Assessment of Water Rights and Irrigation Pricing Reforms in Heihe River Basin in China

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Abstract: The purpose of this paper is to understand the progress of water rights and irrigation pricing reform in Heihe River Basin (HRB) and their influence on irrigation application. The data came from a village and household level survey conducted in 2009 and 2014 in five counties in Zhangye City, HRB. The main component of reforming water rights was issuing water certificates to individual farmers. However, the share of villages that have done so dropped from 70% in 2004 to 28% in 2014. Water pricing reform raised the price of water. For the pricing of surface water, which consists of an area-based fee and a volumetric price, the volumetric price was increased. Econometric results show that amending water rights substantially reduced irrigation application in the early stage of reform (by 2009) but not in the later phase (by 2014). In contrast, higher water prices lowered irrigation applications significantly at both the early and later stages. Further analysis indicates that due to ineffective implementation, high cost of implementation due to large number of farmers, variations in water supply from year to year, and small farm sizes, little benefit is gained from trading. All of these factors played a role in the failure of water rights reforms.

Keywords: water rights reform; irrigation pricing reform; irrigation application; Zhangye City in Heihe River Basin; China

1. Introduction

Expanding irrigation in the 20th century has resulted in serious degradation of the ecological environment in China's Heihe River Basin (HRB). With the low levels of annual precipitation at around 108 mm, agricultural production in the HRB depends heavily on irrigation. Most of the agricultural production occurs in the midstream of the HRB and takes up as much as 90% of total water use. From 1950 to 2000, irrigated areas in the HRB have increased from 100,000 to 300,000 ha (Heihe River Bureau). As a result, the runoff downstream has declined from 1.5 billion·m^3 in the 1950s to about 0.6 billion·m^3 in 1999 [1]. The number of days during which Heihe River is dry increased from 100 to 200 days [2,3]. Lakes, springs, and marshlands in the region also dried up. Other consequences include declining groundwater levels and the deterioration of water quality. Furthermore, the area of Populus euphratica forest has shrunk from 50,000 ha in 1944 to 23,000 ha in 2000; 78% of the forest lost its ability to naturally regenerate [2–4]. About 50% of the available land degraded from wetlands and grasslands to desert and salt marshes, which grew by 8660 ha per year [2–4].

Under such dire circumstances, Heihe River Bureau, with the guidance of the Ministry of Water Resources (MWR), the national agency in charge of water management, launched a water transfer project that substantially increased the discharge of water to downstream in the HRB. Zhangye, a major metropolis in the HRB's midstream, was selected as the first pilot city to build a water-saving society [5]. The goal was to increase irrigation efficiency and transfer water remaining in the midstream irrigation sector to downstream for environmental use. Unlike most previous reform efforts in the irrigation sector, the government focused on the demand side of water management. The core component, agricultural water rights reform provided farmers with water rights certificates that specified the water rights areas and the amount of water they were entitled to. Another important tool was the irrigation pricing policy reform, which had been used by the government since the 1980s [6].

Water rights institutions can improve the reliability of water supply, the efficiency of water allocation, and in some cases the equity of water allocation [7,8]. In regions outside China such as western USA [9] and Australia [10], water rights are well established and are traded on water markets. In other countries such as Chile and Spain, water markets are emerging and have been somewhat successful in meeting the demands of non-irrigation sectors [11,12]. Establishing water rights and developing water markets can incentivize farmers to decrease their irrigation applications by providing a venue for them to sell or lease their water rights to higher value users [13,14]. However, whether institutions and policies can achieve intended goals depends on a wide range of factors, including institutional environments, governance structures, social customs, policy designs, infrastructure, available technology and investment options [15–17]. In Canada, irrigators are reluctant to embrace water markets, partly due to lack of information [18]. There may also be unintended consequences. In Australia, water rights holders have sold in water markets water access entitlements they did not use or under-used before, which led to greater water use and to the need to spend billions to recover water for the environment [19]. In short, the assessment of water rights and water trading schemes needs to be conducted in the specific local context where they take place.

Similar to many other parts of the world, irrigation water in China is priced much below its cost. In Zhangye, the levels of water price range from 10% to 90% of the cost of water [20,21]. Using household data from Zhangye, Shi et al. [22] have found farmers' irrigation demand is not sensitive to water price, because the shadow price of agricultural water is much higher than the cost of water farmers are paying. Similar results are found in other countries. The meta-analysis of research from the United States during 1963 and 2004 by Scheierling et al. [23] revealed an average price elasticity of −0.48. Irrigation water demand in other countries such as Australia and Tanzania are also found to be inelastic [24,25]. Tian [26] argues that there is still room for increasing the price of irrigation water in Zhangye based on farmers' income levels and the value water has generated in agricultural production. The general consensus is that the price of water needs to be increased by a large amount to induce sizable water savings [27–29]. The effectiveness of water pricing policy also depends on the pricing scheme. The closer the pricing scheme is tied to the volume of water used, the more motivated farmers will be to reduce their irrigation application [30,31]. For example, farmers under volumetric pricing schemes are much more sensitive to water prices than farmers under area-based pricing schemes [32,33].

Previous studies have assessed the reforms that took place in Zhangye. Most studies only covered one or two irrigation districts (ID). Partly because of the small sample sizes, there is no consensus on the impact of the reforms. For example, in Liyuanhe irrigation district, farmers have moved to less water-intensive crops, which reduced the overall agricultural water consumption of Liyuanhe [34]. Yang and Xu [6] have observed a shift from traditional flooding irrigation to more efficient irrigation technology, which may be induced by the changes in water pricing. In other IDs, farmers exceeded water quota and did not participate in trading their water rights [35,36]. Scholars also argue that the reform in Zhangye only worked because the upper level government reduced the total quantity of water use through a command-and-control approach, but such quota management is not sustainable over a long period of time [37,38].

Our study differs from the existing literature in several significant ways. First, we have collected data in multiple IDs in Zhangye. Our sample of villages is a representative sample of the whole region of Zhangye. This enables us to assess both the overall effects of the reforms as well as the heterogeneous effects across places. Second, the survey has collected information on a large set of factors that may influence the performance of the reforms. In addition, unlike most studies that rely on only descriptive statistics, we also employ econometric analysis to control for many confounding factors in our in-depth assessment of the reforms. Third, our survey was conducted in both 2009 and 2014. This allows us to evaluate the impact of the reforms over years and answers the question of whether the reforms are viable in the long term.

To better understand the water rights and irrigation pricing reforms, and to design more functional policy strategies in the HRB and other regions either inside or outside of China, it is imperative to answer the following questions: How were water rights reform and irrigation pricing policy implemented in Zhangye? Have these reforms achieved their intended goals on reducing irrigation application? Are both reforms (water rights and water pricing) successful? Or has one reform fared better than the other?

The second section of this paper presents the study region, the sampling approach, and the information collected. The third section describes water rights reform and irrigation pricing policy in Zhangye. The fourth section discusses descriptive analysis and econometric models employed to assess the impacts of water rights reform and irrigation pricing policy. The final section concludes and draws policy implications.

2. Study Region and Data

2.1. Description of Study Sites

Heihe River is China's second largest interior river. It originates from the Qilian Mountains in Qinghai province, passes through Gansu province, and ends in East Juyanhai Lake in Mongolia (Figure 1). The HRB is divided into upstream, midstream, and downstream two hydrological stations (Yingluoxia and Zhengyixia). The historical mean annual precipitation declines sharply from approximately 338 mm in the upstream, 127 mm in the middle stream, and 49 mm in the downstream (China Meteorological Administration). There is relatively sufficient water upstream, but it is scarce in the other two areas, especially downstream. Hills dominate the terrains in the upstream, and animal husbandry is the main income source for farmers. The midstream consists of broad, flat plains suitable for irrigated agriculture. In contrast, the river's lower reaches contains mostly deserts. Water use in the midstream accounts for the majority of total water use in the river basin. For instance, the share of water consumption by the upstream, midstream, and downstream in 2012 was 5%, 94%, and 1%, respectively (Heihe River Bureau). The major economic sector that uses water in the HRB is irrigation agriculture, which occurs midstream.

Zhangye is located in the midstream of the HRB. The annual average water in Zhangye is only 1350 m^3 per capita or 7950 m^3/ha, which are only 60% and 30% of the national average, respectively [39,40]. The agricultural sector in Zhangye is the key sector where water savings would be generated and transferred to the downstream areas of the HRB. Surface water supplied about 67% of the irrigation water and the rest came from groundwater (Zhangye Water Authority). This study area covers Zhangye's four counties (Linze, Gaotai, Minle and Shandan) and one urban district (Ganzhou) (Figure 1).
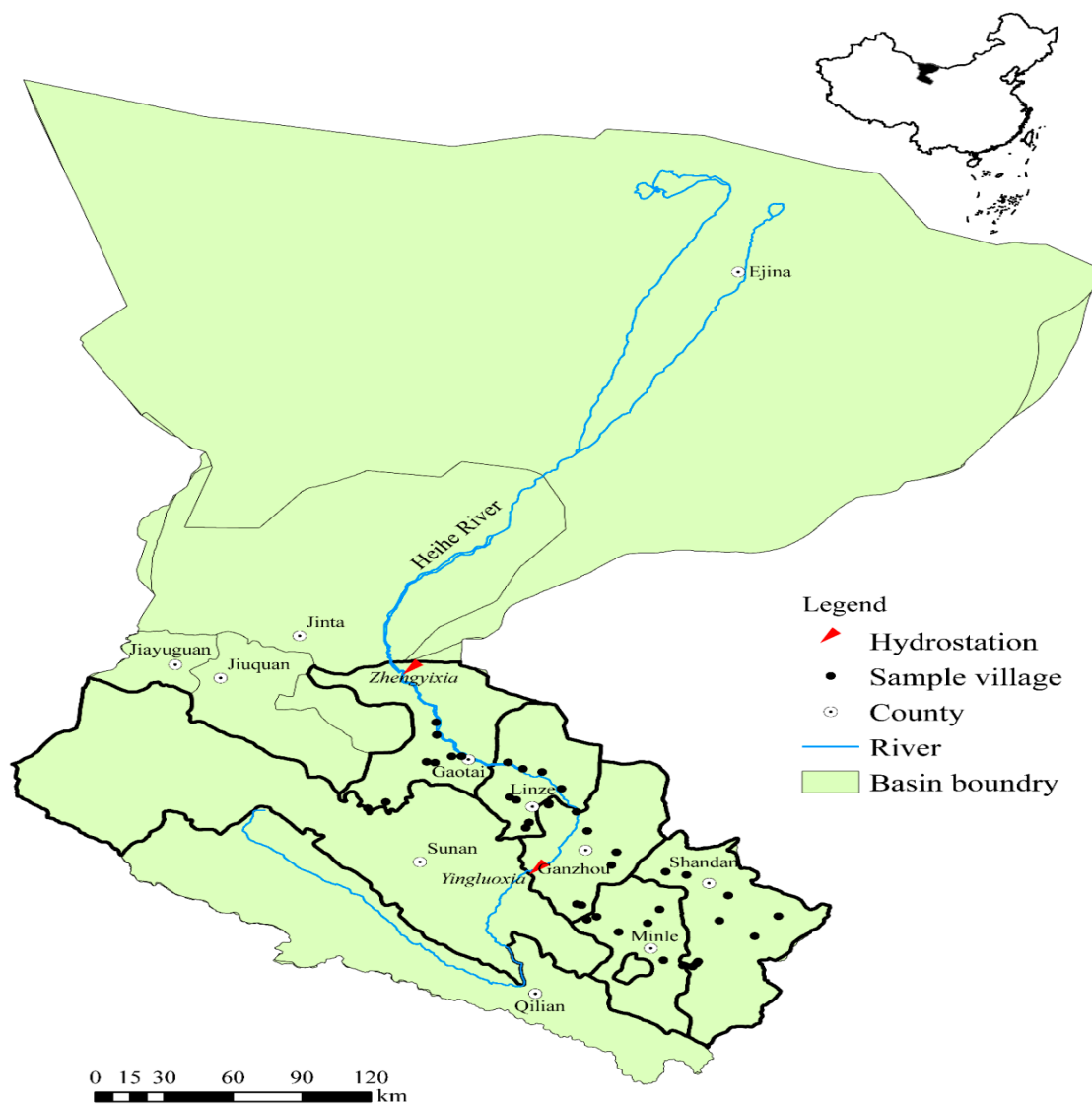
Figure 1. Study region and sample villages.

2.2. Survey Data

Our data came from the two rounds of surveys that we conducted in Zhangye's five counties in 2009 and 2014. There is an irrigation district (ID) in all the townships of each county; we randomly chose four townships from each county. We adopted a stratified sampling approach to select villages, which means that we randomly chose two villages based on a census of villages in the upper and lower reaches of the canals within an ID, respectively (Figure 1). In each village, we randomly selected four farm households. After obtaining the basic information about each household's plot, we chose two plots from each household for more careful investigation.

In 2009 we interviewed 40 village leaders, 40 irrigation channel managers, 55 well managers, and 160 farm households; that year, we gathered information on 320 plots (in 2014, we observed another 310 plots). In 2014, we returned to the same sample sites to collect the same variables that we had amassed in 2009. However, for various reasons (such as household migration and land transfer), we were only able to follow up with 109 families (68%) of the samples we had surveyed in 2009; in 2014, we added 47 new households. Due to the change in planting structure of specific villages, the 320 plots that we observed in 2009 were not completely consistent in types of crops in 2014. In total, we obtained pool data that encompassed 207 households and 630 plots.

Surface water is Zhangye's main irrigation source, while groundwater takes up a relatively small share of water use. For instance, in the sample plots where wheat was grown, the share of plots only irrigating surface water increased from 58% in 2008 to 62% in 2014 (Table 1). In contrast, the share of plots only irrigating groundwater was no more than 28% during these years. The remaining plots used both surface and groundwater, which occupied only 16% in 2008 and 10% in 2014. Moreover, in the plots with conjunctive irrigation, the share of surface water comprised more than 50% in terms of both irrigation volume and irrigation times.

Table 1. Share of irrigation water sources in the sample plots that grew wheat, Zhangye, 2008–2014.

Irrigation Water Sources	2008	2014
Percentage of sample plots (%)		
Only surface water	58	62
Only groundwater	26	28
Conjunctive irrigation	16	10
Irrigation application in conjunctive irrigation (%)		
Surface water	56	53
Groundwater	44	47
Irrigation times during conjunctive irrigation (%)		
Surface water	50	56
Groundwater	50	44

Note: Source: Authors' survey.

In order to understand the implementation, effectiveness, and sustainability of agricultural water rights reform and irrigation pricing policy in Zhangye, we designed three separate survey instruments: one for farmers, one for irrigation managers (including managers of irrigation channels and wells), and one for village leaders. In our survey, we identified agricultural water rights reform and irrigation pricing policy. In our questionnaires for the village leaders and irrigation managers, we recorded the implementation of each institution within the villages in 2008 and 2014, respectively. For water rights reform, we recorded detailed information on water rights certificates including acquisition time, method, type, service life, and content. Moreover, the water rights areas and amounts listed in the certificates contrasted with the reality of each village. It is at this point that we explored the reasons for the contradictions between the number listed in the certificates and the reality in each village. For irrigation pricing policy, we collected the irrigation pricing scheme and corresponding price level.

In the survey, we also gathered data to measure the effects of agricultural water rights reform and irrigation pricing policy, including irrigation application and times by plot. Farmers were always unaware of the volume of irrigation application, while managers were usually able to give us detailed information on both groundwater and surface water irrigation. For groundwater, based on knowledge of a well pump's size and the average volume of irrigation that each pump withdrew from the well per hour, we could calculate the volume of groundwater irrigation; we did this by multiplying the average volume of groundwater pumped per hour by the length of irrigating time. Comparatively, for surface water, it was relatively difficult to measure irrigation application by plot. During the enumeration process, we developed a methodology based on eliciting information from more than one respondent in each community and asking about irrigation application in various ways [41,42]. To carry out this approach, we included special blocks on irrigation application in both the forms for village leaders and irrigation managers. We also asked irrigation district officials in each area for information that could be used to check our survey-based estimates. We not only requested that respondents provide estimates of irrigation application per ha based on cubic meters, but also recorded other details about the application process, such as the length of time it took to apply water in the village, the depth to which the average field was flooded, the type of the soil, and irrigated area. We elicited these data

for each irrigation per crop during the growing season. With this information and other knowledge gained from households, we combined the various measures into a single one. Based on the data above, we calculated the total irrigation application and average irrigation application per ha, which led us to develop our final estimates of irrigation application.

In addition, we collected information on irrigation fees and the characteristics of each plot, household, and village. For irrigation fees, there were various pricing schemes for both surface and groundwater, on which we will elaborate in the next section. Household attributes included the age and education level of the household head, and the share of labor in a family; plot features included soil type (loam, clay, or sandy soil), the rate of lined canals from water outlets to plots, plot area, and the adoption of irrigation technology. For the survey with village leaders, the most important information we collected is how institutions were implemented in each village, which we will also describe in detail in the next section. Furthermore, we asked village leaders to assess water scarcity in their villages, such as whether water was insufficient and the number of areas irrigated by each water source.

3. Implementing Agricultural Water Rights and Irrigation Pricing Reforms

3.1. Agricultural Water Rights Reform

With the 2002 Water Law, China's central government has been trying to set up a water rights system and optimize the allocation of water resources via market mechanisms [43,44]. China's 11th Five Year Plan requires establishing "an initial water rights distribution network and a water rights transfer scheme", which more explicitly implements reform via water allocation plans and an abstraction permit system [36,45]. At the irrigation district level, water rights have only been granted to farmers at a few select trial sites where water rights transactions among individual farmers are not always effective. In these areas, there is no uniform legal framework for water rights transactions; Zhangye's agricultural water rights institutions are typical examples [36].

In Zhangye, there is a specific procedure for distributing water rights. Zhangye earmarks limited overall water rights for various uses according to the circumstances of the population and development of industries. Then, the amount of agricultural water rights is dispensed to each county in line with the status of their water resources, water rights area, and cropping structure. Later, the agricultural water rights of each county are further distributed to each irrigation district according to the same principle. Lastly, irrigation districts apportion agricultural water rights to each farm household based on their water rights area and irrigation quota.

In Zhangye, water rights have been granted to individual farmers in the form of water rights certificates. The water rights certificate states the upper limit of the amount of water a household can buy, which is computed by water rights area and crop irrigation quota. A water rights certificate is coupled with a ticket system under which farmers pre-pay for the water they want during a particular year, season, or watering period [46]. However, transactions involving water tickets are rare in Zhangye. The water available to all farmers in a specific village is usually same, sufficient or deficient; this cannot result in a demand for transactions [47]. The reform began in 2001 in two irrigation districts and covered all irrigation districts in 2003.

Survey results show that not all villages were issued the certificates and the rate of spread of certificates has shown a significant downtrend. In 2004, 70% of villages had the water rights certificate, and the share of sample villages with certificates dropped to 38% in 2008 and to 28% in 2014, which signals that certificates were gradually being abandoned by farmers (Table 2). Moreover, the proportion of sample villages with certificates varied across the five counties. Except for Minle county, the share of sample villages still using certificates in the other four counties declined dramatically during these years. The number of sample villages with water rights certificates disappeared by 2008, especially in Gaotai and Shandan counties.

Table 2. The institution of water rights certificates in the sample villages, Zhangye, 2004–2014.

County	Percentage of Sample Villages with Water Rights Certificates (%)		
	2004	2008	2014
Zhangye	70	38	28
Ganzhou	75	63	38
Linze	75	50	25
Gaotai	75	0	0
Minle	75	75	75
Shandan	50	0	0

Note: Source: Authors' survey.

3.2. Irrigation Pricing Policy

Zhangye has experienced several shifts in irrigation pricing policy for surface water resources since the 1980s. In 1988, with approval from the city's administrative office, the water price for the plains was 0.01 yuan/m^3, and 0.008 yuan/m^3 in the mountains. With the development of the local economy, the two prices were raised to more than 0.03 yuan/m^3 and 0.035 yuan/m^3 in 1995, respectively. Three years later, explicit regulations stated that the surface agricultural water price consisted of a basic expense and a volumetric cost. The basic water price was higher than 30 but less than 60 yuan/ha per year (which is determined by water rights area); this price must be charged, regardless of whether the land is irrigated. After 2008, Zhangye's counties increased the volumetric price to over 0.1 yuan/m^3. However, due to a shortage of water measurement facilities, it had no way to implement the volumetric water price; and 75% of villages collected the fee by areas and 25% by time in 2014 (Table 3). In the end, farmers absorb all the costs, including basic water price, volumetric price, and even management fee in some villages.

Table 3. Pricing schemes of surface water for farmers, Zhangye, 2008–2014.

Pricing Scheme	Percentage of Sample Villages (%)	
	2008	2014
Area-based	77	75
Time-based	23	25

Note: Source: Authors' survey.

To facilitate a comparison, we unified all the prices of different schemes by volume based on the 2008 price level (Table 4). Based on the method in Section 2.2, we calculated the average irrigation application per ha and the corresponding irrigation fee during the growing season of wheat, then we estimated the average volumetric price, dividing the irrigation fee by the irrigation application. On the whole, the survey results indicate that the price rose from about 0.11 to 0.20 yuan/m^3 between 2008 and 2014, approximately by 83%. The growth rate of surface water price for area- and time-based schemes was 90% and 100%, respectively. However, the water price of time-based schemes tends to exceed that of area-based schemes by about 20%.

Table 4. Unified surface water price by volume based on the price level of 2008, Zhangye, 2008–2014.

Pricing Scheme	Surface Water Price (yuan/m^3)	
	2008	2014
Area-based	0.10	0.19
Time-based	0.12	0.24
Total	0.11	0.2

Note: Source: Authors' survey.

For groundwater, the water price mainly consisted of two parts: the irrigation electricity price and the water resource fee. The biggest part of the groundwater price is the cost of irrigation electricity, which comprises about 90% of the price and is charged by China's Electric Power Department. The groundwater price has increased over the last ten years due to the rising cost of irrigation electricity. The information from our sample villages indicates that Zhangye's overall irrigation electricity price increased from 0.34 yuan/kw·h in 2008 to 0.41 yuan/kw·h in 2014 (Table 5). In Zhangye, the water resource fee was 0.01 yuan/m^3, and started to be charged in 2006 in Gaotai, Minle, and Shandan counties, while the other two counties took action in 2011.

Table 5. Unified irrigation electricity price based on the price level of 2008, Zhangye, 2008–2014.

County	Irrigation Electricity Price (yuan/kw·h)	
	2008	2014
Zhangye	0.34	0.41
Ganzhou	0.36	0.43
Linze	0.36	0.42
Gaotai	0.32	0.42
Minle	0.34	0.42
Shandan	0.31	0.35

Note: Source: Authors' survey.

In addition, the groundwater price in some villages contains the managers' wages. Managers' wages are included because they are part of groundwater price paid by farmers beside the cost of energy. They were determined within the village and may be related to irrigated area, length of irrigation or other factors. There is no uniform criteria. In our survey, the share of villages that paid for managers' wages by withdrawing from the groundwater price was 43%.

4. The Impact of Water Rights Reform and Irrigation Pricing Policy on the Irrigation Application for Wheat

4.1. Descriptive Statistical Analysis

Descriptive statistics from data show that water rights reform might have played a role in reducing the irrigation application for wheat. For instance, with water rights certificates, in 2008, the irrigation application per ha for wheat was 4795 m^3, saving 2.06% of irrigation water (Table 6). However, this was not consistent in 2014, when farmers increased their water use if they had certificates.

Table 6. Irrigation application for wheat as affected by water rights certificates in Zhangye, 2008–2014.

Irrigation Application (m^3/ha)	2008	2014	All Samples
With water rights certificate	4795	6609	5463
Without water rights certificate	4896	5542	5240

Note: Source: Authors' survey.

Increasing water prices reduced the irrigation application in 2008 and 2014. As a whole, from the lowest quarter interval (for water price) to the highest one, the irrigation application per ha for wheat declined from 6628 m^3 to 3590 m^3, and the mean irrigation times decreased from 3.73 to 2.2, dropping by 45.84% and 41.02%, respectively (Table 7). Specifically, for irrigation application per ha, the rate of reduction was 56.61% in 2008 and 30.53% in 2014, respectively. Correspondingly, the rate of decline for irrigation times was 49.07% and 33.55%, respectively. In 2008, farmers in the second quartile of water prices reduced irrigation application rates by 28% compared to those in the first quartile. Farmers in the third quartile reduced irrigation application rates by 30% compared to those in the second quartile. However, farmers in the fourth quartile only reduced irrigation application rate

by 13% although the mean price spiked from 0.19 yuan/m^3 to 0.63 yuan/m^3. This unusual result is most likely due to the villages' water scarcity for the famers in the 4th quartile being more severe, thus farmers used more groundwater. The story in 2014 was similar.

Table 7. Irrigation application and irrigation times for wheat based on diverse water prices in Zhangye, 2008–2014.

Water Price Interval	Mean Price of the Interval (yuan/m^3)	Irrigation Application per ha (m^3/ha)	Irrigation Times
2008			
1%–25%	0.06	7342	4.32
26%–50%	0.10	5282	3.08
51%–75%	0.19	3678	2.27
76%–100%	0.63	3186	2.20
2014			
1%–25%	0.09	5813	3.13
26%–50%	0.13	7488	3.83
51%–75%	0.21	5773	2.92
76%–100%	0.56	4038	2.08
All Samples			
1%–25%	0.07	6628	3.73
26%–50%	0.11	6287	3.49
51%–75%	0.20	4715	2.47
76%–100%	0.60	3590	2.20

Note: The water price is based on the price level of 2008. Source: Authors' survey.

The results above imply that water rights reform and irrigation pricing policy can possibly reduce irrigation application. However, due to many other factors affecting irrigation application, such as household characteristics or regional circumstances in nature, we cannot determine the real relationship (of irrigation application to water rights reform and irrigation pricing policy) merely by using simple descriptive statistical analysis. Therefore, multivariate econometric analysis is required to analyze the real relationship between irrigation application and water rights reform or irrigation pricing policy.

4.2. Econometric Model

Based on the above discussions, the link between irrigation application per ha for wheat and its determinants (such as water rights reform, irrigation pricing policy, and other factors) can be represented by the following equation, which applies plot level data in Zhangye:

$$W_{ijkc} = \alpha + \beta I_{kc} + \gamma P_{ijkc} + \rho Z_{ijkc} + \theta Y_{kc} + \lambda R_{kc} + \varepsilon_{ijkc}$$

where W_{ijkc} represents the average irrigation application per ha for wheat from the *ith* plot of *jth* household in *kth* village in *cth* county. The rest of the variables explain the irrigation application. I_{kc} is our variable of interest, indicating the water rights reform, measured by whether the village has been issued water rights certificate (1 = yes, 0 = no). P_{ijkc} is the irrigation water price in the *ith* plot of *jth* household in *kth* village in *cth* county, measured by yuan/m^3.

Other control variables in the equation, represented by a matrix Z_{ijkc}, are included to represent other villages, households, and plot factors that affect irrigation application. In particular, we included two variables to hold the status of a village's water resources constant: the percentage of areas irrigated only by surface water, and the dummy indictor, which signals whether water is scarce in the village. Household characteristics include age and the education level of the household head and share of labor. We also added three plot attributes: plot area, soil type, and rate of lined canals from water outlets to plots. Finally, our models included year dummy variable (Y_{kc}), 1 means 2014, 0 means 2008. R_{kc} is a regional dummy variable representing the county in which a household is located. In addition,

county dummies can capture the time invariant factors at the county level such as crop prices, general climate conditions and hydrology of the sample areas. Year dummies help capture the general trend of policy and changes in agricultural technologies. The symbols α, β, γ, ρ, θ, and λ are parameters to be estimated, and ε_{ijkc} is the error term, which is assumed to be uncorrelated with the other explanatory variables in our initial equation.

4.3. Estimation Results: The Impacts of Water Rights Reform and Irrigation Pricing Policy on the Irrigation Application for Wheat

The empirical estimations perform well for wheat's irrigation application model (Table 8). The goodness of fit measures (adjusted R^2) are around 0.3, which sit at the upper end of the range of R^2s observed in empirical analysis that use household level repeated cross sectional or longitudinal survey data. There are examples of the similar empirical studies that have much larger sample sizes, but lower R^2. For example, Zhang and Xu (2016) [48] reported R^2s around 0.25 with a sample of 4729 observations and Giles (2006) [49] reported lower R^2s with a large sample of about 17,000 observations. To test the hypothesis of homoscedasticity that is the most prominent problem in the ordinary least square (OLS) regression based cross-section data, we have done the White's test. From the results, we fail to reject the null hypothesis of homoscedasticity for each model because the *p*-values of all tests (Prob > Chi2) are greater than 0.1. Even though it is unnecessary to use a robust standard, we do the robust regression for the robustness of results. Since our dependent variable is one continuous variable, independent variables in the regressions are exogenous and have no serious multicollinearity, and the error terms are also uncorrelated, it is rational for us to use robust OLS regression. Most of the coefficients for the control variables have the expected signs and are statistically significant. For instance, the results indicate that after holding other factors constant, in villages with a larger share of irrigated areas serviced only by surface water, the farmers used more water per ha for wheat. In addition, the relationship between irrigation application and the age of the household head appears in an inverted U shape, with a turning point at the age of about 53. This means that after experiencing some years of farming, farmers tended to reduce irrigation application per ha. In addition, the demographic factors in our models are continuous variables, like education level and share of farming labors in a household, which are more accurate than dummies used in Wheeler et al. (2009, 2010) [50,51]. Despite the differences above, the conclusions are similar that higher education and older age of farmers may reduce the irrigation application or increase the probability of water rights trade. There is also some evidence that larger plots use less water per unit of land. One reason may be that it is easier to level a larger plot so that less irrigation water is needed to reach the whole plot. Even though the coefficient of year dummy is not significant, it does control the hydrologic uncertainty in different years. If we do the pooled regression that uses all observations, changing every variable to two variables (one interacting with 2008 dummy, one interacting with 2014 dummy), the results are robust. Other control variables had no consistent effects on irrigation application, and were only significant in 2008 or 2014.

Table 8. Regression results of the determinants of the irrigation application for wheat.

Variables	Irrigation Application (m³/ha)		
	2008	**2014**	**All Samples**
Water rights reform			
Whether having a water rights certificate (1 = yes; 0 = no)	−1112.78 *	−120.52	−558.26
Absolute value of *t*-statistics	(1.73)	(0.11)	(1.08)
Water price			
Weighted average water price (yuan/m³)	−2721.17 **	−6161.01 **	−3698.76 ***
Absolute value of *t*-statistics	(2.68)	(2.47)	(3.66)

Table 8. *Cont.*

Variables	Irrigation Application (m^3/ha)		
	2008	**2014**	**All Samples**
Village characteristics			
Share of irrigated areas in a village serviced only by surface water (%)	22.19 ***	7.13	14.11 *
Absolute value of *t*-statistics	(2.32)	(0.47)	(1.91)
Indicator of water scarcity in the village (1 = yes; 0 = no)	−1746.54 **	138.28	−635.64
Absolute value of *t*-statistics	(2.33)	(0.13)	(1.19)
Household characteristics			
Age of household head (years)	412.26 *	501.30 *	317.13 *
Absolute value of *t*-statistics	(1.79)	(1.96)	(1.90)
Age of household head, squared	−4.29 *	−4.28 *	−2.99 *
Absolute value of *t*-statistics	(1.98)	(1.91)	(1.94)
Education of household head (years)	−97.32	−54.95	−48.49
Absolute value of *t*-statistics	(1.40)	(0.48)	(0.71)
Share of labor (%)	0.19	−21.31	−3.05
Absolute value of *t*-statistics	(0.02)	(0.99)	(0.32)
Plot characteristics			
Area of plot (ha)	−664.95	−7521.82 *	−3940.09
Absolute value of *t*-statistics	(0.23)	(2.22)	(1.44)
Loam (1 = yes; 0 = no)	−637.58	1865.88 *	271.59
Absolute value of *t*-statistics	(0.74)	(1.84)	(0.38)
Clay (1 = yes; 0 = no)	−1277.59 **	839.38	−351.57
Absolute value of *t*-statistics	(2.03)	(0.93)	(0.58)
Share of lined canals (%)	8.70	1.28	5.70
Absolute value of *t*-statistics	(1.21)	(0.18)	(1.10)
County dummy	Not reported	Not reported	Not reported
Year dummy			
Year is 2014 (1 = yes; 0 = no)			679.55
Absolute value of *t*-statistics			(1.16)
Constant	−1026.40	−7407.85	−1914.97
Absolute value of *t*-statistics	(0.14)	(0.96)	(0.38)
Adjusted R-squared	0.333	0.221	0.271
Chi2	101.00	93.90	134.02
Prob > Chi2	0.3976	0.1942	0.2957
Observations	101	95	196

Notes: Absolute value of *t*-statistics in parentheses. * Significant at 10%; ** Significant at 5%; *** Significant at 1%.

Clearly, water price motivates farmers to reduce irrigation application for wheat all the time. The regression results show that the coefficients of water price are all negative and significant at the 1% level. Especially in 2014, when water price increased a great deal (Tables 4 and 7), the negative effects on irrigation application were relatively huge. Moreover, the overall price elasticity of agricultural water demand, calculated based on the estimated results, was approximately −0.17; this means that irrigation application per ha for wheat would lessen by 0.17% if water price rose by 1%. In addition, when we analyze the marginal effects of prices for both surface water and groundwater in the respective regression, the marginal effect of groundwater price is bigger than that of surface water. Moreover, farmers use less surface water when irrigation is charged in the time-based scheme.

However, regarding water rights reform, water rights certificates do not have a sustainable function on reducing irrigation application. The results signal that changes in water rights were possible at the beginning of reform, but failed in the end. For example, the coefficient of the water

rights certificate was negative and significant at the 10% level in 2008. In other words, if the institution was implemented, the irrigation application per ha of wheat could be reduced by 23%. On the contrary, the results from 2014 are not significant.

A lack of effective implementation is a possible reason for the ineffectiveness of the certificates. We can demonstrate this based on three aspects. First of all, there are more and more irrigated areas that cannot obtain water rights, which leads to more water demand for excrescent land. For example, the share of villages with actual irrigated areas was greater than the number of areas listed on the water rights certificates; this proportion of villages increased from 43% in 2008 to 50% in 2014, while the corresponding equality relation declined from 50% to 36% (Table 9).

Table 9. Irrigation area and water rights amount listed on the certificate in comparison with the actual situation, Zhangye, 2008–2014.

Comparison	Percentage of Sample Villages (%)					
	Irrigation Area on Certificate vs. Real Irrigation Area		Water Rights Amount on Certificate vs. Irrigation Water Demand		Water Rights Amount on Certificate vs. Actual Irrigation Water	
	2008	**2014**	**2008**	**2014**	**2008**	**2014**
Equal	50	36	10	0	8	13
More	7	14	0	0	25	0
Less	43	50	50	87	67	75
Unknown	0	0	40	13	0	12
Total	100	100	100	100	100	100

Note: Source: Authors' survey.

Secondly, most villages with certificates believe that the water rights amount listed on the certificate cannot meet their demand for irrigation water. Our survey data show that in 2008, half of these villages thought they should receive more water than the amount listed on their certificates; this figure rose to 87% in 2014. Finally, as expected, the actual irrigation application exceeded the water rights amount listed on the certificates. For instance, 67% of villages were using more water than the regulated amount in 2008; this share grew to 75% in 2014.

The specific reasons why the actual demand for irrigation water was greater than the water rights amount can provide a deeper insight into water rights reform. In 2008, most of the villages, about 57%, which were limited by their certificates thought that water scarcity was the main cause of why they were not assigned more water; 29% of villages believed this was due to an administrative order being executed that stipulated agriculture should save water in terms of irrigation application (Table 10). However, water resources were relatively abundant, and there was no intense mandatory requirement of water conservation in 2014. Hence, the primary explanations were unscientific water management and extensive irrigation patterns, occupying 75% of villages that were limited by their certificates.

Table 10. Reasons for actual irrigation water demand more than water rights amount, Zhangye, 2008–2014.

Reason	Percentage of Sample Villages (%)	
	2008	**2014**
Water scarcity	57	25
Governments' water conservation order	29	0
Unscientific water management	7	25
Extensive irrigation patterns	7	50

Note: Source: Authors' survey.

In addition, farmers receive almost no punishment if they exceed their amount of water rights, which encourages them to use yet more water. Our survey data show that in 2008 and 2014, approximately 80% of villages had no punitive measures to penalize those who violated their amount of water rights (Table 11). Even if there was a regulated punishment, it was never implemented. Only about 20% of the villages had the two really effective measures of penalty or cutting water source, yet the penalty disappeared in 2014.

Table 11. Punitive measures under the conditions that actual irrigation water exceeds the water rights amount as listed on the certificate, Zhangye, 2008–2014.

Punitive Measure	Percentage of Sample Villages (%)	
	2008	**2014**
No punishment	80	79
Penalty	10	0
Stop supplying the exceeded amount of water	10	14
Punishment, but not implemented	0	7
Total	100	100

Note: Source: Authors' survey.

The facts above indicate that the institution of water rights certificates was not implemented strictly and accurately, which emboldened farmers to use more irrigation water. This implies that besides the impetus of natural conditions, water rights reform in Zhangye was conducted rapidly in the beginning stages, with distinctive administrative features. Once the passion of reform winded down, the implementation of the reform was ineffective. This indicates that superficial water rights reform may be effective in the short term. Based on the above investigation, we can see that water price persistently played a role on reducing irrigation application. In addition, water rights reform was only helpful in the early phases; it failed in the later stages, meaning that it is not sustainable in the long run.

The analysis in the third part of the paper demonstrates how water rights reform in Zhangye, which has unique administrative characteristics, lacks effective implementation in the long term. In the beginning of reform, having a water rights certificate could mean that reform was relatively normative, then reached the expected goal of reducing irrigation application. However, without successful execution in the later phases, water rights certificates could simply become a form of water rights reform because the true basis of water allocation was water rights areas that every village had. In this case, water rights certificates had no distinct role in reducing irrigation application, which means that nominal water rights reform was ineffective and unsustainable. The econometric results provide evidence for our reasoning.

5. Conclusions and Policy Implications

In this paper, we explored how irrigation management reform in Zhangye has proceeded since 2002. In particular, we are interested in whether water rights reform and irrigation pricing policy play a role in reducing irrigation application in the HRB. We organized field surveys in two rounds (2009 and 2014) in Zhangye's five counties. The findings show that Zhangye allocated water rights to villages through issuing water rights certificates. However, not all villages got the certificates and the popularizing rate of the certificates has a significant downtrend, dropping from about 70% in 2004 to 38% in 2008, and then to 28% in 2014. After several irrigation pricing policy reforms, the surface water price continued to rise and due to increase of electricity price groundwater price also increased. Due to short of measurement facilities, water price is mainly charged by area.

Based on both descriptive statistical analysis and econometric models, the results reveal that water rights reform has only played a role on reducing irrigation application in the early reform stage (2008), and had no significant effect in the later stage (2014). However, irrigation pricing policy has

significantly reduced irrigation application in both 2008 and 2014. Further analysis indicates that a lack of effective implementation is the foremost reason for the failure of water rights reform in its later stages. Most villages used more irrigation water than the water rights amount listed on their members' certificates, but there were no consistent punitive measures to hold people accountable. The significant effects of water rights certificates in the early stages of reform resulted from water scarcity and the execution of a relative strong administrative order to save water. In the later stage, the government's passion for reform gradually faded and resulted in the ineffective implementation. This also implies the increase of implementation cost related with water rights reform. Compared with water rights reform, it is more feasible to effectively implement water pricing reform.

Both the water rights reform and the water pricing reforms in Zhangye are done in the specific context of China. However, its reform has important policy implications for the other regions in China, and also for the design of national water management strategies. In recent a few years, China's government is implementing the three red line policies and the two important red lines are controlling total water use and improving water use efficiency (the third one is controlling water pollution). As the major water user, how to reduce irrigation application and increase irrigation efficiency is highly relevant as to with whether the policy goal can be realized. In order to control the total water use, the government relies on implementing a quota management system and using administrative power. In fact, as the reform pilot sites, Zhangye has implemented this policy and their experience indicates that though this policy can reduce total water use in the early stage, it is hard to play its sustainable role in the long term. In the water short regions, it also is impossible to establish water markets and play the market on water allocation. In the long term, water pricing policy has the potential to reduce irrigation application and contribute to improvement of irrigation efficiency if the saved water can be used effectively. Importantly, with increasing investment in measurement facilities, volumetric water pricing police can play an even larger role on reducing irrigation application. Some components of the water pricing reform, such as time-based pricing, is moving the pricing of water to be closer to be volumetrically priced in Zhangye. However, this is a gradual process since infrastructure is needed to measure volumes of water.

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