in north China.

To reach this objective, the study aims at answering the following four specific research questions:

1. Regarding user-based water management (Chapter 2):

To what extent do differences in WUA characteristics affect the productivity of irrigation water use by WUA member households?

2. Regarding a government intervention directly affecting availability of water for different crops (Chapter 3):

What is the impact of the water allocation intervention on farmers' crop planting decisions?

3. Regarding valuation of irrigation water (Chapter 4):

a. What is the economic valuation (i.e. marginal value) of irrigation water for different crops?

b. How does the introduction of the water allocation intervention (Chapter 3) influence the valuation of irrigation water for various crops?

4. Regarding water trading (Chapter 5):

a. What is the impact of output market development on irrigation water trading?

b. What factors impede the functioning of water markets?

1.3 Data and Methodology

1.3.1 Research area and data collection

The information used for the empirical analyses in this study largely comes from two surveys that were carried out in Minle County, Zhangye City, Gansu Province in northern China in May 2008 and May 2010, covering information for the years 2007 and 2009.

In early 2002, the Ministry of Water Resources initiated a pilot project "Building a Water-saving Society in Zhangye City", the first project of its type in the country. One major aim of the project was to establish a new water use rights (WUR) system with tradable water quotas and to reallocate and use resources efficiently through market-based instruments

(Zhang et al., 2009). Pilot projects typically take place within a limited scope. In case of failure it would be stopped, in case of success it would be extended to larger scale (Malik, 2012). Therefore, examining the effects of different policy measures regarding water resource management in Zhangye City is of great importance for the Chinese government to decide whether or not to implement the policies in other regions.

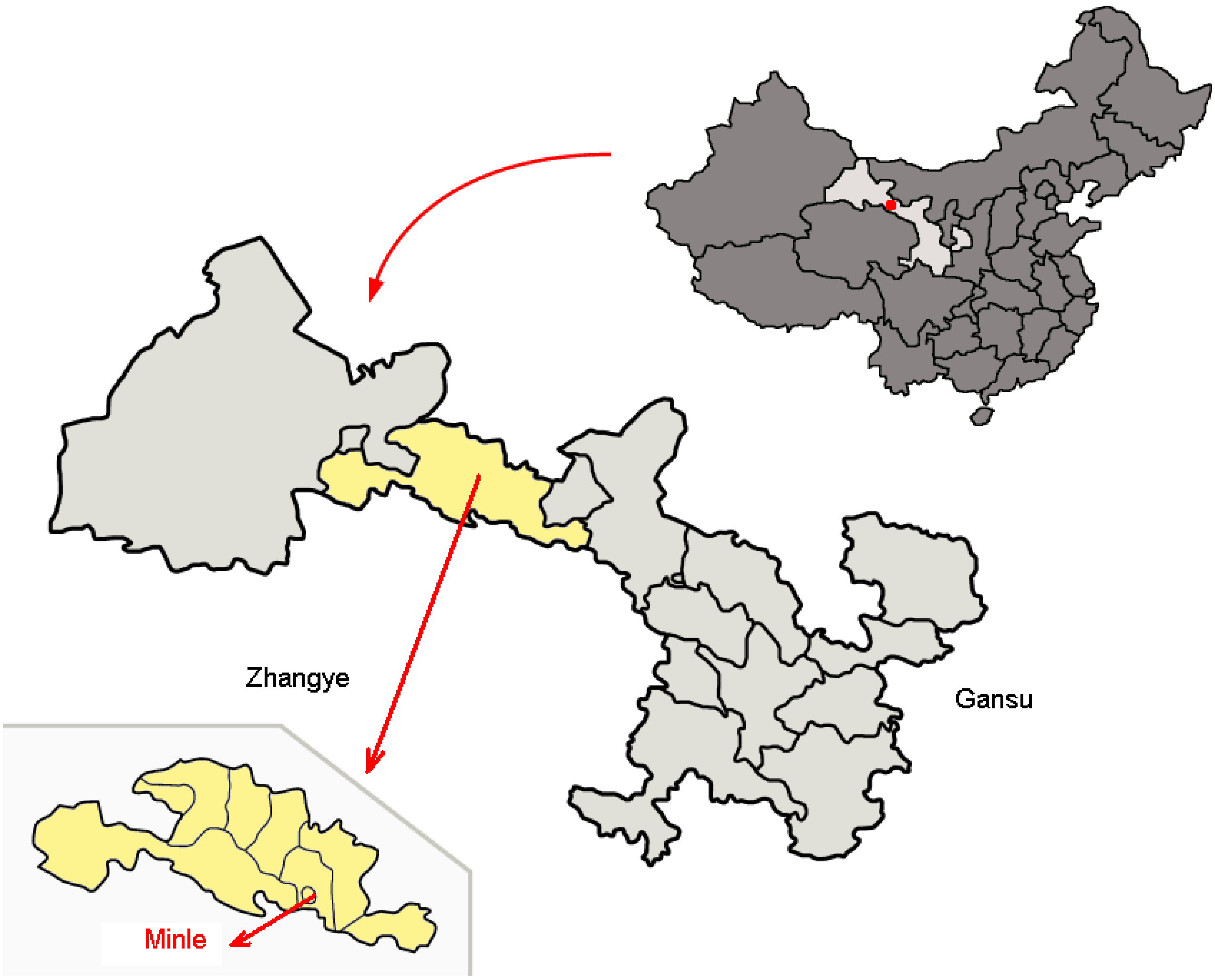
Moreover, one of the six counties in Zhangye City, Minle County (see Figure 1.1 for its location), has become involved in the international market of potato production with high water requirement, since the entry of a Dutch potato processing company in this region in 2008. To meet the growing demand for potatoes of the Dutch potato processing company as well as two local potato processing companies, the government assigned water allocation priority for potato production, in order to stimulate the potato growing in this area. The entry of the new company provides a good opportunity to examine the impact of output market development – as an external driving factor of institutional change – on the performance of irrigation water institutions.

Household interviews were done in 21 villages and WUAs, 15 households per village / WUA, giving us a dataset containing 315 observations[1] (see Wachong Castro et al., 2010 for a description of the sampling method). Where possible, the same households that were interviewed in 2008 were also interviewed in May 2010. In cases where the same household could not be found, it was replaced by another, randomly selected, household in the same village. This resulted in a panel dataset containing 265 households. It includes information about crop production, use of water and other inputs, water trading, WUA participation, water and other prices, land tenure and land use, and so on. But due to data limitations, for some of

[1] In two villages, 16 instead of 15 households were interviewed in May 2008. The last observation in these two villages was included in panel dataset containing 265 households.

the analyses only the cross-section data set for the year 2009, collected in May 2010, could be used.

Figure 1.1: Location of Minle County, Zhangye City, and Gansu Province, People's Republic of China



Source: Adapted from http://en.wikipedia.org/wiki/File:Location_of_Zhangye_Prefecture_within_Gansu_(China).png

1.3.2 Methodologies

Chapter 2 applies a random intercept regression model to the data set covering information over the year 2009. It involves information about 21 WUAs and 315 households in the research area. As the dependent variable in the models, two different measures of water productivity are used, namely total crop production value and household income from crop production, both expressed per m^3 of water. Explanatory variables in the analysis are derived from an established user-based resource governance framework, and are measured at the WUA level. As we use hierarchical data in the models with variables varying at two different levels (i.e. WUA and household levels), a random intercept method is applied for the estimation.

Chapter 3 estimates a system of unconditional crop acreage demands (i.e. four crop-specific functions) based on data collected during the two rounds of the farm household survey held in Minle County. The dependent variables are the shares of land allocated to four different groups of crops. Explanatory variables cover prices of variable inputs, levels of quasi-fixed inputs, prices of outputs, and an indicator measuring the water allocation intervention. The Seemingly Unrelated Regressions Estimator (SURE) approach is applied for estimating the model, as it allows to properly account for correlation in error terms between the four equations and to apply cross-equation restrictions imposed by theory.

In Chapter 4, a system of production functions for the same four groups of crops (Chapter 3) is developed to examine the economic value of irrigation water for the years 2007 and 2009, respectively. Based on initial tests of functional forms, a translog function is applied for the estimation, using the same datasets as in Chapter 3. First, a system of production functions is estimated econometrically to examine the marginal productivity of irrigation water. Second, the internal valuation (i.e. marginal value) of irrigation water is derived by multiplying the resulting marginal productivities with the (average) prices of the four crop groups.

In Chapter 5, a case study approach is used to examine the impact of output market development on changes in water trading between the years 2007 and 2009. In the year 2008 a large-scale potato processing company was established in the research area that mainly uses potatoes grown within the same region. The case study analysis builds on the survey data for two years and on insights gained through informal field visits to the area. Due to the limited number of households that trade water, the analysis does not rely on econometric methods. Instead, descriptive statistics and statistical tests are presented to examine differences between water traders and non-traders and the factors that drive and limit water trading.

2. Water users associations and irrigation water productivity in northern China[2]

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 water savings 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 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.

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[2] This chapter is based on an article submitted to *Ecological Economics* in June 2012, as Lei Zhang, Nico Heerink, Liesbeth Dries and Xiaoping Shi "Water users associations and irrigation water productivity in northern China" (Revised version).

2.1 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, 2012; Calow et al., 2009).

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 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 61.7 mln. ha. in 2011 (World Bank, 2006; NBS, 2012). 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 (World Bank, 2006; NBS, 2012).

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: (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 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 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 rigorous 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 aims to examine the conditions for successful user-based management of irrigation water in northern China, based on a framework of sustainable governance of common-pool resources presented by Agrawal (2003). 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.

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 2.3 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 2.4, 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 2.5. The final section summarizes the main findings and discusses their implications for the ongoing water management reforms in northern China.

2.2 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 Ministry of Water Resources (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 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[3], 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.

[3] 15 mu equals one hectare.

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[4] (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

[4] 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.

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.

2.3 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.[5]

[5] 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).

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 2.1). We expect that water productivity is higher in WUAs with a smaller size, as measured by the length of their 2nd level canals, because water use is easier to monitor in relatively small resource systems (Ostrom, 2009; Agrawal, 2003).

- *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 four, 2nd level canals (see Table 2.1). 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.

Table 2.1: 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

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 2.1). 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. According to Agrawal (2003), appropriate leadership requires that the group leader is young, familiar with changing external environments, connected to local traditional elite. Among these our dataset only includes information about the age of WUA leader, which is used as an indicator of group leadership in the analysis. It ranges from 35 to 59 in our sample, with a mean value of 46. Although young leaders may be more familiar with changing external circumstances, relatively old leaders may receive more respect from member households and therefore be able to establish more efficient rules. 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[6] 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*

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

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 2.1).

- *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 productivity.

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%.[7] We expect that WUAs with a higher share of migrating household heads have lower water productivity.

- *Level of demand*

High levels of user demand 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 5,720 m^3. The impact of this variable on water productivity is indeterminate.

Governance [8]

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 2.2). 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

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

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 2.1). 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 household 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 2.1).

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. Our data set allows us to include one external factor in the analysis.

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%.

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 2.3. 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[9], 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 a regression with household cropping income per m^3 of water as dependent variable.

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

Table 2.2: 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

Table 2.2 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 in the model to control for differences in water productivity caused by conventional factors. This gives the following specification for the regression model:

$$WP_{ij} = f(W_j, F_{ij}, D_{ij}) + \varepsilon_{ij} \quad \text{for i= 1,...,315, j= 1,...,21} \qquad (2.1)$$

Where:

WPij = Water productivity for household i in WUA j ;

Wj = Set of 12 WUA characteristics for WUA j ;

Fij = Set of 10 agricultural production inputs for household i in WUA j;

Dj= Set of two agro-ecological zone dummies for WUA j;

ε_{ij} = Random disturbance terms with standard properties.

As specified in from equation (2.1), we use hierarchical data in the model, with WUA characteristics and agro-ecological dummies varying between WUAs, but not within WUAs, and production inputs varying at the household 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). We assume that the problem of reverse causality is negligible for the characteristics in the model, because the model is estimated from household data. The WUAs in the research area consist on average of 276 households, so if the water productivity of an individual household would affect one of the characteristics of the WUA to which it belongs, its impact will be very small.

Descriptive statistics of the 12 WUA characteristics, and the expected impact of each indicator on water productivity, were discussed in Section 2.3. 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 2.3: 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
Labour	days	310	145	126	6.0	862
Machines	RMB	310	1026	755	45	4680
Water	m3	308	8880	6409	544	42800
Fertilizer	jin	312	3872	2534	360	15312
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

Besides cultivated land size, labour 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 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 2.2). 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 2.4: 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	+ (+/-)[1]
Labour	+ (+/-)
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)	–

[1]: 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 2.3) and control variables (discussed in the current section) on water productivity are summarised in Table 2.4.

We use a Cobb-Douglas specification for the agricultural production inputs, with (the logarithms of) land size, labour 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.

2.5 Regression results

Equation (2.1) was estimated for the 315 households in our data set using the random intercept method. Table 2.5 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 dropped 30 households with negative crop incomes for the estimation of the crop income equation. This gave us 272 observations for estimating that equation.

Table 2.5: 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 (-0.93)	0.132 (1.06)
ln(Number of 2nd level canals)	-0.143	0.105

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

R^2 (overall)	0.67	0.37
Wald chi2	539.86***	141.63 ***

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

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[10]. 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.

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. However, households in WUAs with a relatively large number of WUGs may

[10] 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.

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. A fourth group characteristic, the age of WUA leader, is found to have a significantly positive impact on cropping income per unit water, but not on total crop value per unit water. This result indicates that households in WUAs with more experienced and respected heads do not manage to save more water per unit output, but do manage to save on the other inputs that are used in producing crops.

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-percent 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 their diversified income sources allow them to take more risks and because they spend relatively more on productive inputs. In other words, using the terminology of the so-called new economics of labour migration (e.g. Taylor and Martin, 2001), we find some evidence of positive insurance and income effects that dominate the negative lost-labour 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 put more pressure on water resources and therefore lead to lower water productivity is not supported by our results. The estimated coefficient for the share of land planted with marketed crops is not significantly different from zero in the equation for crop production value per unit water. The same variable, however, is found to have a significantly negative impact in the equation explaining cropping income per unit water. In other words, these results suggest that households belonging to WUAs that are relatively more involved in marketed crops tend to buy more expensive inputs which negatively affect the cropping income, but these inputs do not affect 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.

2.6 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. 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.

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 possibly even farm income levels, if these characteristics are taken into account and, wherever possible, manipulated in appropriate directions.

Appendix 2A

Correlation matrix (1): WUA characteristics

	1	2	3	4	5	6	7	8	9	10	11	12
1. Length of 2nd level canals	1.00	-0.07	0.05	0.12	-0.00	0.04	-0.01	-0.05	-0.08	-0.02	0.08	-0.01
2. Number of 2nd level canals	-0.07	1.00	0.27	0.15	0.53	0.10	-0.07	0.20	-0.29	-0.27	0.43	0.62
3. Number of households	0.05	0.27	1.00	0.22	0.12	0.38	0.04	-0.47	-0.25	-0.21	0.27	0.12
4. Age of WUA leader	0.12	0.15	0.22	1.00	-0.15	0.29	0.07	0.33	-0.35	-0.14	0.09	0.19
5. Share of households with per capita land > twice the average	-0.00	0.53	0.12	-0.15	1.00	-0.11	-0.05	-0.18	0.10	-0.11	0.33	0.43
6. Number of water user groups	0.04	0.10	0.38	0.29	-0.11	1.00	0.22	-0.35	-0.18	-0.01	0.02	0.15
7. Share of poor households	-0.01	-0.07	0.04	-0.07	-0.05	0.22	1.00	0.15	0.04	-0.22	-0.15	-0.24
8. Share of households with migrant heads	-0.05	0.20	-0.47	0.33	-0.18	-0.35	0.15	1.00	0.05	0.14	-0.16	-0.07
9. Water demand at current price	-0.08	-0.29	-0.25	-0.35	0.10	-0.18	0.04	0.05	1.00	0.41	-0.15	-0.14
10. Expenses on guards	-0.02	-0.27	-0.21	-0.14	-0.11	-0.01	-0.22	0.14	0.41	1.00	-0.15	-0.14
11. Involvement of WUA in cropping decision	0.08	0.43	0.27	0.09	0.33	0.02	-0.15	-0.16	-0.15	-0.15	1.00	0.19
12. Share of land planted with marketed crops	-0.01	0.62	0.12	0.19	0.43	0.15	-0.24	-0.07	-0.14	-0.14	0.19	1.00

Correlation matrix (2): WUA characteristics and input variables

	Seed	fertilizer	labour	machine	land	water
Length of 2nd level canals	0.04	0.01	0.06	0.12	0.08	-0.07
Number of 2nd level canals	-0.00	-0.22	-0.03	-0.15	-0.32	-0.09
Number of households	0.16	0.07	0.08	0.11	0.12	-0.30
Age of WUA leader	0.28	-0.17	-0.03	-0.11	-0.26	-0.19
Share of households with per capita land > twice the average	-0.09	-0.20	-0.05	-0.18	-0.16	0.06
Number of water user groups	0.14	-0.02	0.04	0.03	-0.04	-0.17
Share of poor households	-0.15	-0.22	0.03	-0.04	-0.09	0.01
Share of households with migrant heads	-0.05	-0.25	-0.01	-0.11	-0.27	0.02
Water demand at current price	-0.22	-0.11	-0.09	-0.17	-0.19	0.43
Expenses on guards	0.02	0.15	-0.01	0.07	0.07	-0.02
Involvement of WUA in cropping decision	0.05	0.03	-0.04	-0.12	-0.12	-0.02
Share of land planted with marketed crops	0.07	-0.23	-0.04	-0.25	-0.33	0.06

3. Impact of water allocation interventions on farmers' cropping decisions[11]

Abstract:

This article aims to provide more insights into the impact of government interventions on farmers' production decisions. Specifically, we analyse the effects of assigning more irrigation water to a newly introduced cash crop on farmers' cropping decisions. By aggregating crops into four groups, we estimate a system of unconditional crop acreage demand functions from data that were collected during two rounds of a farm household survey held in an arid region in northern China. We find that the water priority given to the cash crop (Atlantic potatoes) does not affect the land allocated to that crop, because its planting decisions are mainly taken by village leaders instead of households. Instead, the intervention results in a shift from planting local potato varieties towards grains with relatively low water requirements.

[11] This chapter is based on an article submitted to *Land Economics* in May 2013, as Lei Zhang, Thomas Herzfeld, Nico Heerink and Xiaoping Shi "Impact of water allocation interventions on farmers' cropping decisions" (under review).

3.1 Introduction

Governments frequently interfere in agricultural production in order to achieve goals such as food self-sufficiency, income equality, and so on. Research on the effects of agricultural policy interventions is under increasing scrutiny and may be used, in some settings, for prescribing policies (Alston and James, 2002). The available literature on domestic commodity policy instruments focuses mainly on price interventions (subsidies) and on supply control policies (output or input quotas). In their review of agricultural policies, Alston and James (2002) conclude that considerable progress has been made in theoretical models that help to analyse the effects of agricultural policies, but that real-world policies frequently deviate from common theoretical generalizations and that empirical studies often misrepresent the market conditions under which a policy is applied. More meaningful empirical analysis requires, in their view, better measures of the conditions of supply of different factors of production in particular industries as well as more realistic representations of policy instruments.

One important factor of production in agriculture is water. The use of water for industrial purposes and domestic consumption is putting more and more pressure on the amount of water available for agricultural production in many countries (Dinar, 2012). As a result, governments in different parts of the world apply various types of water policies aiming at achieving objectives such as income equality, higher food production, environmental sustainability, and resource conservation.

The most frequently used water policies relate to price interventions. The effects of such policies are still under debate. For instance, Tsur et al. (2004) find that water prices have a small effect on income distribution within the farming sector in South Africa, Turkey and

Morocco, and conclude from this evidence that water pricing should be designed primarily to increase the efficiency of water use. On the other hand, Liao et al. (2008) conclude from three case studies for China that increasing the water price to fully recover supply cost may seriously affect grain production and farmers' income.

Available studies regarding supply control policies of water mainly focus on the institutions that are used for allocating water. Much attention is paid in the literature to the roles of water users associations (e.g. Phadnis and Kulshrestha, 2012; Wang et al., 2005) and water markets (e.g. Garrido, 2007; Zhang et al., 2009) in stimulating more efficient water use. The consequences of direct government interventions in the allocation of irrigation water, on the other hand, have received little attention in the literature so far.

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). In addition, water resources are distributed unevenly across Chinese regions. Whereas water scarcity is a major problem in the north, it is less problematic in the south due to abundant precipitation (World Bank 2001; Yang et al., 2003). In response to the growing water scarcity, farmers in the north increasingly resort to water-saving irrigation systems and cultivation methods, and to the cultivation of water-saving crops. On the other hand, policy interventions like the promotion of cash crop production may conflict with the goal of saving irrigation water. When cash crops are relatively water-intensive, as is frequently the case, such policy interventions may negatively affect the availability of irrigation water for, and hence the yields of, other crops.

Facing the more and more serious challenges regarding water resources, the Chinese government has increasingly used policy interventions to reach the goal related to water resource use. Adjusting crop pattern is regarded as a useful method to achieve water saving.

Water consuming crops should be limited at areas with water shortage and, it should be encouraged to grow crops with low consuming less water but with high added value (e.g. Gu, 2001). As direct support of specific crops is impossible due to the WTO agreements, government tends to affect farmers' cropping choices through intervening in the input markets. Effects of relevant policies are however rarely analysed in the existing literature. Our study aims to provide an empirical analysis of the effect of a government intervention in irrigation water supply on farm household cropping decisions in north China. To this end we perform a case study of a government intervention in irrigation water allocation aimed at promoting a newly introduced cash crop, and examine the impact of this policy on farmers' cropping decisions. We use the share of land planted with different crops as the dependent variable. Land allocation decisions of smallholder farmers are thought to be more subject to farmer's control than crop output (Rao, 1989) and have therefore interested researchers and policy makers for decades (e.g. Just and Zilberman, 1983; Chibwana et al., 2011).

This paper contributes to the available literature by performing an empirical analysis of an existing government intervention in the supply of a major agricultural production factor, irrigation water, on farm households' cropping decisions. As argued by Alston and James (2002), there is an urgent need for empirical studies that are based on realistic representations of actual policy instruments in order to provide better empirical estimates of the relevant commodity supply elasticities. Additionally, compared to the standard partial equilibrium analysis used in many studies of the effects of agricultural policy interventions, our study covers the whole cropping part of the farm household and includes indirect effects of the policy intervention on other crops than the intervention crop.

The remainder of this article is organized as follows. The following section derives a set of unconditional land demand functions, which will be estimated econometrically, from an established farm production behavioural model. Next, we describe the study area and the data underlying the econometric analysis. Subsequently, in section 3.4, we present and discuss the econometric results. The final section summarizes the main results of the empirical analysis and provides some policy recommendations.

3.2 Conceptual framework

A farmer's decision of allocating total land to various crops can be modelled basically in three different ways (Arnberg and Hansen, 2012; Moore et al., 1994). Deterministic linear programming optimizing models of the agricultural production system, such as Amir and Fisher (2000), can be used to analyse the system's response to changes in input and output amounts and prices. Such programming models, however, lack a theory-based behavioural model. Specifically, it lacks a behavioural model based on microeconomic theory besides the underlying maximisation of the objective function. Therefore, statistical estimation and validation of the model are impossible[12]. Among the approaches based on neoclassical producer theory, two strands can be distinguished. Models assuming input jointness assign inputs to all crops. For a multi-crop farm with apparent jointness, input use on one crop depends on land allocation to the crop itself as well as acreage of other crops. Such an approach does not allow for a specific analysis of substitution in input use between crops. Alternatively, Moore et al. (1994) and Gorddard (2009) assign all inputs except one quasi-fixed but allocatable input (e.g. land) to individual crops. Input non-jointness is assumed, so that the multi-output function decomposes into the sum of distinct crop-specific functions. This approach has the advantage that interdependences across crops can be accounted for explicitly in the model. Given that output and variable input markets in China can be considered highly integrated (Huang and Rozelle, 2006; Park et al., 2002; Qiao et al., 2003),

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[12] Heckelei and Wolff (2003) discuss the different methods in detail.

we assume that input use of one crop is based on land allocation to the crop itself, while being independent of the land allocation to other crops. Therefore, in this study we follow the non-jointness approach.

Each farmer is assumed to behave rationally and to be risk-neutral. We assume the farmer to maximise profits by deciding how much input to use including the acreage allocated to the different crops. At the optimum the well-known condition of equality of the value of marginal product and input price should hold for all inputs and all crops.

Governments frequently intervene in farm production decisions by providing input subsidies (e.g. Chibwana et al., 2011) or supporting farm output prices (e.g. Floyd, 1965). Input subsidies may encourage farmers to concentrate on a few crops only, as has been the case in Malawi (Chibwana et al., 2011; Harrigan, 2008). Any policy which favours one selected output or input exclusively comes at the cost of reduced diversification and might reduce the household's resilience with respect to production risks.

In our case, giving priority in irrigation water allocation to one specific crop implies an indirect subsidy of the use of water on that crop and an indirect taxation of water applied in alternative uses. To quantify this effect we analyse the allocation of land to the different crops. That is, based on the assumption of profit maximisation, the farmer decides how much land to allocate to output *j*. The resulting unconditional input demand function for land x^{A}_{j} can be established as:

$$x^{A}_{ij} = f(\mathbf{p}, \mathbf{w}, \mathbf{z}); \qquad (3.1)$$

Where $i = 1, ..., N$ refers to households; p refers prices of outputs, w refers to prices of variable inputs, and z refers to levels of quasi-fixed inputs.

Dividing each equation by total area (x_i^A) returns unconditional land demand as a system of land share equations and normalised exogenous variables $\mathbf{p}^*$, $\mathbf{w}^*$, $\mathbf{z}^*$:

$$s_{ij} = x^{A}_{ij}/x^{A} = f(\mathbf{p}^*, \mathbf{w}^*, \mathbf{z}^*) \quad (3.2)$$

The unconditional input demand function can be established as:

$$s_{ij} = \beta_0 + \Sigma_k \beta_{Ak} w^*_{ik} + \Sigma_l \beta_{Al} p^*_{il} + \Sigma_t \beta_{At} z^*_{it} \quad (3.3)$$

The β's refers to unknown parameters to be estimated; *i*, *j*, *w*, *p* and *z* as defined in (3.1).

For the purpose of our study, we are especially interested in the effects of the government intervention in irrigation water supply on farmers' land allocation among different crops. To estimate this, a variable referring to the water allocation intervention is included in the model (more details will be explained in Section 3.4).

3.3 Research area and data collection

Located in one of the driest zones in the world, Zhangye City is an oasis mainly watered by the Heihe River. It is 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 the evaporation is high. But due to the availability of irrigation water from the Heihe River and from reservoirs in the mountains, the area has become a major grain and vegetables production base in Gansu province.

In Zhangye City, water demand is increasing due to the growing population and expanding economy, with variable water demands from different users, regions and industrial sectors. Therefore, water reallocation is a difficult and sensitive issue (Zhang et al., 2009). The Ministry of Water Resources initiated a pilot project called 'Building a Water-saving Society in Zhangye City' in 2002. This project, which is the first of its type in the country, was designed to save water through government investments in a water-saving irrigation system and through establishing a system of water use rights (WUR) 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).

In this paper, we focus on Minle County, one of the six counties in Zhangye City. Agriculture is the biggest consumer of water, taking 88.1% of total water resources.[13] 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 depth of groundwater in this region, pumping water from the wells generates high costs. Thus the use of groundwater is less than 5 % of total water use in irrigated agriculture[14]. 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, decide the water allocations to water users associations (WUAs) within their own irrigation area. WUAs are responsible for arranging the water distribution to households belonging to their own WUA. WUAs 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.

The policy change regarding water allocation has been caused by the entry of a large potato processor in this region which is partly owned by the regional government[15]. The potato processing company entered in 2008 and demands Atlantic potatoes for processing into flakes and starch. In order to meet the growing demand for Atlantic potatoes with high

[13] Water Management Bureau of Minle County, Gansu Province, P.R. China (2007).
[14] The information was provided by Water Bureau of Minle County.
[15] The Government of Minle County owns 51% of the joint venture, and the Dutch company owns the other 49%.

water requirements, the local government assigned water allocation priority for Atlantic potato growing to stimulate its production in this area.

In general, two factors determine water allocation by the WMBs. First a standard water allocation quota is allocated to the so-called WUR land of the WUAs within the irrigation area in question. Not all the irrigated land is classified as WUR land. Its size depends on the labour provided by a village to the construction of the reservoir and some other factors, like the WUR land obtained through auctions. Then, based on the actual availability of water within a reservoir, a certain percentage of the water quota is actually distributed to the WUAs within the irrigation area. Before the government intervention in water allocation, the percentage of water quota that was distributed within an irrigation area was the same for all crops. As a result of the intervention that started in 2009, the percentage of the water quota allocated to Atlantic potatoes is larger than that is allocated to other crops, but differs between the different irrigation areas. The percentages of water quota are determined by the WMBs at the level of irrigation areas, and hence are exogenous from farmers' behaviours.

The household survey data used in this study were collected in May 2008 and May 2010 by staff and students from Gansu Academy of Social Sciences in Lanzhou, Gansu Agricultural University in Lanzhou, and Nanjing Agricultural University. The surveys covered the years 2007 and 2009, respectively. The resulting data set contains information about land use, crop production, input use, prices of water and other inputs, WUA participation, land tenure and related information. To ensure that all townships would be equally represented in the year 2007 survey, the population in Minle County was stratified into ten townships. Next, 10 percent of the villages in each stratum were randomly selected, giving 21 villages. In each of the 21 selected villages, 15 households were randomly selected to be interviewed. This gave us a dataset containing 315 observations[16] (see Wachong Castro et al., 2010 for a more detailed description of the sampling method). Two years later, the same households were interviewed again whenever possible.[17] This resulted in a two-year balanced panel dataset containing 265 households. Six households among them rented out all their land to other households and worked off-farm either in 2007 or in 2009. These six households were excluded. Additionally, households that had missing data on one or more variables or reported outliers[18] were excluded from the sample. As a result, we use a sample of 248 observations (households) with information covering the years 2007 and 2009 for our empirical analysis.

The WMBs of the five irrigation areas in Minle County were interviewed in August 2010 in order to obtain more insight into the institutional setting of irrigation water allocation. One of the questions asked during these interviews was the water allocation to Atlantic potatoes and other crops within their irrigation areas. The variable representing the water allocation intervention in our empirical analysis is derived from that information.

3.4 Data analysis and results

All crops relevant for our analysis have been assigned to four groups[19]: grain crops (barley, wheat and maize), cash crops[20] (sesame, rapeseed and garlic), Atlantic potatoes and other potatoes (various local varieties).

The unconditional input demand function can be specified as equation (3.4):

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[16] In two villages, 16 instead of 15 households were interviewed in May 2008. The last observation in these two villages was dropped from the sample so that we have 15 households in each village in each survey.
[17] In cases were the same household could not be found, it was replaced by another, randomly selected, household in the same village. These households, however, are not included in the panel dataset that we use for this study.
[18] Here we define outliers as households with large changes (>50%) in area shares of any of the four crops between the two years.
[19] Minor crops (e.g. peas, Chinese medicine, vegetables etc.) are not included in this analysis.
[20] Atlantic potatoes are excluded from the group termed 'cash crops' in our analysis.

$$S_{ij} = \beta_0 + \sum_k \beta_{kj} w^*_{kij} + \sum_t \beta_{tj} z^*_{tij} + \sum_j \beta_j p^*_{ij} + \sum_h \beta_j H_{hi} + \beta_w WA + \varepsilon_{ij} \quad (3.4)$$

Where:

w^*_{kij} refers to prices of variable input k (k=1, ..., 4) for household i (i=1, ..., 248) and output j (j=1, ..., 4);

z^*_{tij} refers to levels of quasi-fixed input t (t=1, 2) for household i (i=1, ..., 248) and output j (j=1, ..., 4);

p^*_{ij} refers to prices of output j for household i (i=1, ..., 248);

H_{hi} refers to the value of household and farm characteristic h (h=1, ..., 6) for household i (i=1, ..., 248);

WA is a variable measuring the water allocation intervention and is derived at the level of irrigation areas[21];

The β's refers to unknown parameters to be estimated;

ε_{ij} = Disturbance terms with standard properties.

We estimate the system of land share equations, by taking first differences between 2007 and 2009. Seemingly Unrelated Regressions Estimator (SURE) is used for the estimation. The estimator allows to properly account for correlation in error terms between the four equations and to apply cross-equation restrictions imposed by the theory.[22]

A first investigation of the collected data revealed that the total cultivated land per household remained almost constant between the two survey years. It declined from 15.42 mu[23] in 2007 to 15.34 mu in 2009. But for some households in our sample the cultivated land area changed considerably between the two years due to the renting in or out of land. We therefore apply area shares rather than absolute areas planted with each crop as dependent variables in the crop-specific production functions.

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[21] See detailed explanation in section 3.4.

[22] An alternative approach involves the estimation of a multinomial logit model. However, imposition of cross-equation restrictions is impossible for that method.

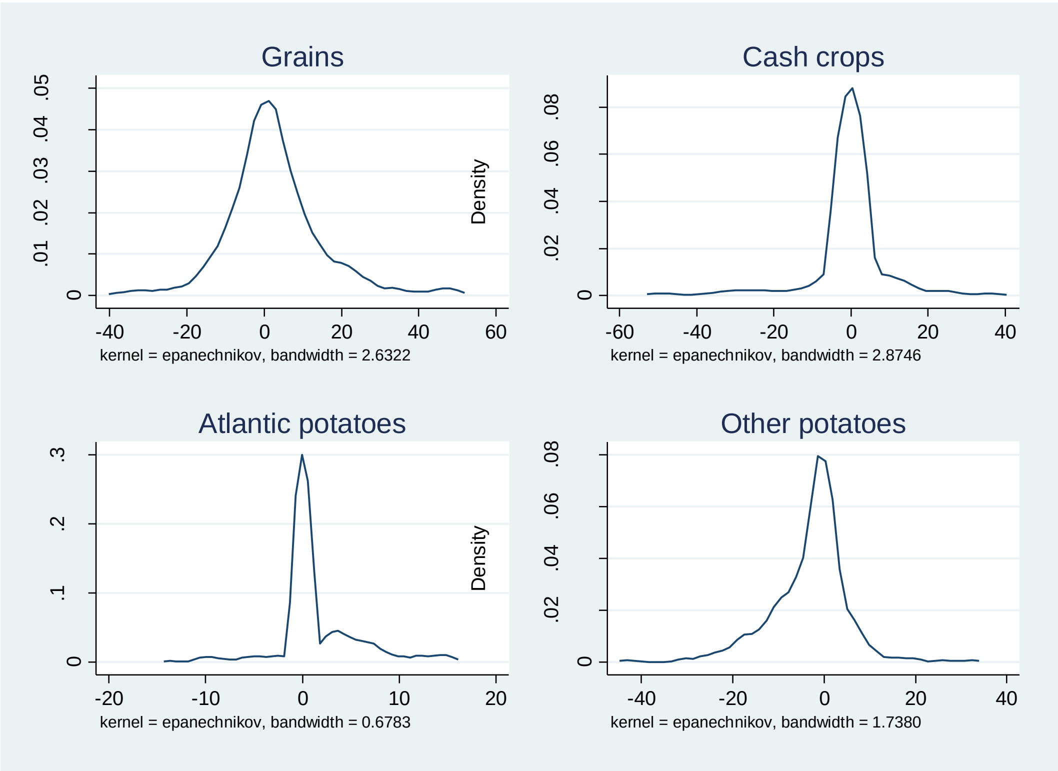
[23] 15 mu equals one hectare.

Table 3.1: Crop-specific area shares, 2007 and 2009

Crop	2007		2009		Change 2007-2009 (%)
	Mean (%)	Std. Dev.	Mean (%)	Std. Dev.	
Grains	80.6	20.4	83.1	22.5	2.54
Cash crops	10.3	20.8	9.80	23.4	-0.48
Atlantic potatoes	0.62	2.51	1.69	3.49	1.07
Other potatoes	8.51	9.62	5.38	7.20	-3.13

Table 3.1 displays the changes in average shares of land allocated to different crops from 2007 to 2009. The distribution of these changes, derived by using Kernel Density estimation, is shown in Figure 3.1.

Figure 3.1: Distribution of changes in land shares between 2007 and 2009, Kernel Density estimation



Grains are by far the most popular crop grown by farmers in the region. The share of land planted with grains increased by 2.54 percentage points between the two survey years. The areas planted with cash crops and other potatoes declined between the two years, with 0.48 and 3.13 percentage points respectively, while the area planted with Atlantic potatoes increased by 1.07 percentage points.[24] The average percentage of land planted with Atlantic potatoes is relatively small even in the year 2009 (1.69%), partly because that potatoes require some rotation due to phytosanitary reasons, and their land share is limited in practice. Moreover, given the constraint explained above, land is competitive between Atlantic potatoes and other potatoes, which further restricts the share of land planted with Atlantic potatoes.

Especially noteworthy is also that the spread in area changes is much larger for grains and other potatoes than for cash crops and, especially, Atlantic potatoes (see Figure 3.1). This reflects the fact that decisions about cash crop contract farming in Minle County, as in many other parts of China, are taken at the local government level with little autonomy in decision making for individual households.

Based on equation (3.4), we explain a household's area share planted with a specific crop group from the prices of variable inputs, the levels of quasi-fixed inputs and the prices of outputs. For the purpose of our analysis we add a variable representing the government intervention in water allocation, namely the ratio of the percentage of the water quota allocated to Atlantic potatoes to the percentage of the water quota allocated to other crops[25]. A higher value of this variable indicates that Atlantic potatoes receive a higher priority in the allocation of irrigation water. Two hypotheses will be tested in the empirical analysis. **First**,

[24] Although the potato processing company became operational in 2008, some farmers already planted Atlantic potatoes in 2007 and delivered them to the storage facility of the company.

[25] As explained in section 3.3, the percentages of water quota allocated to Atlantic potatoes and other crops, and the resulting ratio between them is decided by the WMBs at the level of irrigation areas. They are supposed to be exogenous from decisions at the farm household level.

the intervention results in an increase in land allocated to Atlantic potatoes and a decrease in land allocated to the other crops. **Second**, among the alternative crops (i.e. other crops than Atlantic potatoes), the intervention is expected to cause a stronger response among cash crops and other potatoes than among grains, because grains are mainly grown for home consumption.

Another policy variable that we include in our model is the amount of grain subsidies per mu of land received by a household. Finally, six household and farm characteristics that are expected to affect acreage allocation among crops are added as control factors to the regression equations. The exact definitions of all explanatory variables are presented in Table 3.2.

Table 3.2: Definitions of explanatory variables

Variable	Definition	Unit
	Prices of variable inputs	
Hired labour	Price of hired labour	RMB/hour
Water	Price of irrigation water	RMB/m^3
Seeds	Price of seeds	RMB/jin
Fertilizer	Price of chemical fertilizer	RMB/jin
	Levels of quasi-fixed inputs	
Labour	Amount of own labour and exchanged labour per mu land	Days/mu
Machinery	Amount of money spent on own and hired machinery services per mu land	RMB/mu
	Output prices	
Grains	Price of grains	RMB/jin
Cash crops	Price of cash crops	RMB/jin
Atlantic potatoes	Price of Atlantic potatoes	RMB/jin
Other potatoes	Price of other potatoes	RMB/jin
	Household and farm characteristics	
Non-working	Share of non-working members in the household	%
Gender	Ratio of male labourers in the household	%
Age head	Age of the head of the household	Years
Education head	Years of education of the head of the household	Years
Slope	Ratio of sloping land in total land	%
Fertility	Average fertility of the land: 3 = bad quality, 1 = good quality	
	Grain subsidies	
Subsidy	Amount of grain subsidies per mu land planted with grains	RMB/mu

Water allocation intervention	
Water ratio	Ratio of percentage of water quota allocated to Atlantic potatoes to the percentage of water quota allocated to other crops

Note: 1 jin equals 0.5 kg.

Table 3.3 presents the descriptive statistics of all explanatory variables. In case of aggregated crops, i.e. grains, cash crops and other potatoes, the prices of variable inputs, levels of quasi-fixed inputs and prices of outputs are weighted averages using the acreage shares of each crop within its group as weights.[26]

Table 3.3: Descriptive statistics of explanatory variables

Variable		2007		2009		2007-2009
		Mean	Std. Dev.	Mean	Std. Dev.	Change
Prices of variable inputs						
Hired labour (RMB/hour)		42.8	7.63	50.3	14.9	7.52
Water (RMB/m^3)		0.091	0.011	0.095	0.060	0.003
Seeds (RMB/jin)	Grains	1.36	0.486	1.41	0.453	0.048
	Cash crops	6.08	4.33	8.85	7.54	2.77
	Atlantic potatoes	0.787	0.078	0.997	0.569	0.210
	Other potatoes	0.702	0.082	0.737	0.117	0.035
Fertilizer (RMB/jin)	Grains	0.690	0.811	0.739	0.855	0.050
	Cash crops	0.639	0.246	0.690	0.349	0.051
	Atlantic potatoes	0.832	0.337	0.703	0.395	-0.130
	Other potatoes	0.803	0.218	0.782	0.437	-0.021
Levels of quasi-fixed inputs						
Own and exchanged labour (days/mu)	Grains	9.40	5.79	7.60	6.75	-1.80
	Cash crops	12.5	9.09	12.0	11.6	-0.522
	Atlantic potatoes	1.68	1.23	1.81	1.15	0.134
	Other potatoes	16.7	12.7	15.2	8.49	-1.52
Machine (RMB/mu)	Grains	52.5	28.2	59.8	27.0	7.32
	Cash crops	44.9	29.0	38.5	18.7	-6.41
	Atlantic potatoes	29.8	15.8	35.1	38.7	5.31
	Other potatoes	39.8	31.8	38.4	42.2	-1.38
Output prices						
Grains (RMB/jin)		0.838	0.096	0.786	0.087	-0.052
Cash crops (RMB/jin)		2.12	0.613	1.96	0.566	-0.163
Atlantic potatoes (RMB/jin)		0.320	0.032	0.396	0.072	0.076
Other potatoes (RMB/jin)		0.273	0.040	0.318	0.111	0.045
Household characteristics						
Non-working (%)		14.1	15.9	15.9	16.2	1.75
Gender (%)		50.7	14.0	53.4	14.8	2.71
Age head (yeas)		46.3	10.5	46.7	10.5	0.43
Education head (years)		6.77	3.36	7.48	3.51	0.698
Farm characteristics						
Slope (%)		5.20	20.7	4.54	12.1	-0.664
Fertility (1=good, 2= medium, 3=bad)		1.44	0.559	1.52	0.600	0.085

[26] In case of zero observations for prices of variable inputs or outputs, we use the average price for sampled households within the same village or, if the number of non-zero observations within the same village is less than five, within the same township. To avoid potential endogeneity problems, we use the area shares in 2007 for weighting the 2007 prices as well as the 2009 prices.

Grain Subsidies					
Subsidy (RMB/mu)	20.3	10.8	64.3	45.9	44.0
Water allocation intervention					
Water ratio	1	0.000	1.67	0.616	0.67

Note: Prices of hired labour and water are the same for all crops.

The table shows some interesting price trends during our period of investigation. The mean price received by farmers for Atlantic potatoes increased 27 percent, and the price of local potato varieties went up 11 percent. The mean prices of grains and cash crops, on the other hand went down by 10 and 12 percent, respectively. Moreover, the mean price of fertilizer used on Atlantic and other potatoes declined 16 and 12 percent, respectively, while the price of fertilizers used on the other major crops went up 7 – 8 percent. The prices of seeds and seed potatoes went up for all crops, but most for cash crops (46 percent) and

Atlantic potatoes (27 percent). These widely divergent price trends have had a major impact on the profitability of the four major crop groups that we distinguish. It is important to control for these trends when estimating the impact of the local government intervention in water allocation on farmers' cropping decisions.

Information that we collected from the WMBs corresponding to each irrigation area shows that the average percentage (over all irrigation areas) of irrigation water that was actually allocated in 2007 equalled 63.3% for all crops, while it was 76.3% for Atlantic potatoes and 55.9% for other crops in 2009[27]. As a result, the mean value of the water allocation intervention variable for all households in our sample increased from 1.00 to 1.67. Another noteworthy finding is the rapid increase in grain subsidy, from 20.3 RMB per mu to 64.3 RMB per mu between the two survey years. According to our data, 27.8% and 5.24% of the households (in 2007 and 2009 respectively) could not tell us the amount of grain subsidies that they received even though they did grow grain on their fields. For these households, we used the average values of grain subsidies in the village where they live as an approximation. Huang et al. (2010) found similar problems with non-reporting households (11.4% in their survey held in 2008), and explain it from the fact that grain subsidies are transferred directly to a special, government-initiated bank account, which some farmers do not check frequently. The same study also found a large degree of variation in the amount of grain subsidies received by farm households.[28] Possible explanations include households' confusion in distinguishing between grain subsidies and input subsidies, and differences between localities in the distribution of grain subsidies over their farmers.

[27] In 2007, 63.3% of the standard water quotas were allocated to all crops; and in 2009, water quotas are still consistent for all crops, however, 76.3% of the standard water quotas were allocated to Atlantic potatoes, while 55.9% of the standard water quotas were allocated to other crops.

[28] The coefficient of variation in grain subsidies amounts to 1.88 (for 2007) and 1.45 (for 2008) in Huang et al. (2010), and 0.53 (for 2007) and 0.71 (for 2009) in our sample.

Table 3.4: Regression results

	Grains	Cash crops	Atlantic potatoes	Other potatoes
Prices of variable inputs				
Price of hired labour	-0.004 (-0.30)	-0.001 (-0.09)	0.003 (0.31)	-0.006 (-0.32)
Price of water	8.10 (0.69)	1.58 (0.18)	-0.757 (-0.18)	-9.27 (-1.13)
Price of seeds	0.029 (0.07)	0.057 (1.37)	-0.078 (-0.23)	0.624 (0.42)
Price of fertilizer	0.018 (0.10)	-0.038 (-0.07)	0.728 * (1.64)	0.022 (0.25)
Levels of quasi-fixed inputs				
Amount of own and exchanged labour	0.007 (0.25)	-0.013 (-0.72)	-0.015 (-0.87)	-0.004 (-0.24)
Expenditures on machinery service	-0.002 (-0.35)	0.000 (0.02)	-0.002 (-0.50)	0.002 (0.38)
Output prices				
Price of grains	13.7 *** (2.58)	-11.7 *** (-2.91)	0.732 (0.38)	-2.35 (-0.64)
Price of cash crops	-2.24 ** (-2.18)	2.75 *** (3.53)	0.810 ** (2.24)	-1.27 * (-1.77)
Price of Atlantic potatoes	-16.4 * (-1.64)	13.4 * (1.78)	-4.27 (-1.19)	4.84 (0.70)
Price of other potatoes	-11.9 * (-1.63)	13.0 ** (2.35)	-6.18 ** (-2.42)	4.75 (0.94)
Household and farm characteristics				
Non-working	-0.042 (-0.83)	0.043 (1.14)	0.005 (0.26)	-0.007 (-0.21)
Gender	0.035 (0.75)	0.026 (0.74)	-0.005 (-0.29)	-0.057 * (-1.74)
Age	-0.002 (-0.07)	0.007 (0.31)	-0.007 (-0.66)	-0.006 (-0.31)
Education	0.430 (1.46)	-0.090 (-0.40)	0.214 ** (2.10)	-0.566 *** (-2.78)
Slope	0.087 * (1.70)	-0.037 (-0.94)	-0.008 (-0.44)	-0.043 (-1.21)
Fertility	-0.926 (-0.89)	0.008 (0.01)	-0.131 (-0.36)	1.07 (1.48)
Grain subsidies				
Subsidy	-0.008 (-0.31)	-0.011 (-0.54)	0.004 (0.42)	0.010 (0.53)
Water priority policy				
Water priority	3.47 *** (2.81)	1.36 (1.44)	-0.186 (-0.40)	-4.40 *** (-5.14)
Intercept	-0.499 (-0.18)	-4.87 ** (-2.29)	2.30 ** (2.16)	3.43 * (1.75)
Number of observations	248	248	248	248
R^2	0.17	0.17	0.09	0.17

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses. Homogeneity restriction imposed before estimation.

The regression results are presented in Table 3.4, while the (arc) elasticities that correspond to the estimated coefficients are shown in Table 3.5[29]. Only the coefficients that are statistically significant (at a 10 percent testing level) are included in that table.

Table 3.5: Estimated elasticities

	Grains	Cash crops	Atlantic potatoes	Other potatoes
		Prices of variable inputs		
Price of hired labour				
Price of water				
Price of seeds				
Price of fertilizer			0,48 *	
		Levels of quasi-fixed inputs		
Amount of own and exchanged labour				
Expenditures on machinery service				
		Output prices		
Price of grains	0.12 ***	-0.95 ***		
Price of cash crops	-0.06 **	0.56 ***	1.43 **	-0.37 *
Price of Atlantic potatoes	-0.07 *	0.48 *		
Price of other potatoes	-0.04 *	0.38 **	-1.58 **	
		Household and farm characteristics		
Non-working				
Gender				-0.43 *
Age				
Education			1.32 **	-0.58 ***
Slope				
Fertility				
		Grain subsidies		
Subsidy				
		Water priority policy		
Water priority	0.06 ***			-0.85 ***

Our results do not support the first hypothesis presented above. The intervention in water allocation by the local government does not significantly affect the share of land allocated to Atlantic potatoes. Instead, the policy results in an increase in the share of land allocated to grains and a decrease in the land share of other potatoes, both at the 1% significance level.

[29] The elasticities are derived by multiplying the estimated coefficients with the ratio of the average level of the explanatory variable in 2007 and 2009 to the average level of the dependent variable in 2007 and 2009.

The main explanation for this result lies in the fact that planting decisions of farm households in the research area are strongly influenced by their village leaders. Out of the 86 farm households growing Atlantic potatoes in our survey of the year 2009, 54 households (62.8%) indicated that they were obligated by their village leaders to plant Atlantic potatoes. For 24 out of these 54 households, however, the actual area planted with Atlantic potatoes differed from the area they were required to plant by the village leader. Hence, despite the pressure from their local leader they do seem to have some freedom in deciding upon the actually planted area. Secondly, due to the larger water shares allocated to Atlantic potatoes and the lower water shares available for other crops, farmers tend to switch to crops with relatively low water requirements. This explains why farmers prefer planting a larger share of their land with grains instead of other potatoes after the change in water allocation, as potatoes demand a relatively large amount of water. It also explains why farmers in the research area started to grow fewer local variety potatoes and more grains (Table 3.1) even though the price trends during the period of observation were much more favourable for potatoes than for grains (Table 3.3).

Our second hypothesis, which states that crops grown mainly for home consumption respond relatively less to the intervention, is partly confirmed by the results. We do find that the government intervention in water allocation caused a stronger response for other potatoes (elasticity: -0.85) than for grains (elasticity: 0.06). But the impact on the area planted with cash crops is not significantly different from zero. Output prices seem to play a more important role in cash crop planting decisions, as is evident from the regression results (see Table 4 and Table 5). The own price effect is positive and strongly significant (elasticity: 0.56) while the cross-price effect for grains is negative and strongly significant (elasticity: -0.95). The cross-price effects of Atlantic potatoes (elasticity: 0.48) and other potatoes (elasticity:

0.38) are positive, and significant at the 10 and 5 percent testing level, respectively. The latter result suggests that these crops are considered as complements by farmers.

The own price elasticity of Atlantic potatoes is not significantly different from zero (at a one percent testing level). We do find, however, significant cross price elasticities for the prices of cash crops (elasticity: 1.43) and other potatoes (elasticity: -1.58). These findings suggest that farmers' decision on the share of land allocated to Atlantic potatoes follows other incentives than its own prices. Among these an important factor is that Atlantic potatoes are strongly influenced, but not fully controlled, by village leaders. The cross-price elasticity with respect to prices of other potatoes indicates the substitute relationship between Atlantic potatoes and other potatoes. Due to phytosanitary reasons, only a limited share of land can be allocated to potatoes, and hence land is competitive between other potatoes and Atlantic potatoes. The prices of variable inputs and the available levels of quasi-fixed inputs do not have much impact on acreage allocation decisions of the farmers in our survey. We only find a significant impact (at a 10 percent testing level) for the price of fertilizer on the share of land allocated to Atlantic potatoes.

3.5 Conclusions and policy recommendations

This article analyses the impact of a local government intervention in the allocation of irrigation water on farmer's land allocation to different crops. It adds to the available literature by providing empirical estimates of relevant crop supply elasticities to the government intervention, based on a realistic, evidence-based representation of an actual policy instrument, and taking into account the whole set of cropping options available to households.

Using household survey data collected among 248 households in an arid region in northern China the year before and the year after the government intervention in water allocation, we estimate a system of unconditional crop acreage demands that includes a variable representing the water policy intervention. Our findings indicate that the water priority given to the newly introduced cash crop (Atlantic potatoes) does not significantly affect the land allocated to that crop. This finding can be explained from the fact that planting decisions about Atlantic potatoes are strongly influenced by the village leader, as is evident from the answers given to a question in the survey about this issue. Moreover, the revealed behaviours of farmers show a strong preference of growing grain crops, which require relatively less amount of irrigation water, and are traditional crops mainly used for own consumption within the households.

These findings confirm the well-known empirical fact that direct government interventions often tend to have unintended side-effects. In this case, the government intervention is in the planting decisions of farmers and in the provision of a major productive input with the purpose to increase the yields of a crop that the government is actively promoting. The unintended side-effect is the shift that it causes from growing local potato varieties towards grain crops. Although this side-effect is likely to be unplanned, it does contribute to the realization of another major policy gain in China, namely the ambition to remain self-sufficient in grain production. The extent to which the intervention contributes to raising rural household incomes, another major policy goal, is however doubtful.

4. Valuation of irrigation water and the impact of water allocation interventions[30]

Abstract:

This article aims to provide more insights into the economic value of irrigation water. Specifically, we evaluate the internal valuation (i.e. marginal value) of irrigation water in an arid Chinese region facing the introduction of a new policy assigning more irrigation water to a specific cash crop. A system of crop production functions is estimated, using data that were collected during two rounds of a farm household survey. The results show that the valuation of irrigation water for grains is very low in both years, and is below the actual water prices that are charged to farm households. Potential explanations for this finding include the self-consumption of grains by farm households and grain subsidies that are based on planted areas of grains. Among other crops than grains, we find evidence that increased water allocation to the new cash crop affects farmer's valuation of water. The policy causes the valuation of irrigation water for the preferential crop to be lower than that for other crops. The returns to water for other crops go up after the intervention.

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[30] This chapter is based on an article submitted to *the Australian Journal of Agricultural and Resource Economics* in April 2013, as Lei Zhang and Thomas Herzfeld "Valuation of irrigation water and the impact of water allocation interventions" (under review).

4.1 Introduction

In developing countries, agriculture continues to be an important economic sector as it makes a significant contribution to national incomes and economic growth, and provides livelihood support for 60-80% of the population. However, the potential for continued growth in agriculture is diminishing rapidly due to the limits on further development of water resources in many parts of the world (Hussain et al., 2007). Especially in physically water-scarce regions, competition for water across sectors (agricultural, domestic, industrial, commercial, and environmental) is growing with increasing pressure on available water supplies for agriculture. The key strategy now being advocated for addressing water scarcity problems is increasing productivity of water to obtain more value for each drop of water use (Hussain et al., 2007; Molden et al., 2001).

Water scarcity constitutes a major problem for agricultural producers in China, particularly in the north. Reasons are relatively limited precipitation and the growing use of water for industrial purposes and domestic consumption (Shalizi, 2006; World Bank 2001; Yang et al., 2003). Currently, irrigation water productivity in China is just about 0.8 kg/m^3. In some developed countries, such as Israel or the United States, it almost reaches 2 kg/ m^3 (Liao et al., 2008). In China, before the economic reforms started in 1978, water was generally considered a free good. After the reforms, water fees were gradually introduced and increased in an effort to meet the cost of water supply and improve water use efficiency. In spite of the growing concern on the regulation of irrigation water via pricing, current prices charged for irrigation water in China are still thought to fall far short of the costs of supplying irrigation water to users, and often do not even attempt to recover the initial capital costs (Liao et al., 2008; Wang et al., 2004; Yang et al., 2003; Qu et al., 2011). Since 1 January 2004, China has introduced a new water pricing regulation; its main objectives are that water prices should be increased to fully recover water supply cost and that water should be treated as a market good (Liao et al., 2008). However, regional development goals might conflict with national policy interests in increasing water use efficiency resulting in policy inconsistencies faced by farmers.

Two methods are established in the literature to analyze the economic value of water: Estimation of the opportunity costs of water by using econometric methods (e.g. Moncur and Pollock, 1988), and Contingent Valuation Method (CVM) by using experiments (e.g. Chandrasekaran et al., 2009). There are some available quantitative studies (Esmaeili and Vazirzadeh, 2009; Eshghi and Hosseini-Yekani, 2012; Jamalijaghdani et al., 2012; Speelman et al., 2011; Chandrasekaran et al., 2009), but empirical research on China is still very limited. Wang et al. (2003) estimate the value of agricultural water in Ningxia and Henan Provinces using data collected in surveys carried out in 2001. Focusing on a few major staple crops in these regions, their results indicate that the value of agricultural water ranges from 0.06 to 0.29 USD/m^3 for wheat, 0.08-0.38 USD/m^3 for maize, and 0.04-0.22 USD/m^3 for rice.

Our study analyses the effect of an irrigation policy change directly affecting availability of water for different crops on farmer's internal valuation of water in a northern Chinese region. Previous research analyzed policy interventions mainly with respect to output market interventions (e.g. Buschena et al., 2005; Huang et al., 2011). With respect to water as an agricultural input, previous research has concentrated on comparing the valuation of water between different crops, using cross section data. Our study estimates the valuation of irrigation water in an arid Chinese region for two years, that is, before and after the introduction of the policy. The study contributes to the existing literature by performing a quantitative analysis of the valuation of irrigation water in China, and analyzing the impacts of a government intervention in water availability on the valuation of water at the farm household level. Results of our analysis can be used to inform policy makers about intended as well as unintended effects of policy interventions in water allocation.

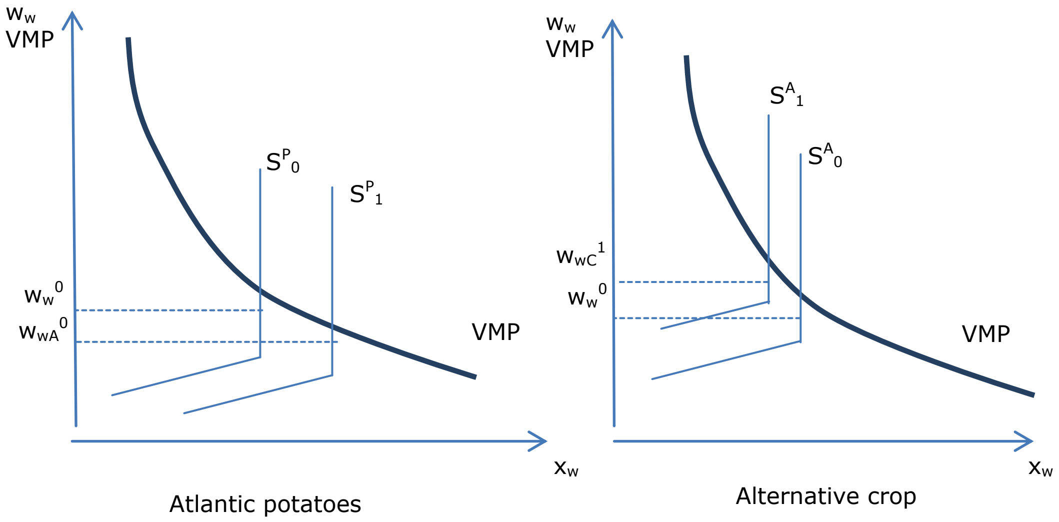
The remainder of this paper is organized as follows. The next section establishes a theoretical framework as the basis of the empirical analysis. In Section 4.3, we describe the research area and the data underlying the econometric results. Then in Section 4.4, we discuss the methodologies, and a set of production functions are established. The econometric results are presented in Section 4.5. The final section summarizes the main results of the empirical analysis and provides some policy recommendations.

4.2 Theoretical framework

Alternative water pricing mechanisms have been adopted as the primary means to regulate irrigation water consumption. Water prices usually consist of a combination of an area–based component, an output-based component and a fixed capital and operation and maintenance (O&M) fee. "Getting prices right" is seen as a desirable way to allocate water efficiently, but how much prices should be raised remains a debatable issue (Johansson, 2000; Johansson et al., 2002; Tsur and Dinar, 1997). The two major views are that water prices should either cover the costs of supplying water (Esmaeili and Vazirzadeh, 2009; Tsur et al., 2004; Tsur and Dinar, 1997) or should reflect the real water resources value (i.e. shadow prices or value of marginal product), also reflecting the resource scarcity (Liu et al., 2009).

Taking perfectly functioning input and output markets as the hypothetical reference case, economic theory provides us with a straightforward tool to assess the impact of government interventions in water allocation. Assuming each farmer behaves rationally and risk-neutral, irrigation water should be distributed across different crops up to the point where the marginal productivity of water valued at output prices across the different crops is equal (‘principle of equimarginal value[31]’). We assume further that water availability is limited. In a graphical way of analysis, the optimal amount of water use is the intersection of irrigation water demand (value of marginal product, VMP) and irrigation water supply. In case of water scarcity, this intersection should be at the inelastic part of the water supply function (Figure 4.1). At the vertical axis we can derive water’s value of marginal product which will be equal across all crops.

Figure 4.1: Changes in valuation of water due to the water priority policy



With the introduction of a water policy assigning more water to a specific cash crop, here Atlantic potatoes (more details will be explained in Section 4.3), water’s value of marginal product will differ across crops. The farmer looks for a new optimal input allocation by maximizing profits subject to the total availability of irrigation water. As shown in Figure 4.1, with all other factors held constant, the water priority allocation to Atlantic potatoes results in

[31] Of course, this principle assumes homogeneity of the good in question. Here, we assume farmers use exclusively surface water with the same quality everywhere. As no farmers in our sample use groundwater, this assumption imposes not too much a restriction.

a higher water availability for Atlantic potatoes (increasing from S^P_0 to S^P_1) and less water for other crops (decreasing from S^A_0 to S^A_1). As a result, water's value of marginal product for Atlantic potatoes is expected to decrease while that for all other crops will increase. In other words, the government intervention in water allocation creates an economic inefficiency. The extent of inefficiency depends on the shape of the MVP curves and the size of the intervention and is an empirical matter.

This study aims to estimate whether the valuation of water for Atlantic potatoes and other crops changes due to the implementation of the regional government's water policy; and if yes, whether the changes are consistent with the hypotheses derived from micro-economic theory. Results of the empirical analysis allow to draw conclusions about the efficiency costs associated with the water policy. Our theoretical framework suggests two hypotheses to be tested in the econometric model. First, before the introduction of the new water policy, valuation of irrigation water is expected to be equal across the different crops. Second, after the water policy change, valuation of irrigation water is expected to be lower for Atlantic potatoes compared to the alternative crops.

4.3 Description of the research area and water institutions

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. The water resources of the Heihe river basin area originate mainly from glacial water from the Qilianshan Mountain, which is perpetually covered by snow. In the midstream of the Heihe River watershed, the land is flat, sunshine is abundant, and annual precipitation is very low while the evaporation is high[32]. 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. Water demand is covered from the Heihe River. Agriculture accounts for approximately 95% of total water use. As a result of continuous excessive water extraction, too little water flows into Juyanhai Lake, which dried out in 1992 and an area of 200 km^2 around the lake became desert (MWR 2004; Zhang et al., 2009).

To deal with these problems, the Ministry of Water Resources 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 in three ways. First, the government invested capital to build a water-saving irrigation system because local farmers could not afford it. Second, the government invested and installed meters for water users (including irrigators) and tried to discourage farmers from wasting water by accurately metering and charging for irrigation water. Finally, a water use rights (WUR) system[33] with tradable water quotas was established. Specifically, a standard water quota is allocated according to the WUR land area, and farm households pay for the amount of allocated water. Based on this, households can trade WUR in excess or short in demand. The first two measures decreased irrigation water use somewhat, but trading of WUR did not become popular (Zhang et al., 2009).

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

[32] The precipitation in Zhangye City is 89-283 mm per year, while the evaporation is 1700 mm per year.
[33] 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 other factors. The average proportion of WUR land in total arable land is 72.6% for all households in our sample.

860,000 mu[34], 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[35]. 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 much rainfall in zone 3, it relies less on irrigation, compared with the other two zones.

There are seven reservoirs, 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 (i.e. Water Users Associations) within their own irrigation area. First a standard water allocation quota is allocated to the WUR land of the WUAs within the irrigation area in question. Then, based on the actual availability of water within a reservoir, a certain percentage of the water quota is actually distributed to the WUAs within the irrigation area.

WUAs are responsible for arranging the water allocation to households belonging to their own WUA. The households within each WUA are sub-divided into water user 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,

[34] One mu equals 0.07 ha.
[35] 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.

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).

The policy change regarding water allocation was caused by the entry of a potato processing company in this region which is partly owned by the regional government[36]. The company entered in 2008 and demands a specific variety of potatoes, called Atlantic potatoes, for processing into flakes and starch. In order to meet the growing demand for Atlantic potatoes with high water requirements, the local government assigned more water for Atlantic potato growing to stimulate its production in the area. Stimulating the production of a crop with relatively high water demands via institutional instruments in a water scarce region evidently may conflict with policy goals at the national level like promoting grain self-sufficiency and increasing water productivity.

The surveys used for this study were carried out in May 2008 and May 2010 by staff and students from Gansu Academy of Social Sciences in Lanzhou, Gansu Agricultural University in Lanzhou, and Nanjing Agricultural University. Household interviews were done in 21 villages; giving us a dataset containing 315 observations[37] (see Wachong Castro et al., 2010 for a description of the sampling method). If possible, the same households in each village that were interviewed in 2008 were also interviewed in May 2010. In cases where the same household could not be found, it was replaced by another, randomly selected, household in the same village. Combining both surveys and excluding households interviewed only once results in a two-year balanced panel data set containing 265 households. The data include information, among others, about crop production, use of water and other inputs, water trading, WUA participation, water and other prices, land tenure and land use. Six households among them rented out their land to other households and were engaged in off-farm work,

[36] The Government of Minle County owns 51% of the joint venture, and the Dutch company owns the other 49%.
[37] In two villages, 16 instead of 15 households were interviewed in May 2008. The last observation in these two villages was included in panel dataset containing 265 households.

thus did not grow any crops either in 2007 or in 2009. Additionally, households that had missing data or reported outliers[38] on one or more variables used in the empirical analysis were excluded. As a result, a two-year panel dataset containing 248 households is used in the following empirical analysis.

4.4 Methodology

Young (2005) classifies methods to derive the value of irrigation water into two groups: inductive and deductive. Deductive methods rely on the estimations of willingness to pay derived from models of human behavior together with conditions of production and consumption. Inductive methods use statistical techniques to infer economic values from data. Hussain et al. (2007) summarize the various indicators of value of water, mainly including average and marginal values[39]. For water resources investment and allocation decisions, marginal values may be more useful and provide greater insights than average values do (Hussain et al., 2007).

In this study, we use an inductive approach to examine the value of marginal productivity of irrigation water by estimating a system of production functions. To reduce the complexity of the system, farm household *i*'s production portfolio of crops is structured in four groups[40] *j*: grain crops (barley, wheat and maize), cash crops[41] (sesame, rapeseed and garlic), Atlantic potatoes and other potatoes (various local varieties).

We include the following factors as inputs into the production function: water (W), other inputs including seed (S), fertilizer and pesticide (F), labour (L), and machinery use (M).

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[38] Here we define outliers as households with large changes (>50%) in area shares of any crops between the two years.
[39] The whole list of indicators is: Average gross value of product per unit of water, average gross margins per unit of water, average gross net value of product per unit of water, value of marginal productivity of water.
[40] Minor crops (e.g. peas, Chinese medicine, vegetables etc.) are not included in this analysis.
[41] Atlantic potatoes are excluded from the group termed 'cash crops'.

Different functional forms can be chosen for the production function, with the Cobb-Douglas and translog functions being the most widely used specifications. Based on initial tests of functional forms, we rely on the more flexible translog functional form in this analysis[42]. The production function can be specified as Equation (4.4):

$$\begin{aligned}\ln Y_{ij} &= \ln A + \alpha_1 \ln W_{ij} + \alpha_2 \ln S_{ij} + \alpha_3 \ln F_{ij} + \alpha_4 \ln L_{ij} + \alpha_5 \ln M_{ij} + \alpha_6 \ln W_{ij} \ln S_{ij} + \\ &\alpha_7 \ln W_{ij} \ln F_{ij} + \alpha_8 \ln W_{ij} \ln L_{ij} + \alpha_9 \ln W_{ij} \ln M_{ij} + \alpha_{10} \ln S_{ij} \ln F_{ij} + \alpha_{11} \ln S_{ij} \ln L_{ij} + \\ &\alpha_{12} \ln S_{ij} \ln M_{ij} + \alpha_{13} \ln F_{ij} \ln L_{ij} + \alpha_{14} \ln F_{ij} \ln M_{ij} + \alpha_{15} \ln L_{ij} \ln M_{ij} + \alpha_{16} (\ln W_{ij})^2 + \\ &\alpha_{17} (\ln S_{ij})^2 + \alpha_{18} (\ln F_{ij})^2 + \alpha_{19} (\ln L_{ij})^2 + \alpha_{20} (\ln M_{ij})^2 \end{aligned} \tag{4.4}$$

Output is measured in physical units (lnY). Similarly, water (lnW), seeds (lnS) and labor use (lnL) enter in their respective natural units. Fertilizer and pesticide inputs (lnF) as well as machinery use (lnM) are measured in monetary units. All variables are normalized by area. The α's refer to unknown parameters to be estimated.

Table 4.1: Definitions of explanatory variables

Variable	Definition	Unit
	Levels of variable and quasi-fixed inputs	
Water (W)	Amount of irrigation water per mu land	m^3/mu
Seeds (S)	Amount of seeds per mu land	jin/mu
Fertilizer and pesticide (F)	Expenditures on chemical fertilizer and pesticide per mu land	RMB/mu
Labour (L)	Amount of labour per mu land	Days/mu
Machinery (M)	Amount of machinery costs per mu land	RMB/mu
	Household characteristics	
Non-working	Share of non-working members in the household	%
Gender	Ratio of male labourers in the household	%

[42] From a methodological perspective alternative estimators have been suggested which support a better identification of production functions and allow for the possible endogeneity of inputs (Olley and Pakes, 1996). However, a higher longitudinal dimension of the sample is necessary to use this estimator..

Age head	Age of the head of the household	Years
Education head	Years of education of the head of the household	Years
	Farm characteristics	
Slope	Ratio of land on slope	%
Fertility	Average fertility of the land: 3 means bad quality, 1 means good	
	Agro-ecological zones	
D1	1=zone 1, 0=otherwise	
D2	1=zone 2, 0=otherwise	

Note: 1 jin = 0.5 kg.

Besides agricultural inputs, factors like farmer's managerial capability and natural conditions affect output levels. We approximate these determinants by adding household characteristics, such as age and education level of the household head, as well as farm characteristics, like slope and fertility of the land. Furthermore, two dummy variables control for the differences in agro-ecological conditions between the three zones in Minle County (see Section 4.3). The definition of all explanatory variables is presented in Table 4.1.

The elasticity of output with respect to the input of water is calculated by taking the partial derivative of output with respect to water use. The water elasticity of output, as derived from Equation (4.4), is shown in Equation (4.5).

$$\varepsilon = \alpha_1 + \alpha_6 \ln S + \alpha_7 \ln F + \alpha_8 \ln L + \alpha_9 \ln M + 2 * \alpha_{16} \ln W \tag{4.5}$$

The marginal productivity of water then is: $\rho = \varepsilon * (Y/W)$, and the marginal value (i.e. shadow price) of water is: $v = \rho * P$, where P refers to the output price (average price for all households). In case of aggregated crops, i.e. grains, cash crops and other potatoes, the price is a weighted average using acreage shares of each crop within the group as weights.

4.5 Data analysis and results

Table 4.2 displays yields of the four output categories in 2007 and 2009. Our data shows that a large majority of farmers grew grain crops in both years (247 households in 2007 and 245 households in 2009). 110 households planted cash crops in 2007 and 116 households did in 2009. The numbers of households planting other potatoes are 177 and 152, in 2007 and 2009 respectively. In terms of the Atlantic potato growing, in 2007, only 21 households were involved[43], and the number increased to 86 in the year 2009.

Table 4.2: Yields of different crop groups in 2007 and 2009

Crops	2007		2009	
	Mean (jin/mu)	No. of observations	Mean (jin/mu)	No. of observations
Grains	892	247	911	245
Cash crops	674	110	812	116
Atlantic potatoes	2400	21	2534	86
Other potatoes	3343	177	3288	152

It is shown in Table 4.2 that the yields of most crops go up on average from 2007 to 2009, except that of other potatoes, which declines on average from 3343 to 3288 jin[44]/mu. A remarkable change is that yields of cash crops go up from 674 to 812 jin/mu during this period. On the one hand, yields of both cash crops (i.e. rapeseed and garlic) increase during this period. Specifically, the yields of rapeseed and garlic (for all households on average) are 387.4 and 1923 jin/mu in 2007, and increase to 410.4 and 2128 jin/mu in 2009. On the other

[43] Although the potato processing company became operational in 2008, some farmers already planted Atlantic potatoes in 2007 and delivered them to the storage facility of the company.
[44] One jin equals 0.5 kg.

hand, the share of land planted with garlic in total cash crop area (for all households on average) goes up from 20.7% to 24.5% during this period.

Table 4.3: Input use in 2007 and 2009

Input	2007				2009			
	Grains	Cash crops	Atlantic potatoes	Other potatoes	Grains	Cash crops	Atlantic potatoes	Other potatoes
Water (m^3/mu)	499	776	577	645	310	542	699	607
Seeds (jin/mu)	70.9	66.8	320	361	65.8	56.2	421	403
Fertilizer and pesticide (RMB/mu)	76.8	80.0	129	114	76.3	80.0	112	116
Labour (days/mu)	9.71	12.1	20.8	18.0	7.76	12.8	19.5	16.2
Machine (RMB/mu)	53.5	37.5	36.4	52.1	58.7	41.4	35.2	34.5

Table 4.3 presents descriptive statistics of input use for both years separately. The data indicate that due to the water policy change, the quantity of water use on Atlantic potatoes goes up from 577 to 699 m^3/ mu; while the amount of water use for all other crops declines from 2007 to 2009. Especially for cash crops, the amount of water use decreases from 776 to 542 m^3/ mu. Descriptive statistics of other explanatory variables used in the production function are presented in Table 4.4.

Table 4.4: Descriptive statistics of other explanatory variables

Variable	2007		2009	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
Households characteristics				
Non-working (%)	14.1	15.9	15.9	16.2
Gender (%)	50.7	14.0	53.4	14.8
Age head (years)	46.3	10.5	46.7	10.5
Education head (years)	6.77	3.36	7.48	3.51
Farm characteristics				
Slope (%)	5.20	20.7	4.54	12.1
Fertility (1=good, 2= medium, 3=bad)	1.44	0.559	1.52	0.60
Agro-ecological zones				
D1 (1=zone 1, 0=otherwise)	0.20	0.40	0.20	0.40
D2 (1=zone 2, 0=otherwise)	0.66	0.47	0.66	0.47

Table 4.5 shows the prices of different outputs in the two years. Zero observations of output prices[45] are replaced by the average prices of interviewed households within the same village. If the number of observations within a village is less than five, we replace the zero observation by the average value at the township level. The data show that prices of grain crops and cash crops go down during the two years. On average, grain prices drop from 0.840 to 0.759 RMB/jin, and prices of cash crops decline from 2.16 to 1.92 RMB/jin. Prices of the two groups of potatoes go up during this period. The price of Atlantic potatoes increases from 0.325 to 0.421 RMB/jin, and the price of other potatoes goes up slightly, from 0.274 to 0.298 RMB/jin.

[45] Some farm households use (part of) the crops for own consumption, and therefore did not indicate the market prices of outputs in the surveys.

Table 4.5: Output prices in 2007 and 2009 (unit: RMB/jin)

Crop	2007		2009	
	Mean	Std. Dev.	Mean	Std. Dev.
Grains	0.840	0.098	0.759	0.084
Cash crops	2.16	0.959	1.92	0.526
Atlantic potatoes	0.325	0.043	0.421	0.056
Other potatoes	0.274	0.039	0.298	0.118

The regression results for the translog production functions are presented in the Appendix. Based on these coefficient estimates, the output elasticities, marginal productivity and marginal value of irrigation water are derived and presented in Table 4.6. Due to the limited number of observations of farm households growing Atlantic potatoes in 2007, we cannot estimate its production function for that year.

Table 4.6: Economic valuation of water in 2007 and 2009

		Units	Grains	Cash crops	Atlantic potatoes	Other potatoes
2007	Output elasticity of water		0.044	0.177		0.008
	Marginal productivity of water	(jin/m^3)	0.079	0.153		0.041
		(kg/m^3)	(0.039)	(0.077)		(0.021)
	Marginal value of water	(RMB/m^3)	0.066	0.331		0.011
		(USD/m^3)	(0.011)	(0.053)		(0.002)
2009	Output elasticity of water		0.021	0.197	0.174	0.336
	Marginal productivity of water	(jin/m^3)	0.061	0.295	0.632	1.82
		(kg/m^3)	(0.031)	(0.148)	(0.316)	(0.91)
	Marginal value of water	(RMB/m^3)	0.046	0.567	0.266	0.543
		(USD/m^3)	(0.007)	(0.091)	(0.043)	(0.087)

Note: Too few observations of farmers growing Atlantic potatoes in 2007.

Our first hypothesis of equality of shadow prices of water for different crops before the water policy change can be rejected based on statistical grounds. The low marginal returns of water for grains (0.066 RMB/m^3) and other potatoes (0.011 RMB/m^3) are a bit surprising, and are even below the charged water prices (i.e. 0.091 RMB/m^3 for all households on average). Farmers may attach significant non-market values to traditional crops, which are crucial for understanding supply response and on-farm conservation of these crops (Arslan, 2011). In this case, there may be a few reasons for the low marginal value of water for grains: First, a majority part of grains are used for intra-household consumption in this region. In 2007, 58.8% of grains[46] were used for own consumption by the farm households; and in 2009, it goes up to 61.2%. Second, grain subsidies received by farmers [47] may be another reason for the farmers to grow more grains and apply more irrigation water on it, which lead to the low marginal returns of water for grains. A possible reason for the low valuation of water for other potatoes is that they are also partly used for own consumption by the local farmers. Our data indicate that in 2007, 28.0% and 32.0% of other potatoes [48] were used for own consumption, in 2007 and 2009 respectively.

After the water policy change, the valuation of water for grains (0.046 RMB/m^3) is still rather low[49], probably because of the first reason as explained in the previous paragraph. Our second hypothesis is however partly confirmed by the results. Specifically, after the water policy change, the valuation of water for Atlantic potatoes is relatively low (0.266 RMB/ m^3), compared to cash crops (0.567 RMB/ m^3) and other potatoes (0.543 RMB/ m^3).

Moreover, comparing the results of the two years shows that valuation of water for cash crops and other potatoes increases from 2007 to 2009. Specifically, the marginal returns of

[46] Output (unit: jin).
[47] The amount of grain subsidies received by the farm households is 11.8 RMB per mu and 56.2 RMB per mu in 2007 and 2009 respectively.
[48] Output (unit: jin).
[49] The water price charged in reality in 2009 is 0.095 RMB/m^3.

water for cash crops go up from 0.331 to 0.567 RMB/m^3. Turning to other potatoes shows an interesting result, the valuation of water for this crop is the lowest among all crops in 2007 (0.011 RMB/ m^3), but rises remarkably to 0.543 RMB/ m^3 in 2009. Similarly, the marginal productivity of other potatoes shows the highest increase. One possible explanation may be that irrigation water is mainly diverted from regular potatoes to Atlantic potatoes. They are the closest substitutes among all crop groups, in terms of production cycle and water requirements[50].

4.6 Conclusions and policy recommendations

This article analyses the impact of a policy affecting the water availability for various crops on the valuation of irrigation water for different crops. To accomplish this, we estimate a system of crop production functions with water, seed, fertilizer and pesticide, labour and machinery costs as inputs. The analysis is based on a data set collected among 265 households for two years in an arid Chinese region. Previous research on valuation of water in agriculture has concentrated on comparing the valuation between different crops, using cross section data. This study to our knowledge provides the first quantitative analysis on the changes in valuation of water caused by government interventions in water availability for different crops.

Policy makers may have different and sometimes contradictory goals. In our research area, water saving is the major goal for the government of Zhangye City, while the lower level government of Minle County mainly aims to stimulate the production of Atlantic potatoes with relatively high water requirements. Whereas the first goal seems to be driven by long term considerations, e.g. securing future development of the wider city, the local

[50] As shown in Table 4.3, both Atlantic potatoes and other potato varieties are relatively water-intensive, particularly compared to grains.

government seems to have relatively short term financial interests, i.e. returns on investment in a potatoes processing company.

Our findings indicate that government interventions in water allocation have major effects on the economic valuation of water for different crops. Specifically, due to the increased amount of water allocated to Atlantic potatoes, the marginal return of water for this crop is relatively low compared to other cash crops and other potatoes. Because of the limited observations of Atlantic potato growers in 2007, we are unfortunately not able to examine whether the valuation of water for this crop has declined over time policy, which would be expected on theoretical grounds. We further find that the marginal returns for water for other cash crops and other potatoes increase over time, which is consistent with the theoretical hypotheses.

The valuation of water for grain crops is found to be very low in both years. It is not only much lower than the value of water for grain crops as estimated by Wang et al. (2003), but also below the water prices that are charged in our research area. Nevertheless, a large majority of farm households persist in growing grains and applying irrigation water on them, probably because of the household use (own consumption) of grains and grain subsidies received by farmers[51]. This result further implies that government interventions in water allocation have little impact on grain production and hence hardly affect grain 'security' (i.e. grain self-sufficiency), which is a major policy goal in China.

However, due to the limitation of the datasets used for this research, the changes in the marginal value of irrigation water as estimated in our study should be considered as gross results of changes in water availability and changes of output prices. Further research should in particular apply a similar methodology to data collected from neighboring regions with

[51] Since 2004, farmers received grain subsidies based on planted areas of grains.

similar price development but without such a water policy change to isolate the effects of the policy change from other conditions that changed over time.

Further research is also needed to provide more insights into the reasons for the low returns for water for grains crops. Evidence from the behavioral economics literature suggests that people try to avoid losses (e.g. Frank, 2010). In the case at hand, farmers might apply more water (relative to the physical water requirements of the crop) to grain crops as an economically rational way to avoid bad harvests of this strategically important crop. Thus, low shadow values of water in grain production might also be a result of above economically optimal water use. More data are needed, e.g. on physical water requirements for various crops, to test this hypothesis.

Appendix 4A

4A1: Regression results **2007**

	Grains	Cash crops	Other potatoes
Levels of variable and quasi-fixed inputs			
lnwater	-1.27	0.019	-0.479
	(-1.01)	(0.02)	(-0.24)
lnseed	-0.198	0.104	-0.506
	(-0.11)	(0.18)	(-0.26)
lnfertilizer	-1.21	1.19	-0.591
	(-1.16)	(0.63)	(-0.44)
lnlabour	-2.07 **	-4.43 **	-0.774
	(-2.52)	(-2.25)	(-0.43)
lnmachine	0.559	0.131	0.500
	(1.04)	(0.13)	(0.98)
lnwater*lnseed	-0.171	0.044	0.128
	(-0.91)	(0.59)	(0.48)
lnwater*lnfertilizer	0.122	-0.257	0.388 **
	(0.95)	(-0.86)	(2.06)
lnwater*lnlabour	0.231 **	0.136	0.002
	(2.27)	(0.54)	(0.01)
lnwater*lnmachine	-0.029	0.129	-0.012
	(-0.67)	(0.94)	(-0.24)
lnseed*lnfertilizer	0.202	-0.076	-0.273
	(1.28)	(-1.31)	(-1.15)
lnseed*lnlabour	0.040	-0.104 *	0.220
	(0.41)	(-1.97)	(1.09)
lnseed*lnmachine	-0.028	.009	-0.103
	(-0.67)	(0.30)	(-1.14)
lnfertilizer*lnlabour	0.072	0.925 ***	0.041
	(0.73)	(3.06)	(0.41)
lnfertilizer*lnmachine	-0.072	-0.191 *	0.024
	(-1.05)	(-1.75)	(0.66)
lnlabour*lnmachine	0.024	-0.136	-0.023
	(0.80)	(-1.61)	(-0.53)
$(\text{lnwater})^2$	0.089	0.030	-0.155
	(1.42)	(0.88)	(-1.10)
$(\text{lnseed})^2$	0.059	0.084 ***	0.083 **
	(0.59)	(5.47)	(2.01)
$(\text{lnfertilizer})^2$	-0.027	-0.076	-0.031
	(-0.43)	(-1.29)	(-0.82)
$(\text{lnlabour})^2$	0.012	-0.015	-0.115 **
	(0.40)	(-0.12)	(-2.32)
$(\text{lnmachine})^2$	-0.006	0.025	0.021
	(-0.96)	(1.03)	(1.65)

Household characteristics			
Non-working	0.001	0.003	0.002
	(0.85)	(0.75)	(0.76)
Gender	0.002 *	-0.000	0.000
	(1.68)	(-0.10)	(0.03)
Age head	-0.001	0.008	0.006
	(-0.72)	(1.22)	(1.41)
Education head	0.001	0.009	0.028 **
	(0.20)	(0.42)	(2.25)
Farm characteristics			
Slope	-0.004 ***	-0.002	0.002
	(-4.46)	(-0.74)	(0.55)
Fertility	-0.062 *	0.028	-0.034
	(-1.95)	(0.26)	(-0.46)
Agro-ecological zones			
D1	0.413 ***	-0.365	-0.021
(1=zone 1, 0=otherwise)	(5.59)	(-1.23)	(-0.07)
D2	0.334 ***	-0.293	0.039
(1=zone 2, 0=otherwise)	(5.39)	(-1.49)	(0.13)
Intercept	14.4 *	6.80	10.7
	(1.92)	(0.91)	(1.01)
Number of observations	247	110	177
R^2	0.38	0.64	0.28

Notes:

1. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses.

2. Only 21 households planted Atlantic potatoes in 2007, so the production function for Atlantic potatoes cannot be estimated for the year 2007.

4A2: Regression results **2009**

	Grains	Cash crops	Atlantic potatoes	Other potatoes
		Levels of variable and quasi-fixed inputs		
lnwater	1.15	0.363 ***	2.12	-1.07
	(1.28)	(3.84)	(0.19)	(-0.28)
lnseed	1.06	0.085	7.58	-1.57
	(1.28)	(0.16)	(1.44)	(-0.59)
lnfertilizer	0.417	2.64 *	3.44	0.408
	(0.56)	(1.74)	(1.62)	(0.31)
lnlabour	0.137	-0.949	1.28	3.44 *
	(0.34)	(-1.02)	(0.42)	(1.82)
lnmachine	0.463	-0.404	-0.805	-1.17
	(1.01)	(-0.43)	(-0.48)	(-1.47)
lnwater*lnseed	-0.077	-0.062	-0.764	0.498
	(-0.64)	(-0.88)	(-0.98)	(1.29)
lnwater*lnfertilizer	-0.041	-0.347	-0.489	-0.251
	(-0.40)	(-1.62)	(-1.56)	(-1.13)
lnwater*lnlabour	-0.061	-0.102	0.341	-0.512 **
	(-1.33)	(-0.67)	(0.83)	(-2.17)
lnwater*lnmachine	-0.029	0.085	0.152	0.121
	(-0.48)	(0.60)	(0.56)	(1.19)
lnseed*lnfertilizer	-0.076	-0.076	-0.115	0.327 *
	(-0.98)	(-0.98)	(-0.60)	(1.69)
lnseed*lnlabour	0.005	-0.002	-0.531 *	0.237
	(0.08)	(-0.04)	(-1.88)	(1.45)
lnseed*lnmachine	-0.007	-0.008	-0.104	0.038
	(-0.13)	(-0.26)	(-0.64)	(0.55)
lnfertilizer*lnlabour	0.010	0.295 **	0.048	-0.335 **
	(0.20)	(2.31)	(0.41)	(-2.38)
lnfertilizer*lnmachine	-0.103 *	-0.094	0.085	0.043
	(-1.88)	(-0.92)	(0.58)	(0.74)
lnlabour*lnmachine	0.050 **	0.086	-0.097	-0.011
	(2.12)	(1.28)	(-0.99)	(-0.26)
$(\text{lnwater})^2$	-0.037	0.112	0.253	0.046
	(-0.64)	(1.44)	(0.33)	(0.14)
$(\text{lnseed})^2$	-0.032	0.094 ***	-0.020	-0.294
	(-0.50)	(3.61)	(-0.09)	(-1.48)
$(\text{lnfertilizer})^2$	0.070	-0.048	0.038	0.016
	(1.60)	(-0.65)	(0.53)	(0.50)
$(\text{lnlabour})^2$	-0.013	0.033	-0.037	0.005
	(-0.69)	(0.85)	(-0.22)	(0.07)
$(\text{lnmachine})^2$	0.010	0.026	0.054	0.008
	(1.14)	(1.08)	(1.11)	(0.40)
		Household characteristics		
Non-working	0.001	-0.003	-0.004	0.002
	(0.72)	(-0.69)	(-0.65)	(0.55)
Gender	0.000	-0.007 *	-0.003	0.003

	(0.08)	(-1.84)	(-0.57)	(0.77)
Age head	0.003	0.009	-0.001	0.003
	(1.41)	(1.43)	(-0.07)	(0.58)
Education head	-0.001	-0.007	-0.011	0.024
	(-0.15)	(-0.40)	(-0.35)	(1.63)
		Farm characteristics		
Slope	-0.004 **	0.006	0.002	-0.001
	(-2.51)	(1.42)	(0.19)	(-0.24)
Fertility	-0.057 *	-0.079	-0.128	-0.134 *
	(-1.87)	(-0.73)	(-0.73)	(-1.69)
		Agro-ecological zones		
D1 (1=zone 1, 0=otherwise)	0.187 ***	-0.535	-0.391	-0.153
	(2.69)	(-1.25)	(-0.72)	(-0.79)
D2 (1=zone 2, 0=otherwise)	0.141 **	-0.389	-0.074	0.002
	(2.35)	(-1.43)	(-0.19)	(0.01)
Intercept	-1.04	1.33	-30.8	9.61
	(-0.25)	(0.41)	(-0.68)	(0.68)
Number of observations	245	116	86	152
R^2	0.20	0.71	0.45	0.34

Note: *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels respectively. True parameters are presented, instead of the estimated coefficients, and t-statistics are in parentheses. Homogeneity restriction imposed before estimation.

5. Does output market development affect irrigation water institutions? [52]

Abstract

The main aim of this paper is to provide some insights into the impact of changing external conditions on irrigation water institutions in northern China. To this end, we perform a case study analysis of the impact of output market development on irrigation water trading, using data collected among 315 households in two surveys in Minle County, Zhangye City, Gansu Province, covering the years 2007 and 2009. The establishment of a large potato processing company in Minle County in 2008 provides a unique opportunity to examine the impact of an exogenous driving force on the functioning of water markets. Since Minle County is located within the water-saving pilot area of Zhangye City, our research also provides important insights into further policy reforms needed for establishing an efficient system of water allocation and trading. Our survey results indicate that water markets have emerged at a small scale in response to the development of the potato market in the region. Those who have started trading water rights tend to have more land with water use rights than other potato farmers. High transaction costs and information asymmetry between the government and water users, however, severely constrain the trading of water use rights in the region.

[52] This chapter is based on an article that has been accepted, subject to satisfactory moderate revision, for publication by *Agricultural Water Management*, as Lei Zhang, Xueqin Zhu, Nico Heerink and Xiaoping Shi "Does output market development affect irrigation water institutions? – Insights from a case study in northern China".

5.1 Introduction

China is a country with substantial water resources, but their regional distribution is highly unequal. Water availability in the north (757 m^3 per person in 2003) is almost 25 percent below the internationally accepted water scarcity threshold of 1,000 m^3 per person, while water availability in the south (3,208 m^3 per person in 2003) is relatively abundant (Shalizi, 2006).

The water resources available for agricultural production in China are rapidly declining due to increased water demand for industrial use and household consumption. The use of water in agriculture as a share of total water use has steadily declined from around 80 percent in 1980 to 61.3 percent 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). The Ministry of Water Resources of the P.R. China has initiated a number of pilot projects to gain experience with the development of water-saving irrigation systems. The first of these pilot projects was initiated early 2002 in Zhangye City, an oasis with rich agricultural resources in Gansu Province in northern China. Measures taken under this project include the construction of an engineering system that optimizes the water distribution and an innovative system of water resources property rights allocation and trading.

Zhang (2007) and Zhang et al. (2009) examine the water property rights system that was implemented in Zhangye City. These studies find that high transaction costs in some parts of the region, and management, legal, administrative and fiscal barriers in cases where transaction costs are low, discourage farmers from saving and trading surplus water. As a result, trading of water use rights is almost non-existent in this pilot project area.

Induced institutional innovation theory suggests that new institutions, such as tradable water use rights, may emerge when resources become more scarce due to growing population density, expansion of trade, or exogenous technological change (Hayami and Ruttan, 1985; Deininger, 2003). Although the theoretical literature elaborating the gains from institutional changes is vast and growing (Bromley, 1989; Saleth and Dinar, 2000), empirical studies examining drivers of institutional change are scarce due to lack of suitable data sets. Appropriately chosen case studies can provide deeper insights into the role of changing external conditions in stimulating institutional change, and may be used to formulate hypotheses on driving forces of institutional change that can be tested at a larger scale.

In Minle County, one of the six counties in Zhangye City, a large potato processing factory was established in 2008. To meet the demand of this factory, the area grown with potatoes in Minle County is rapidly being expanded at the instigation of the local government. Potatoes need a relatively large amount of water, but the water should be applied at a later stage in the season than many other crops grown in the region. A detailed examination of the changes in the allocation of water to farm households and the trading of water by households that occurred since 2008 in Minle County may add to a better understanding of the impact of output market development on water institutions.

The objective of this paper is to examine the impact of changing external conditions on the trading of irrigation water after the establishment of a large potato processing company in 2008 in Minle County, northern China. Among the various external conditions identified in the existing literature, such as macroeconomic reform, political reform, international agreements, natural calamities, and technological progress (Saleth and Dinar, 2004), this study focuses on the development of a market for agricultural output. We use data collected for the years 2007 and 2009 among 315 households to compare water trading before and after the potato processing company was established, and to examine how this trading was affected by changes made by the local government in the allocation of water to households in response to the arrival of the new factory. We find that water markets have emerged at a small scale in response to the development of the potato market in the region, but that high transaction costs and information asymmetry between government and water users may severely constrain the trading of water use rights in the region, and thereby limit also the potential efficiency gains that can be obtained from such markets.

The next section presents the theoretical framework, focusing in particular on efficiency gains obtained by water markets, the role of transaction costs and the impact of exogenous and endogenous factors on water management institutions. Section 5.3 briefly summarizes recent developments in irrigation water management in China, while section 5.4 introduces the research area (Minle County, Zhangye City) and the data collection method. In section 5.5, we use the survey data and insights gained through informal field visits to examine changes in water trading in the period 2007-2009 and to explain the very limited functioning of the water market in the region. Section 5.6 draws conclusions and discusses their policy implications.

5.2 Theoretical framework

Water is used for many purposes such as irrigation in agriculture, hydropower generation, domestic consumption, industrial use and for environmental purposes. Water has an economic value in all its competing uses and should therefore be treated as an economic good (ICWE, 1992). Due to its physical attributes, however, natural water is not a standard (private) economic good. Its consumption is non-rival when water is available in abundant quantities, but becomes rival when scarcity arises. Due to its fluid nature, exclusion is frequently impossible or may be obtained at high costs.

When scarcity arises, appropriate water institutions (such as well-defined water rights and water markets) are required to achieve an efficient allocation of water such that the total net benefits of water are maximized. Water institutions can be defined as the humanly devised constraints that regulate water development, allocation and utilization. Different institutions are combined in reality for water management, and continued public sector participation is required to deal with the public good property and fluidness of water and to address externalities (Griffin, 2006). As a result, various types of water institutions have been established in different areas around the globe.

According to the first welfare theorem, when transaction costs are zero, establishing water property (use) rights and water markets are important for achieving water use efficiency, because a resource being managed as a transferable property will cause a market to arise and the market will produce a resource-conserving signal, namely its price (Griffin, 2006). Water trading means the exchange of water rights by willing buyers and sellers. Water trading is a scarcity-addressing strategy to achieve economic efficiency because water can be used to the highest value (e.g. Zhu and Van Ierland, 2012).

When individual agents possess property rights in (natural) water, they will be able to exchange water for money or other property. Economic theory suggests that, in the absence of transaction costs, trading of water rights takes place until the marginal net benefits of all users are equalized. When a water trading scheme is implemented, the amount of water being transferred therefore depends on the differences between the marginal net benefits of different users. With a relatively large difference in marginal net benefits, water users are expected to trade water (transfer water rights). If there exist only small differences between the marginal net benefits, the traded amounts are expected to be small.

The existence of transaction costs in water market operations, however, can pose a serious hurdle for traders and limit the effectiveness of water exchange. When transaction costs exist, the welfare gains of tradable water will be reduced. If water is not very scarce, the transaction costs of trading water may be greater than the benefits. However, as demand for water expands over time and the shadow value of water increases, the benefits of trade will outweigh any transaction costs. Evidence for this is suggested by observations that in developed countries that allow water trading, trading activities increase significantly during drought years (Schoengold and Zilberman, 2007).

There exists a close linkage between the form of water institutions (including water markets) and the performance of water users (i.e. water allocation efficiency) through the effects that different water institutions have on the costs of exchanges (transaction costs) and on the production costs (transformation costs) (Saleth and Dinar, 2004; Griffin, 2006; Zhu and Ierland, 2012). Various factors affect this relationship between the form of water institutions and the performance of water users. Previous studies distinguish between endogenous factors such as water scarcity and financial constraints and exogenous factors such as macroeconomic reform, political reform, international agreements, natural calamities, and technological progress (e.g. Saleth and Dinar, 2004).

With respect to endogenous factors, the relative scarcity of water and the transactions costs required to enforce water rights and establish water markets are found to have significant impacts on the functioning of water institutions. Water scarcity, arising e.g. from competing uses of water, creates an endogenous pressure for change, inducing change in the performance of water institutions and thus water-using sectors (Saleth and Dinar, 2004). In locations where market exchanges are novel or infrequent, transaction costs can be especially high due to a lack of familiarity either by market participants, their legal representatives, or the administrative agency (Griffin, 2006).

Changes in the structure of water institutions are also affected by exogenous factors such as historical forces, political arrangements, demographic conditions, resource endowments, and economic development. Economic policies, especially macroeconomic and trade (export market) reforms, also play an important role in providing impetus for institutional changes within the water sector (Saleth and Dinar, 2004).

Given that various (endogenous and exogenous) factors influence the performance of water institutions and the water sector, it follows that similar water institutions that operate in different environments may greatly differ in their performance. It also means that the actual performance of an existing water institution in a given setting is an empirical question. Gaining insights into the most important factors explaining institutional change and performance in the water sector is not only relevant from a scientific point of view, but may also contribute to the design of policies that stimulate a more efficient use of limited water resources.

The pilot project 'Building a Water-saving Society in Zhangye City' provides a unique opportunity to examine changes in water institutions and their performance in a market-oriented setting. The establishment of a large-scale potato processing factory in Minle County makes it possible to examine the impact of a major exogenous driving force, namely rapid output market development, on water markets. Focusing on the existing water allocation and trade framework in Minle County, we intend to gain more insight into how the associated water markets work, to what extent water use rights are exchanged, and which factors drive the (absence of) exchange of water use rights, when such a major exogenous driving force comes into play.

5.3 Irrigation water management in China

Before the agrarian reforms in China in the late 1970s, water resources were managed primarily through collective ownership arrangements. Since the start of the reforms, a variety of institutional arrangements have been established to govern water resources (Mukherji and Shah, 2005; Zhang et al., 2008). Besides contracting out of water management and joint management through water users associations (WUAs), recent changes in irrigation water management in China mainly involve tradable water use rights and introduction of water pricing (Qu et al., 2011; Wang et al., 2010).

The establishment of water markets was made possible by the revised national Water Law that came into force in late 2002 (Yuan and Chen, 2005). However, water markets in China are at an elementary stage and are generally occurring outside of a structured trading framework (WET, 2006). Examples of water use rights (WUR) exchange to date mainly include sales from one local government to another, and the transfer of WUR from irrigation districts to industries following water efficiency initiatives (Gao, 2006; Speed, 2009). Notably, these have been driven by the relevant governments and not by the free market (Speed, 2009).

Water was generally considered a free good until the agricultural reforms, since when the central government encouraged the adoption of a system of volumetric surface-water pricing (Lohmar et al., 2003; Qu et al., 2011). Water fees were gradually introduced and increased since then in an effort to meet the cost of water supply and improve water efficiency. Current prices charged for irrigation water, however, are generally believed to be well below levels that are efficient (i.e. that markets would set). Irrigation water prices often do not even cover the costs of operating and maintaining irrigation systems (Hussain, 2005; Wang et al., 2004; Yang et al., 2003).

5.4 Description of the research area and data collection

In our research we use information that we collected via two surveys held in Minle County, Zhangye City, Gansu Province. In this section we first introduce the research area and then briefly discuss the method of data collection.

5.4.1 Research area

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 the 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 Ministry of Water Resources (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, which dried out in 1992 and an area of 200 km^2 around the lake became desert (MWR 2004; Zhang et al., 2009).

Minle County is located between the foothills of the Qilian Mountains and the lower lying Hexi corridor. Its total cultivated land area equals 860,000 mu, with irrigated land constituting 67 percent. Major crops in Minle County include barley, wheat, maize, sesame, rapeseed, garlic and potato[53]. Surface water is the major water resource for irrigated agriculture in the area. According to Water Bureau of Minle County, , the use of groundwater is less than 5 percent of total water use in irrigated agriculture due to the high costs of pumping water from the wells.

The water used for surface irrigation in Minle County is stored in five reservoirs in the Qilianshan mountains. Each of these reservoirs serves its own irrigation area within Minle County. One reservoir serves two irrigation areas, while the other reservoirs each serve one irrigation area. A county-level water management bureau (WMB) is responsible for the water allocation institutions within the region. Six 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 allocation to its member households. The households within each WUA are sub-divided into water user 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. A water price is charged to all farmers according to volume and is approximately 0.09 RMB/m^3 in both 2007 and 2009.

Water is allocated to farmland in the form of several rounds of irrigation each year. Standard water quantities per mu[54] are assigned for each round of irrigation, and 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 that was provided by a village to the construction of the reservoirs, and on other factors like WUR land obtained through auctions.

[53] Atlantic potatoes as well as some local varieties.
[54] 15 mu equals one hectare.

5.4.2 Data collection

A baseline survey, covering the year 2007, was carried out in May 2008. The collected information reflects the situation before the entry of the potato processing company, a joint venture[55] of a Dutch company and the local government of Minle County. A follow-up survey, covering the year 2009, was held in May 2010. Comparison of the outcomes of the two surveys allows us to examine the changes that took place in irrigation water allocation and water markets since the establishment of the new company and the concomitant expansion of the potato market.

The new company demands a specific variety of potatoes, named Atlantic potatoes, for processing into flakes and starch. In order to meet the growing demand for Atlantic potatoes, the local government assigned quota for Atlantic planting areas to lower level governments. And it also ordered the Water Management Bureaus (the 'sellers' of irrigation water) in the region to give priority to land planted with Atlantic potatoes in the allocation of water over the WUAs in their districts.

The water allocation priority policy requires that in spite of the water scarcity in this region, a sufficient amount of irrigation water has to be reserved for irrigating Atlantic potatoes. The remaining quantity of irrigation water is allocated to land planted with other crops. Specifically, water is allocated to Atlantic potatoes according to its actual planting area, while water allocation to other crops is based on the WUR area. Normally the WUR area is smaller than the actual growing area[56]. Moreover, two or three rounds[57] of irrigation are carried out for most crops, while four or five rounds are carried out for Atlantic potatoes.

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[55] The Government of Minle County owns 51% of the joint venture, and the Dutch company owns the other 49%.
[56] The average proportion of WUR land in total arable land is 72.6% for all households in our sample.
[57] Depending on the altitudes, some villages receive two rounds of irrigation, while others receive three rounds (to be explained later this section).

The surveys used for this study were carried out by staff and students from Gansu Academy of Social Sciences, Gansu Agricultural University, and Nanjing Agricultural University. Fifteen households per village were interviewed in 21 villages, giving us a dataset containing 315 observations[58] for the years 2007 and 2009 (see Wachong Castro et al., 2010 for a description of the sampling method). Out of these 315 households, 265 households were interviewed in both surveys. The dataset includes information about crop production, use of water and other inputs, water trading, WUA participation, water and other prices, land tenure and land use, and so on.

5.5 Water allocation and water markets in Minle County

Zhang et al. (2009) analyses the implementation of the tradable water rights system as part of the water-saving pilot project carried out in Zhangye City since 2002, using survey data covering the year 2003 collected in five different irrigation areas (out of the 25 main irrigation areas in Zhangye City). One of the selected irrigation areas, Hongshuihe, is located in Minle County while the other four are located in other counties. Their study finds no WUR exchanges in the four irrigation areas where there are groundwater sources, and a very limited number of water exchanges in the Hongshuihe irrigation area, where use of groundwater is not a realistic alternative due to the high pumping costs involved. Among the 380 households in the Hongshuihe irrigation area interviewed in their survey, five households traded WUR[59] with other households. All exchanges took place within the own village, and against payment. The average price was 0.025 USD/m^3 (or 0.20 RMB/ m^3)

[58] In two villages, 16 instead of 15 households were interviewed in May 2008. The last observation in these two villages was dropped from the sample so that we have 15 households in each village in each survey.
[59] For reasons mentioned below, we disregard the 8 so-called ‘long-term trades’ distinguished by Zhang et al. (2009) consisting of water and land use rights that are being transferred together.

According to our first survey in Minle County, none of the 315 interviewed households traded water in 2007. In the second survey round, however, 15 of the 315 interviewed households (4.8 percent) answered that they traded water in 2009. Among these 15 households, seven are living in the Hongshuihe irrigation area, where the water exchanges observed in the study by Zhang et al. (2009) occurred. Given that 105 out of the 315 households interviewed in our survey live in the Hongshuihe area, this means that 6.7 percent of the interviewed households in that area traded WUR in 2009. Table 5.1 summarizes the trend in WUR exchanges in the Hongshuihe irrigation area based on Zhang et al. (2009) and our two surveys. The data suggest an increasing trend, but overall the percentage of households involved in exchanging WUR remains very small.

Table 5.1: Water trading in Hongshuihe irrigation area in 2003, 2007 and 2009

	2003	2007	2009
Number of households interviewed	380	105	105
Number of households exchanging WUR	5	0	7
Percentage of households exchanging WUR	1.3	0	6.7

Sources: Zhang et al. (2009) for 2003; our surveys for 2007 and 2009

Water trading may possibly be related to land rental transactions among households, since rented land also needs water. Seven out of the 15 households that traded water in 2009 (i.e. 47 percent) were involved in the renting out/in of land. Among the 300 households that did not trade water in 2009, 128 (43 percent) rented out/in some land. In other words, land transfers do not seem to play a role in the reported water exchanges. When land is being rented out to other households, the water rights are normally part of the same deal and are unlikely to be considered by households as water trade.

Out of the 15 households that traded water in 2009, 12 were involved in water exchanges without payments (see Table A1 in the Appendix for details). That is to say, a household received an amount of water from another household in one round of irrigation and returned the same amount of water in another round, or even within the same round. Such water exchanges normally occur between households that are very familiar with each other. The quantities of water that were exchanged varied from 10 to 3000 m^3. Two of the 15 households bought water from another household (at a price of 0.1 RMB/m^3, roughly equal to the fee of 0.094 RMB//m^3 paid for the allocated water) in one irrigation round in 2009, and sold the same quantity of water (100 and 150 m^3, respectively) to the same household at the same price in another irrigation round in 2009. One household that exchanged water with another household also bought a large quantity of water (3,000 m^3) later in the season at a price of 0.2 RMB/m^3. And finally there was one household that received 900 m^3 of water without payment in 2009 and also bought some water (100 m^3) at a price of 0.16 RMB/m^3 early in the year.

What role did the establishment of the potato processing company and the priority given to Atlantic potatoes in water allocation play in promoting these water exchanges? Among the 15 households who traded water in 2009, ten households (i.e. 2/3) grew Atlantic potatoes that were supplied to the new company. Out of the 315 households that we interviewed, 105 (i.e. only 1/3) grew Atlantic potatoes in 2009. This result indicates that Atlantic potato growers were relatively more involved in water trade than other farmers.

As mentioned before, Atlantic potatoes require a relatively large amount of water, but later in the season. They do not need water during the first irrigation round (early May), when the seedlings are still small, but receive water during the other irrigation rounds and extra irrigation rounds later in the year. As discussed in section 5.2, water users have an incentive to trade WUR whenever the marginal net benefits of water differ between water users. For Atlantic potato growers, the marginal benefits of water are expected to be relatively low during the first irrigation round and much higher during the later rounds. In our data, however, we hardly find any Atlantic potato growers who provide water to other households during the first round (early May) and obtain water in return during a later irrigation round (see Table A1 in the Appendix). The spring period is a very dry season in Minle County, and hence there is a high demand for applying water to most crops during the first irrigation round. It may therefore be assumed that the marginal benefit of water is very high for all farmers during the first irrigation round, and no water trading takes place. Later in the year, when there is more precipitation, the marginal benefits of irrigating water become lower. The water that Atlantic potato farmers receive during extra irrigation rounds may not always fit the growing requirements of the crop. Hence, it makes sense for them to exchange part of this additional water with other households in their own water user group or village.

Why did only ten of the Atlantic potato growers trade water in 2009, and the other 95 did not? A number of factors may play a role. Firstly, households with better-educated heads possibly have more knowledge about water markets and may be more efficient farmers that obtain higher marginal net benefits of water. The average education level of the head of the household for all the non-trading households who planted Atlantic potatoes in 2009 is 7.95 years, while that of the households who traded water in 2009 is 8.50 years on average (see Table 5.2). But the difference is not statistically significant. Secondly, a larger area planted with Atlantic potatoes results in the allocation of more water due to the water allocation priority policy, and may induce more water trading. In 2009, the size of the area planted with Atlantic potatoes for the ten households that traded water was 1.04 mu while it was 0.91 mu for the other farm households growing Atlantic potatoes (Table 5.2). But again the difference is not statistically significant. Likewise, the difference in the total arable land size did not differ significantly between the two groups in 2009. One important aspect that differed significantly (at a 5% testing level) was the size of the WUR land (see the last two columns of Table 5.2). Atlantic potato farmers who traded water rights had significantly more WUR land (22.0 mu on average) than other Atlantic potato farmers (14.8 mu on average). As mentioned in Section 5.3, water is allocated to crops other than Atlantic potatoes according to their WUR area. Therefore, households owning land with a large WUR area receive relatively much water for irrigating all crops that they grow, and may find it profitable to transfer some of their surplus water to other households.

Table 5.2: Characteristics of Atlantic potato growers: water traders vs. non-traders

	Education of head (years)		Arable land (mu)		Atlantic potatoes area (mu)		WUR land (mu)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Atlantic growers	8.00	2.42	20.0	11.2	0.92	0.657	15.3	11.7
Water traders	8.50	2.97	22.0	12.4	1.04	0.847	20.0 **	7.0
Others	7.95	2.91	19.8	11.1	0.91	0.638	14.8 **	7.6
Whole sample	7.49	3.51	19.6	12.5	0.31	0.575	13.8	7.8

Notes: ** indicates that the difference between the group means is statistically significant at the 5% testing level. The differences between the mean values of the other variables are not significant at the 10% level for water traders and other Atlantic growers.

Another important aspect of the functioning of water markets is the pricing of water. Under a proper water trading scheme, the water price should reflect its marginal value to buyers and sellers. In the absence of transaction costs, each unit of water will be worth the same at the margin to each agent after the exchange. For this to happen, water users should be free to set their own prices for exchanged WUR. However, water prices are not fully market determined in Minle County. According to the Bureau of Water Resource Management in Zhangye City, the prices of exchanged water are not allowed to exceed 0.3 RMB/m^3. If a household charges a higher price for its WUR, the WUR allocated to that household can be withdrawn by the local government.

High transaction costs may also be an important obstacle to the development of water markets (see Section 5.2). Transaction costs faced by households interested in trading water include time and costs involved in acquiring information on possible water trading procedures, in searching for households willing to sell or buy water, in negotiating the conditions of the water transfer, and in monitoring and enforcing water transfers (see also Zhang et al., 2009). In this respect, trust may play an important role. Low levels of trust result in relatively high transaction costs. The exchanges of WUR that we observed in our survey all occurred between relatives or neighbors, where levels of trust tend to be high.

Information that we obtained during field visits and informal talks with farmers provides additional insights into the reasons why only few households traded their water rights. In the first place, the amount of water allocated to households is often considered insufficient for irrigating all the crops that they planted, let alone that they would have redundant water for selling. This implies that it is difficult for households willing to buy water to find potential sellers, given the prevailing water price ceiling. In the second place, if there exist large differences in marginal benefits of water between farm households, the incentives for exchanging water will be large. In our research area, however, differences in marginal benefits between farm households may be relatively small. Irrigation requirements mean that farmers need to tune their crop choice and management decisions with other households within the same WUGs and WUAs. As a result, farmers within the same village tend to grow similar crops with similar (planting and irrigation) technologies.

Costs of obtaining (reliable) information are an important element of transaction costs. In our survey held in May 2010 we asked questions about farmers' understanding of the tradability of their WUR in 2007 and 2009. Although the exchange of WUR is permitted since 2002 in this area, only 9.8% of the interviewed households were aware that they could exchange water with payment, while 24.1% realized that they were allowed to exchange water without payment in 2007. In 2009, these percentages were only slightly higher: 10.8% thought that they were allowed to exchange water with payment, and 27.9% thought that they were allowed to exchange water without payment (Table 5.3). Therefore, the information asymmetry between the government and water users may be one of the main obstacles of water trading in this region.

As mentioned above, the price that farmers can charge for water should not exceed 0.3 RMB/m^3. Theoretically, the price constraint is expected to affect the exchange of WUR, through limiting the supply of water and increase its demand. However, in our survey we found that only six people were aware of the upper limit set by the government. Therefore, the price limit does not seem to constrain the exchange of WUR in this case.

Table 5.3: Farmers' understanding of the exchange of Water Use Rights

Are you allowed to exchange water **without payment**?					
2007			2009		
Yes (%)	No (%)	No idea (%)	Yes (%)	No (%)	No idea (%)
24.1	52.4	23.5	27.9	48.9	23.2
Are you allowed to exchange water **with payment**?					
2007			2009		
Yes (%)	No (%)	No idea (%)	Yes (%)	No (%)	No idea (%)

9.8	64.4	25.7	10.8	62.5	26.7

Given the current low water price and limited availability of water, the marginal benefits of water will probably exceed the actual water price (0.09 RMB/m^3 on average) for many farmers. The lack of appropriate information and the low water price charged by the WMBs, however, limit the functioning of the water market even though a tradable WUR system has been introduced through the pilot project and even though the establishment of the large potato processing company has created more economic incentives for water trading. If farmers would be well-informed that they are allowed to exchange WUR and would be free in choosing a water price without any restriction, more farmers will be expected to sell or buy water at prices that most likely will exceed the current fixed water price and in some cases perhaps even the current ceiling on the water price.

5.6 Conclusions and policy implications

This case study analyses the impact of output market development on irrigation water institutions, using a two-year household survey data sets collected in Minle County in northern China. The study contributes to the research area of impact of output market development of the functioning of water markets, which has received very little attention in the existing literature so far. Our findings indicate that development of an output market does not tend to have significant impact on water markets, they however provide a basis of future research to be undertaken in this field.

Previous research by Zhang et al. (2009) based on a household survey data set covering the year 2003 shows that water exchange took place at a very small scale in Zhangye City after a system of tradable WUR was introduced in 2002. Our case study of Minle County, one of the six counties within Zhangye City, shows that a slightly larger water market has set off after the entry of a potato processing company in 2008. Potatoes need a relatively large amount of water, but they need it later in the season than many other crops grown in the region. To secure an adequate supply of potatoes to the newly established factory, the government of Minle County allocated more water to farmers planting Atlantic potatoes, the variety that the factory needs. Observed water trade in our survey of the year 2009 consists mainly of the exchange of water without payment between relatives or neighbors, and seems to be meant to improve the timing of water applications to crops with different seasonal water requirements. Yet, only 4.8 percent of the interviewed households were involved in WUR trade in 2009. A more detailed analysis of the water transactions made by these households shows that a relatively large share of Atlantic potato farmers are involved, and that these farmers tend to have better access to irrigation water than other (Atlantic as well as non-Atlantic) farmers.

We further find that high transaction costs, particularly costs of obtaining adequate information, and the existing information asymmetry between government and farmers may be two major factors limiting the trading of WUR and thus the overall functioning of water institutions which are supposed to improve water allocation efficiency. Our survey results indicate that in 2009, only 27.9 percent of the interviewed households was aware that they were allowed WUR without payment, while only 10.8 percent knew that they were allowed to charge money for exchanging WUR.

Efficient use of scarce water resources requires that the price of water reflects its true scarcity value. This can be achieved by leaving the prices of water resources to be decided by the market instead of setting a ceiling on the price that can be charged for trading WUR.

Creating proper institutions for the development of water markets, reducing transaction costs involved in using water markets (particularly through provision of more adequate information) and removing existing restrictions on water prices are important preconditions for improving economic efficiency of water use. In the implementation of these measures, due attention should be given to potential negative effects on the achievement of other important policy goals such as reduced income inequality and maintenance of grain self-sufficiency. If such negative effects are found to occur, appropriate counteracting measures may need to be undertaken without compromising the goal of achieving more efficient water use in irrigated agriculture.

Appendix 5A

Traded water quantities and prices in Minle County, 2009

Household	**Atlantic potato grower**	**Direction**	**Quantity** (m^3)	**Price** (RMB/ m^3)	**Time**	**Direction**	**Quantity** (m^3)	**Price** (RMB/ m^3)	**Time**
1	no	in	150	0*	NA	out	150	0*	NA
2	yes	in	440	0*	12 June	out	440	0*	12 July
3	no	in	10	0*	April	out	10	0*	June
4	yes	in	100	0.1	July	out	100	0.1	August
5	no	out	350	0*	August	in	350	0*	September
6	yes	in in	240 3000	0* 0.2	12 June 20 Sept.	out	240	0*	17 June
7	yes	in	400	0*	Early July	out	400	0*	End July
8	yes	out	150	0.1	May	in	150	0.1	June
9	yes	in	250	0*	May	out	250	0*	May
10	no	in	25	0*	3 June	out	25	0*	10 June
11	yes	in	500	0*	May	out	500	0*	May
12	yes	in	350	0*	August	out	350	0*	2010
13	yes	in	540	0*	20 June	out	540	0*	20 Sept.
14	no	in	900	0*	June	in	100	1.6	January
15	yes	in	100	0*	5 June	out	100	0*	20 June

Note: * refers to water exchange between different irrigation rounds, without any payment.

6. Conclusions and discussion

6.1 Introduction

The competition for scarce water resources is becoming more and more intense, particularly in developing countries. Agriculture is central in meeting this challenge because the production of food and other agricultural products takes around 70% of the freshwater withdrawals from rivers and groundwater (Molden, 2007). Water scarcity may become an important constraint on future food production growth (Rosegrant and Cai 2002; Dinar 2012), and policies and institutions are important for efficient and sustainable use of water resources (Binswanger-Mkhize, Meinzen-Dick et al. 2010).

In China the average amount of water per person is only 2300-2400 m^3/year, about one quarter of the world average (Falkenmark et al., 1989). Water available for use in agriculture in China has been reduced by increased water demand for industrial and consumption usage (increasing by 23.8 percent over the period 1997-2006). In addition, water resources are distributed in a highly uneven way across Chinese regions, and current water scarcity in the North is most intense (World Bank 2001).

In order to address the rapidly increasing resource scarcity, market-oriented instruments as well as institutional innovations like water pricing and water users associations (WUAs) have been introduced in recent years by the Chinese government (Qu et al., 2011). Analyzing the impact of these water policies and institutional innovations is of great importance, and can be used to inform policy makers about intended as well as unintended effects of their policies and institutional arrangements.

Empirical analysis of policies and institutions regarding irrigation water use in China are scanty due to limited data availability. Relevant topics analyzed in the available studies mainly include, among others, performance of farmer-managed systems through WUAs, and barriers of development of water markets. These existing quantitative analyses, however, suffer from a lack of well-established theoretical frameworks. This study aims to provide more insights into the household-level effects of some major recent water policies and institutions in northern China, by taking into account the specific local context.. In particular, existing differences in government objectives (such as sustainable water use, promoting cash crop production, and ensuring grain self-sufficiency) between different levels of government are taken into account. The policies and institutional innovations examined in this study include WUAs (Chapter 2), government intervention in the allocation of water (Chapters 3 and 4), and the establishment of a market for tradable water use rights (Chapter 5). Relevant theoretical frameworks are used in each of the chapters to guide the empirical analyses.

The study is based on a dataset collected through two surveys that were carried out in Minle County, Gansu Province in northern China in May 2008 and May 2010, covering information for the years 2007 and 2009. Econometric methods and a case study approach are used to examine the effects of the aforementioned policy interventions and institutional innovations on the surveyed households. The rest of this chapter proceeds as follows: Section 6.2 summarizes and integrates the main findings, and discusses the contribution to the available literature. The policy recommendations are then discussed in section 6.3. Finally, the limitations of this study and suggestions for future research are outlined in section 6.4.

6.2 Summary of the main findings

Conditions for successful performance of WUAs:

An important topic in the available literature on non-price factors in irrigation water management is the performance of farmer-managed systems through WUAs (Wang et al., 2005; Wang et al., 2006; Wang et al., 2010; Ricks and Arif, 2012; Phadnis and Kulshrestha, 2012). The limited available literature for northern China focuses on the performance of World Bank initiated WUAs versus other WUAs and on five key factors that have been identified by World Bank project officers as crucial factors in successful WUA performance. They neglect, however, other factors that have been identified in the available literature on sustainable governance of common-pool resources and which may play an important role in the sustainable management of irrigation water systems (Wade, 1988; Ostrom, 1990; Baland and Platteau, 1996; Agrawal, 2003; Ostrom, 2007; Ostrom, 2009; Ostrom, 2010).

By applying a theoretical framework developed by Agrawal (2003), we examine which WUA characteristics affect the water productivity of WUA member households. Our results indicate that WUA group characteristics, in particular group size, number of sub-groups and heterogeneity of land endowments, are important factors in explaining water productivity. Other factors that play a role include the pressure on the water resource caused by a large unmet water demand and the degree of dependency on the resource as measured by the share of households with migrant heads in a WUA. Another noteworthy result is that 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.

Impact of government interventions in water allocation on farmers' acreage allocation to different crops

Despite the economic liberalization process, the Chinese government at different levels continues to intervene into decision making processes for a variety of (often well-intended) reasons. Such interventions include, for example, farm household decision making on crops that will be planted and the preferential allocation of irrigation water allocation to households that plant specific crops. They may affect the planting of, and irrigation water use on, crops that are not subject to interventions. More insight is needed in such (frequently unintended) side-effects in order to assist policy makers in their decision making.

Existing studies of the effects of government interventions in farmers' production decisions focus in particular on input subsidies (e.g. Chibwana et al., 2011) and farm output price support (e.g. Floyd, 1965). The impact of direct government intervention in a major input market on farmers' cropping decisions is a neglected issue. In the research area of this study, the regional government intervenes in the availability of water for farm households by allocating more water to a specific cash crop (i.e. Atlantic potatoes) that it would like to promote. Assigning more irrigation water to one crop implies an indirect subsidy of the use of water on that crop and an indirect taxation of water applied in alternative uses.

The results of the empirical analysis confirm the well-known observation that direct government interventions often tend to have unintended side-effects. Specifically, while the government intervention in water allocation aims to stimulate the production of Atlantic potatoes, we find that farmers decisions on land allocated to Atlantic potatoes are not significantly affected. The survey answers given by interviewed households on questions about planting decisions indicate that Atlantic potato planting decisions are mainly taken by village leaders instead of households.

Due to the government intervention in water allocation, a smaller amount of water is available for other crops than Atlantic potatoes. The results of the empirical analysis show that farmers respond by planting more grain crops and fewer other potatoes (i.e. other varieties of potatoes than Atlantic potatoes), as potatoes have relatively large water requirements.

The finding that planting decisions of farm households are strongly affected by village leaders is consistent with findings for cotton farmers in southern Xinjiang (Spoor et al. 2013). Given the fact that contracts on high-value crops with processing companies and traders are frequently signed by village leaders and higher level governments in order to save on transaction costs, it may be expected that planting decisions in other parts of China are also strongly influenced by local governments. This finding clearly has important implications for the analysis of farm household behaviour in China, which tends to apply standard approaches derived from neoclassical micro-economic production and farm household theory. I will return to this issue in Section 6.4.

Economic valuation of irrigation water and the impact of government interventions in water allocation

Previous studies estimating the value of agricultural water in China have concentrated on comparing the valuation between different crops, based on cross section data. The main conclusion of these studies (e.g. Yang et al., 2003; Wang et al., 2003; Lohmar et al., 2003) is that the water price charged by the WMBs is considerably below its value.

This study adds to the available literature, for China as well as other countries, by examining the impact of a government intervention in water allocation to specific crops on (changes in) the economic value of crops. Two hypotheses on the economic values of different crops before and after the intervention are derived from standard micro-economic theory, and are tested with the household survey data set for Minle County.

The results show that before the water allocation intervention the valuation of irrigation water differed considerably between various crops, which is inconsistent with theoretical expectations. In particular, the returns of water used for grain crops are very low and are even below the water prices that are charged to farm households. Potential explanations of this finding are that a large part of grain crops are used for own consumption by households, and that farmers may have incentives to grow more grains and apply more irrigation water on them in order to receive (area-based) grain subsidies.

The regression results for the year after the government intervention in water allocation are consistent with the hypothesis that value of irrigation water is lower for the crop that receives extra water (Atlantic potatoes) than for other crops, and that the water value increases for those other crops. The only exception is the water value for grains, which remains low after the government intervention in water allocation and in fact underlies the water value of Atlantic potatoes. But the water values of other cash crops (i.e. other cash crops than Atlantic potatoes) and especially other potatoes (i.e. other potatoes than Atlantic potatoes) exceed those of Atlantic potatoes in our data set and increase over time as predicted by theory.

Impact of output market development on functioning of water markets

Market-based allocation of water resources is considered a key mechanism for promoting more efficient water use. Several studies have shown theoretically and empirically the benefits of such markets (Rosegrant and Binswanger, 1994; Rosegrant et al., 1995; Easter et al., 1998; Ringler et al., 2006). Water markets have emerged only recently in north China, and have received limited attention in the literature so far. Based on what is known for other countries (Grafton et al., 2012; Lefebvre et al., 2012; Wildman and Forde, 2012), issues related to property rights and transaction costs are expected to play a relatively major role in the development of water markets during the rapid transition process that the Chinese economy is undergoing. Empirical research examining in detail the water trading among farm households in pilot areas where innovative system of water resources property rights allocation and trading are implemented is needed to provide deeper insight into the factors that determine whether or not water markets are successful. The research area where the survey data for this study are collected is located within such a pilot area.

Available theory (summarized e.g. in Saleth and Dinar) suggests various factors that play a role in the performance of water institutions such as water markets. These factors may be grouped into endogenous factors such as water scarcity and financial constraints, and exogenous factors such as macroeconomic reform, political reform, international agreements, natural calamities, and technological progress. Given the establishment of a major potato processing company in the research area that became operational after the first survey year and before the second survey year, the focus of this study is on the impact of output market development as a major exogenous factor on the performance of the water market.

The survey results show that water markets have emerged at a very limited scale in response to the establishment of the potato processing company. Observed water trading in the survey is mainly the exchange of water without payment between relatives or neighbors, and seems to be meant to improve the timing of water applications to crops with different seasonal water requirements. Potatoes need a relatively large amount of water, but they need it later in the season than many other crops grown in the region. Those potato farmers who have started trading water rights tend to have more land with water use rights than other potato farmers in the research area. High transaction costs, particularly costs of obtaining adequate information, and information asymmetry between government and farmers, however, severely limit the trading of water use rights.

Conclusion

Various market-oriented instruments and institutional innovations like water pricing and WUAs have been introduced in recent years by the Chinese government to address the problem of growing water scarcity in northern China. Given the fast growth rates of the Chinese economy, the limited availability of water and land resources, and the process of economic and institutional transformation that the country is going through, important lessons can be learned from research on the irrigation policies and institutional innovations that are being implemented in northern China. Before implementing a new policy at a large scale, the Chinese government usually first experiments with the policy at a small scale in one or more pilot project areas. Lessons learned from these pilots are then taken into account when the policy is scaled up to the national level.

The research area in this study, Minle County in Zhangye City, Gansu Province, is particularly interesting for research on irrigation policies and institutions for two main reasons. In the first place, Zhangye City was the first region in China where the Ministry of Water Resources initiated a pilot project in 2002 to examine the implementation of tradable water use rights and other policy measures promoting water savings in agriculture. And in the second place, a large-scale potato processing company has been established in Minle County, and became operational in 2008. Because the factory mainly processes potatoes that are grown within Minle County, it allows us to examine in detail the impact of a major external driving factor of institutional change – growing output demand – on the functioning of (novel) irrigation water institutions

In the chapter on WUAs it is found that the external environment of WUAs, as measured by the share of land planted with marketed crops in a WUA, does not significantly affect the water productivity of member households. The water productivity of WUA member households is significantly affected by the size of a WUA and several other WUA characteristics, but the degree of involvement in cash crop production does not seem to play an important role. In the chapter on water markets it is found that markets for tradable water use rights have emerged at a very limited scale in response to the establishment of the potato processing company. Ten percent of the farmers that grow potatoes for the new factory were involved in water use rights transactions in 2009, while no trading of water use rights took place in the year before the factory became operational. High transaction costs and information asymmetry between the local government and farmers in the region, however, continue to serve as major bottlenecks for the further development of water markets.

In the chapters on farmers' cropping decisions and irrigation water valuation, a government intervention related to output market development, namely the allocation of additional water to farmers growing potatoes for the new potato factory, is examined. It is found that the intervention induces farmers to plant more grains instead of local potato varieties that are not sold to the new factory and that require more water than grains. But the share of land allocated to the potato variety that is sold to the new factor is not affected, because its planting decisions are mainly taken by village leaders instead of households. In the chapter on irrigation water valuation it is found that the government intervention augments existing economic inefficiencies in water allocation. Estimated water values are consistent with the hypothesis that increased water allocation to a specific crop causes the value of irrigation water used on that crop to be lower than the value of irrigation water used on other crops.

In conclusion, the empirical results presented in this study show that output market development had just a limited impact on the development of a tradable water use rights market in Minle County, and no significant impact on water productivity. The government intervention in irrigation water allocation that accompanied the introduction of the new cash crop in the region led to economic inefficiencies in the allocation of irrigation water and in farmers' cropping choices.

6.3 Policy implications

In this section the policy implications of the research findings will be stipulated by suggesting some policy measures for improving the management of water resources. A few important ongoing water policies and institutional innovations in northern China are analyzed separately in this study. The revealed impacts of these policies and institutions provide more insights to policy makers into whether their interventions in water resource management have achieved their intended goals, and what unintended effects have been generated. Since the research area (i.e. Minle County) is located within the water-saving pilot area of Zhangye City, these policy implications may guide future policy making regarding irrigation water use at a larger scale.

Increasing irrigation water productivity is of crucial importance for maintaining food self-sufficiency, a major national-level policy goal in China. Collection action within WUAs may play an important role in this respect. Much attention is paid by policy makers and in the available literature to the five so-called key design principles of WUAs as identified by World Bank project managers. The findings in Chapter 2 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 it is found 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 possibly even farm income levels, if these characteristics are taken into account and, wherever possible, manipulated in appropriate directions.

The impact of a government intervention in the allocation of irrigation water is examined in Chapter 3 and Chapter 4. With regard to crop choices of farm households, the empirical evidence in Chapter 3 indicates that planting decisions of the crop that receives additional water (i.e. Atlantic potatoes) are not affected because those planting decisions are mainly taken by village leaders. Instead, the evidence indicates that the policy intervention induces a shift in planted land area from other potato varieties to grains, because Atlantic potatoes require more water than other potato varieties, while grains need less water than both Atlantic potatoes and other potato varieties. In other words, the government intervention in water allocation induces an economic inefficiency that is expected to influence farm household incomes in a negative way. More evidence of the inefficiency created by the government intervention is presented in Chapter 4. In theory the value of irrigation water should be equal for all crops. But the estimates presented in Chapter 4 show that the water value is lower in Atlantic potatoes than in other potato varieties and in other cash crops. Moreover, the value of water has gone up for other potato varieties and other cash crops after the intervention. Interventions in water allocation may be motivated by the need to increase the yields and profits of a newly introduced crop, so that farmers become more familiar with the crop and its management needs. Such interventions should, however, be temporary and be abolished when farmers have become accustomed to the new technology. In addition, local governments should take into consideration the economic inefficiencies that may be created by an intervention when deciding whether or not to stimulate a specific crop by intervening in the allocation of irrigation water.

The third and last policy that was examined in this study is the introduction of markets for tradable water use rights. The establishment of water markets is a major element of the pilot project in Zhangye City, and some local officials claim that it is a big success, saving about one-sixth of the annual water consumption (Zhao, 2007; Lin, 2008). The reality on the ground, however, is quite different. The data presented in Chapter 5 confirm results of earlier studies showing that hardly any water is being traded among households in the region. Even though an important output market is developed in Minle County, the county within Zhangye City where the data for this study were collected, the trading of water use rights within that county remains very limited. The development of well-functioning markets for irrigation water requires that a number of basic conditions are satisfied. These conditions include the reduction of information costs and other transaction costs involved in using water markets and reducing information asymmetry between the local government and farmers by improving information access for farmers. In particular, farm households need adequate information about the prices that can be charged for traded water (i.e. to what extent farmers have the freedom to charge their own prices), and about potential sellers/buyers of water. Results of the valuation of irrigation water (Chapter 4) indicate that the returns of irrigation water used on non-grain crops exceed the water prices that are charged to farmers. Therefore, when the basic conditions for a properly functioning water market are met, trading of water use rights is expected to become more popular and to provide an important contribution to increased water productivity in the research area of this study as well as in other parts of northern China where similar policies are implemented.

6.4 Limitations and suggestions for future research

The research done in this study has a number of limitations that may be addressed in follow-up studies that address the issue of follow-up research on policies and institutions in irrigation water management in northern China. These limitations concern the approaches used in each of the empirical chapters as well as the study as a whole.

The WUA characteristics used as explanatory variables of water productivity in Chapter 2 are based on the theoretical framework formulated by Agrawal (2003). Not all elements of that framework are included in the analysis. Only those elements were included for which suitable indicators can be identified in the survey data set and for which the indicators show a sufficient degree of variation between the WUAs in the sample. As a result, the roles of a few factors as identified in the theoretical framework have not been tested in this study. For example, according to Agrawal (2003), appropriate levels of external aid are needed in cases where local residents may not undertake conservation activities without such compensations. The amount of government subsidies (e.g. for canal construction and maintenance) received by the WUAs may be used as an appropriate indicator in this regard. However, only two out of the 21 WUAs in the study area received such subsidies during the surveyed year. The variation between WUAs in this indicator is therefore too limited to be included in the empirical analysis.

In Chapter 3, we concluded that the government intervention in water allocation results in a shift from planting local potato varieties towards grains with relatively low water requirements. Further research is required to investigate whether it is the water requirements of different crops or other factors that motivate farmers to switch between the two groups of crops. Moreover, the reason for the insignificant response of land allocated to cash crops needs further investigation. In particular, given the role played by village leaders in planting decisions for Atlantic potatoes, it may be investigated to what extent farmers' decisions on cash crop growing are influenced by the local government (village leaders).

In Chapter 4, the theoretical hypotheses were partly confirmed by the empirical results. Yet, other factors that changed during the period 2007-2009 may at least partly have been responsible for the results that were obtained in addition to the government intervention in water allocation. Further research is needed to identify to what extent the results are confounded by such parallel changes. Another noteworthy finding is the very low valuation of irrigation water used on grain crops. Research is needed to test the propositions that were forwarded in that chapter to explain this finding.

In Chapter 5, a case study approach was used to examine the development of the water market in the study region. The limited number of observations on water trading did not allow the application of statistical methods. Given that water trading is recently also being promoted in other parts of northern China, more insights into the drivers of and obstacles to water market development may be obtained by doing a large-scale survey across different regions and applying appropriate econometric methods to the collected data.

The research carried out in this study raises a number of methodological issues that may be addressed in further research. In the first place, the research was carried out in a region where water markets are being promoted and where the local government actively intervenes in the allocation of irrigation water. No comparison was made with regions having comparable characteristics that did not implement similar policies. Further research should preferably concentrate on making a comparison between a region undergoing a 'natural experiment', like the region examined in this study, and a 'control group' region.

A second major methodological issue concerns the use of farm household data and microeconomic theory for analyzing cropping decisions in China. In Chapter 3 it was found that planting decisions of the newly introduced cash crop are strongly affected by village leaders. Given the fact that contracts on high-value crops with processing companies and traders are frequently signed by village leaders and higher level governments in order to save on transaction costs, it may be expected that the independence of farm households in making cropping decisions is declining throughout China. Little empirical evidence is available, however, on this phenomenon, and empirical studies of cropping decisions continue to treat farm households as the unit of decision making. Further research in this field should focus on the interactions between farm households and their local leaders in the decision making on cash crops, and should preferably also take into account the need for tuning planting and irrigation decisions for farmers belonging to the same farmer group within WUAs.

Finally, the scope of the research issues addressed in this study is limited. A related major policy issue that is not addressed in this study is the extent to which a policy that would raise the price of irrigation water to a level that more closely reflects its actual scarcity value (as estimated in Chapter 4) would increase the level of poverty among farm households and the degree of income inequality among farm households. A related issue would be the impact of markets for tradable water use rights on rural poverty and income inequality. Although these issues are beyond the scope of the current study, research on them is urgently needed in order to provide an adequate foundation for future irrigation water policies in China.

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Summary

Water is increasingly becoming a limiting factor for sustainable economic growth and development, particularly in developing countries. Besides technical innovations, water institution reforms may contribute to improving water allocation decisions. Appropriately designed water institutions can motivate water users to conserve and use water efficiently for irrigation and other uses.

In northern China, growing demands on agricultural water due to relatively low water availability and increasing grain production are putting more and more pressure on improving water resource management. The Ministry of Water Resources of the P.R. China has initiated a number of pilot projects to gain experience with the development of water-saving irrigation systems. These pilot projects focus on the construction of engineering systems as well as institutional innovations in water resource management. Analysing the household-level effects of the implemented measures is hence of great importance for further policy development.

The project 'Building a Water-saving Society in Zhangye City', initiated early 2002 in Zhangye City in northwest China, is the first pilot project of this kind in China. It provides a unique opportunity to examine the economic effects of changes in water policies and institutions. Minle County, the research area for this study, is located within Zhangye City. A large potato processing company was established in Minle County in 2008. After the factory started its activities, the local government intervened in the allocation of irrigation water within the region by assigning more water to a specific variety of potatoes (i.e. Atlantic potatoes) that the factory needs for processing. This further makes Minle County an interesting case for analysing the link between output market development and institutional change in irrigation water management.

The general objective of this study is to empirically investigate the household-level impacts of policies and institutional changes in irrigation water use. From this general objective, the following four specific objectives are defined and analysed in separate chapters. 1) To examine the impact of the institutional setup of Water Users Associations (WUAs) on productivity of irrigation water use by the WUA member households, based on a user-based resource governance framework. 2) To analyse the effects of a policy affecting the availability of water for different crops on farmers' acreage allocation among crops. 3) To evaluate the internal valuation (i.e. marginal value) of irrigation water, before and after the introduction of the water policy as explained above. 4) To investigate the effects of output market development on irrigation water trading.

The information used for the empirical analyses mainly comes from two surveys that were carried out in Minle County in May 2008 and May 2010. These surveys cover information for the years 2007 and 2009, that is before and after the potato processing factory became operational. A stratified sampling approach was used for selecting the households and WUAs to be interviewed in the surveys. Additional interviews were held by the author in August 2010 with the Water Management Bureaus (WMBs) that are responsible for water allocation within the seven irrigation areas in Minle County.

Chapter 2 investigates the underlying causes of differences in WUA performance by analysing the impact of WUA characteristics on the productivity of irrigation water use. Total crop production value and household income obtained from crop production, both expressed per m^3 of water, are used as dependent variables in the empirical analysis. The explanatory variables in the analysis are derived from an established user-based resource governance framework, that specifies the conditions under which user groups are expected to sustainably govern common-pool resources. These conditions are grouped into resource characteristics, group characteristics, relationships between resources and user groups, and the external environment (markets, technology). Applying a random intercept model, the estimation results show that group characteristics, particularly group size and number of water users groups, and the existing pressure on available water resources are important WUA characteristics explaining water productivity.

Chapter 3 analyses the impact of the local government intervention in irrigation water allocation on farmers' crop planting decisions. A system of unconditional crop acreage demand functions depending on prices of variable inputs, levels of quasi-fixed inputs and prices of outputs is estimated. Two hypotheses are tested: Firstly, the government intervention results in an increase in land allocated to Atlantic potatoes and a decrease in land allocated to other crops; Secondly, among the alternative crops (i.e. other crops than Atlantic potatoes), the water policy is expected to cause a relatively small response for grain crops, because grains are mainly used for domestic consumption. The empirical results do not support the first hypothesis. The increased water allocation to Atlantic potatoes does not significantly affect the land allocated to this crop, because its planting decisions are mainly taken by village leaders instead of households. Instead, the intervention results in a shift from planting potatoes towards grains with relatively low water requirements. The second hypothesis is partly supported by the empirical results. The estimated impact of the government intervention is found to be stronger for local potato varieties than for grains, but the impact on the area planted with cash crops does not differ significantly from zero. Output prices seem to play a more important role in cash crop planting decisions than the water allocation intervention.

Chapter 4 examines the economic valuation (i.e. marginal value) of irrigation water, before and after the local government intervention in water allocation. To accomplish this, a system of translog production functions is estimated. Two hypotheses are tested: Firstly, the valuation of irrigation water is expected to be equal across different crops before the start of the new water policy. And secondly, valuation of irrigation water is expected to be lower for Atlantic potatoes as compared to the alternative crops after the water policy change. The empirical results do not support the first hypothesis. The valuation of irrigation water used on grain crops is very low, and is even below the actual water prices charged to farm households. This is probably due to self-consumption of grain by households, and to government subsidies for grain farmers that are based on the planted area with grains. The second hypothesis is supported by the empirical results, except for grains. The valuation of irrigation water used on Atlantic potatoes is lower than the value of water used on other (non-grain) crops. Moreover, the returns for irrigation water used on other crops are higher in the year after the water allocation intervention than in the year before the intervention.

Chapter 5 aims to provide insights into the impact of output market development on the trading of water use rights by farm households. The results of the two farm household surveys indicate that water markets have emerged at a small scale in response to the development of the potato market in Minle County. Observed water trade in the second survey, that was held after the establishment of the potato processing factory, consists mainly of the exchange of water without payment between relatives or neighbours, and seems to be meant to improve the timing of water applications to crops with different seasonal water requirements. Those who have started trading water rights tend to have more land with water use rights than other potato farmers. High transaction costs and information asymmetry between the government and water users, however, severely constrain the trading of water use rights in the region.

Chapter 6 summarizes and integrates the main findings, discusses the policy implications and the limitations of the research, and presents some suggestions for further research.

Samenvatting

Water is in toenemende mate een beperkende factor aan het worden voor duurzame economische groei en ontwikkeling, met name in ontwikkelingslanden. Naast technische vernieuwingen kunnen hervormingen van waterinstituties een bijdrage leveren aan het verbeteren van beslissingen inzake watertoewijzing. Waterinstituties die op een juiste wijze ontworpen zijn, kunnen watergebruikers motiveren om water te besparen en efficiënt te gebruiken voor irrigatie en andere doeleinden.

In het Noorden van China leidt de stijgende vraag naar water voor gebruik in de landbouw door een relatief geringe waterbeschikbaarheid en toenemende graanproductie, tot een steeds grotere druk om het waterbeheer te verbeteren. Het Ministerie van Waterstaat van de Volksrepubliek China heeft een aantal proefprojecten geïnitieerd om ervaring te verwerven met het ontwikkelen van waterbesparende irrigatiesystemen. Deze proefprojecten zijn gericht op het construeren van technische systemen alsook op institutionele vernieuwingen in waterbeheer. Het analyseren van de effecten van de genomen maatregelen op het niveau van huishoudens is derhalve van groot belang voor verdere beleidsontwikkeling.

Het project ‘Opzetten van een Waterbesparende Samenleving in Zhangye City’, dat begin 2002 geïnitieerd werd in de prefectuur Zhangye City in het noordwesten van China, is het eerste proefproject van dit type in China. Het biedt een unieke gelegenheid om onderzoek te doen naar de economische effecten van veranderingen in waterbeleid en -instituties. Het district Minle County, het onderzoeksgebied van deze studie, ligt binnen Zhangye City. In 2008 vestigde zich in het district Minle County een groot aardappelverwerkend bedrijf. Nadat de fabriek gestart was met zijn activiteiten, intervenieerde de lokale overheid in de toewijzing van irrigatiewater binnen het gebied en stelde meer water beschikbaar voor een specifieke

aardappelras (‘Atlantic’), dat de fabriek nodig heeft voor verwerking. Om die reden is het district Minle County tevens een interessante casus voor de analyse van het verband tussen productmarktontwikkeling en institutionele verandering in het beheer van irrigatiewater.

Het algemene doel van deze studie is het verrichten van empirisch onderzoek naar de effecten op huishoudniveau van beleid en institutionele veranderingen betreffende het gebruik van irrigatiewater. Op basis van dit algemene doel worden de volgende vier specifieke doeleinden gedefinieerd en behandeld in afzonderlijke hoofdstukken: 1) Analyse van de invloed van de institutionele opbouw van watergebruikersverenigingen (Water Users Associations, ofwel WUA’s) op de productiviteit van irrigatiewater gebruikt door huishoudens die deel uitmaken van een WUA, op basis van een gebruikers-georiënteerd theoretisch raamwerk van het beheer van hulpbronnen. 2) Analyse van de effecten van een beleid dat de waterbeschikbaarheid voor verschillende gewassen beïnvloedt, op het landareaal dat boeren aan de verschillende gewassen toewijzen. 3) Evaluatie van de interne waardering (marginale waarde) van irrigatiewater, vóór en na invoering van het hierboven beschreven waterbeleid. 4) Analyse van de effecten van productmarktontwikkeling op handel in irrigatiewater.

De informatie die werd gebruikt voor de empirische analyses is hoofdzakelijk afkomstig uit twee enquêtes die werden uitgevoerd in het district Minle County, in mei 2008 en mei 2010. Deze enquêtes bevatten informatie over de jaren 2007 en 2009, dat wil zeggen vóór en na het operationeel worden van de aardappelverwerkende fabriek. Bij de selectie van huishoudens en WUA’s die tijdens de enquêtes zouden worden geïnterviewd, werd gebruik gemaakt van een gelaagde steekproef. In augustus 2010 werden door de auteur aanvullende interviews afgenomen bij de Watermanagementbureaus (WMB’s) die verantwoordelijk zijn voor watertoewijzing binnen de zeven irrigatiegebieden in het district Minle County.

In Hoofdstuk 2 worden de onderliggende oorzaken voor prestatieverschillen van de WUA’s onderzocht door middel van een analyse van de impact van WUA-kenmerken op de productiviteit van irrigatiewater. De totale waarde van de geproduceerde gewassen en het huishoudinkomen verkregen uit die gewassen, beide uitgedrukt per kubieke meter water, worden gebruikt als afhankelijke variabelen in de empirische analyse.

De verklarende variabelen in de analyse zijn afgeleid van een gevestigd gebruikers-georiënteerd theoretisch raamwerk van het beheer van hulpbronnen dat de voorwaarden specificeert waaronder gebruikersgroepen verondersteld worden gemeenschappelijke hulpbronnen duurzaam te beheren. Deze voorwaarden worden in een viertal groepen verdeeld, t.w. kenmerken van de hulpbron, groepskenmerken, verbanden tussen hulpbronnen en gebruikersgroepen, en externe omgeving (markten, technologie). De resultaten van een zg. *random intercept*-model geven aan dat groepskenmerken, met name groepsgrootte en aantal watergebruikersgroepen, en de bestaande druk op beschikbare waterbronnen, belangrijke factoren zijn in de verklaring van waterproductiviteit.

In Hoofdstuk 3 wordt de impact van een interventie van de lokale overheid in de toewijzing van irrigatiewater op beslissingen van boeren betreffende de aanplant van gewassen geanalyseerd. Er wordt een empirische schatting gemaakt van een systeem van onvoorwaardelijke gewasareaal-vraagfuncties, met prijzen van variabele inputs, niveaus van quasi-vaste inputs en productprijzen als verklarende variabelen. Twee hypotheses worden getoetst: ten eerste, de overheidsinterventie resulteert in een toename van het areaal waarop Atlantic aardappels worden geteeld en resulteert in een afname van het areaal met andere gewassen; ten tweede, wat betreft de andere gewassen wordt verwacht dat de interventie een relatief kleine respons oplevert voor granen, aangezien granen hoofdzakelijk gebruikt worden voor eigen consumptie door huishoudens.

De eerste hypothese wordt niet ondersteund door de empirische resultaten. De toegenomen watertoewijzing aan Atlantic aardappels heeft geen significante invloed op het landareaal waarop dit gewas wordt geteeld, aangezien de plantbeslissingen betreffende Atlantic aardappels hoofdzakelijk genomen worden door de dorpsleiders in plaats van huishoudens. In plaats daarvan resulteert de interventie in een verschuiving in het areaal beplant met aardappels naar granen met relatief geringe waterbehoeften. De tweede hypothese wordt gedeeltelijk ondersteund door de empirische resultaten. De geschatte impact van de overheidsinterventie blijkt sterker te zijn voor lokale aardappelrassen dan voor granen, maar de impact op het areaal dat beplant wordt met marktgewassen verschilt niet significant van nul. Marktprijzen lijken een belangrijker rol te spelen bij de plantbeslissingen voor marktgewassen dan de interventie in de watertoewijzing.

In Hoofdstuk 4 wordt de economische waardering (marginale waarde) onderzocht van irrigatiewater, voor en na interventie door de lokale overheid in de watertoewijzing. Om dit te realiseren wordt een empirische schatting gemaakt van een systeem van translog-productiefuncties. Er worden twee hypothesen getoetst: ten eerste, met betrekking tot de waardering van irrigatiewater wordt verwacht dat deze gelijk voor de verschillende gewassen voor de interventie in de watertoewijzing. En ten tweede wordt verwacht dat na de waterbeleidswijziging de waardering van irrigatiewater lager zal zijn voor Atlantic aardappelen dan voor alternatieve gewassen. De eerste hypothese wordt niet ondersteund door de empirische resultaten. De waardering van irrigatiewater dat wordt gebruikt in graangewassen is erg laag en ligt zelfs lager dan de feitelijke waterprijzen die aan boerenhuishoudens in rekening worden gebracht. Dit is waarschijnlijk te verklaren uit het eigen gebruik van graan door huishoudens en uit overheidssubsidies aan graanboeren die worden gebaseerd op het areaal dat met graan beplant is. De tweede hypothese wordt ondersteund door de empirische resultaten, behalve voor granen. De waardering van irrigatiewater voor Atlantic aardappelen ligt lager dan de waarde van water voor andere gewassen, behalve graan. Bovendien liggen de opbrengsten van irrigatiewater dat gebruikt wordt voor andere gewassen, hoger in het jaar na de interventie in de watertoewijzing dan in het jaar voorafgaand aan de interventie.

Hoofdstuk 5 is gericht op het verkrijgen van inzicht in de impact van marktontwikkeling voor landbouwproducten op de handel in watergebruiksrechten door boerenhuishoudens. De resultaten van de twee enquêtes onder boerenhuishoudens geven aan dat er op kleine schaal waterrechten verhandeld worden als respons op de ontwikkeling van de aardappelmarkt in het district Minle County. De waargenomen handel in water tijdens de tweede enquête, die gehouden werd na komst van de aardappelverwerkende fabriek, bestaat voornamelijk uit het uitwisseling van water zonder betaling tussen verwanten of buren, en lijkt bedoeld te zijn om de timing van het watergebruik in gewassen met verschillende seizoensafhankelijke waterbehoeftes te verbeteren. Degenen die waterrechten zijn gaan verhandelen zijn gewoonlijk in bezit van meer grond met watergebruiksrechten dan andere aardappelboeren. Hoge transactiekosten en informatieasymmetrie tussen overheid en watergebruikers beperken echter in hoge mate het verhandelen van waterrechten in het gebied.

In Hoofdstuk 6 worden de belangrijkste bevindingen samengevat en geïntegreerd, worden de beleidsimplicaties en de beperkingen van het onderzoek besproken, en worden enige suggesties gedaan voor nader onderzoek.

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Looking back now I feel pleased to have made that decision, as I consider it to be a milestone in my life. I am very much grateful for the assistance from all the people and organizations who have contributed to the completion of my thesis.

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Being born in a fertile region in Southeast China, I met lots of expected and unexpected difficulties when carrying out fieldwork in a water-scare region in Northwest China. Hence I would like to express my gratitude to all of the organizations and officials in my research area for the efforts that you made in setting up the field work: Gansu Academy of Social Sciences, Water Management Bureau (WMB) of Minle County, and WMBs of all the irrigation areas. Thanks for your help, I managed to overcome these difficulties and finally completed my research. I will always remember your hospitality and our talks over very nice local dishes and drinks.

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Training and Supervision Plan (TSP)

Wageningen School of Social Sciences

Name of the course	Department/ Institute	Year	ECTS (=28 hrs)
Project related competences			
Econometrics (AEP 21306)	WUR	2009	6
SURE course on institutional theories	WUR, ENP	2008	4.3
The economic institutions of agriculture of food & rural areas: institutional dynamics, organizations and governance	WUR, AEP	2009	4
Writing research proposal	WASS	2008-2009	6
General research related competences			
Mansholt introduction course	MG3S	2008	1.5
Scientific Writing	WGS	2009	1.5
Techniques for literature search and argumentation building for SURE PhD students	WUR, ENP	2009	1.8
Career related competences			
"Irrigation water management in northern China"	Shanghai, China	2010	1
"Water allocation mechanisms: An overview"	Shenyang, China	2009	1
"Impact of water allocation interventions on farmers' cropping decisions"	Kaifeng, China	2012	1
"Water users associations and agricultural water use efficiency"	Foz do Iguacu, Brasil	2012	1
"Impact of water allocation interventions on farmers' cropping decisions"	Beijing, China	2012	1
"Water users associations and agricultural water use efficiency"	Nanjing, China	2012	1
Annual workshops SURE	Wageningen. Nanjing, Lanzhou	2009-2012	4
TOTAL			35.1

Curriculum vitae

Lei Zhang was born on 23 February, 1984, in Jiangsu in P.R. China. Lei accomplished her BSc and MSc studies in the College of Economics and Management at Nanjing Agricultural University, P.R. China (2002 - 2008). During this period Lei focused her research on food safety management, and at the meantime she worked as a College Counsellor for undergraduate students in the university.

Lei started her PhD study in Development Economics at Wageningen University in September 2008. Her PhD research concerns the effects of institutional design and its ongoing transformation on sustainable agricultural water use in China. During the past four years she worked as a Teaching Assistant for a course 'Methodology for Field Research in the Social Sciences', and as a Scientific Researcher for a project 'Food security and the productivity, health and nutrition nexus', both at Wageningen University.

Lei actively participated in international conferences and presented her papers. These conferences, among others, include the 28th ICAE (International Conference of Agricultural Economists) conference held in Foz do Iguacu in Brazil and the 2012 CES (Chinese Economists Society) conference held in Kaifeng in P.R. China.

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