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Agricultural Water Management 97 (2010) 1609–1616

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Access to groundwater and agricultural production in China

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ARTICLE INFO

Article history:
Received 4 February 2009
Accepted 23 May 2010
Available online 20 June 2010

Keywords:
Irrigation service markets
Water use
Yields
Income

ABSTRACT

Although the ways in which farmers access irrigation services in areas that rely on groundwater have changed over the past decade, little empirical work has measured the impact of these changes. This is surprising given the potential effects—both positive and negative. In this paper we explore the impacts of the emergence of the markets for irrigation services from groundwater on agricultural production – including crop water use and crop yields – and farmer income in northern China. From a survey of 35 randomly sampled villages and 338 households in two provinces (Hebei and Henan Provinces) in 2001 and 2004, we show that when farmers access water from markets for irrigation services, they significantly reduce water use, compared with farmers who have their own tubewells. However, there is no significant difference between the volume of water used by farmers who access irrigation services provided by the village, and the volume used by farmers who access water from markets for irrigation services. Importantly, although water use decreases, we find little effect on either agricultural productivity (yields) or income.

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1. Introduction

During the past two decades on the North China Plain, farmers have changed their access way to groundwater irrigation services. Before the 1980s farmers access to irrigation services only from collective tubewells, which were owned and operated by the leaders of each village. In the early 1980s almost all tubewells were collectively owned (Wang et al., 2005). However, with the onset of reforms during the early 1980s, private individuals were encouraged to take the responsibility for providing irrigation services, and with the declining groundwater tables in many areas, tubewell ownership has steadily shifted from collective to private. By 2004 the share of private tubewells reached 70%.

With the rise of private tubewells, there has been an emergence of irrigation service markets in many regions (Zhang et al., 2008). While almost no farmers purchased water from other farmers in what is sometimes called a groundwater market in the 1990s, by 2004 there were active groundwater markets in 44% of villages on the North China Plain. This development has enabled farmers in many villages to obtain water from other farmers through irrigation service markets.

These new ways of accessing irrigation services from groundwater have attracted the attention of researchers, particularly those studying South Asia. Pant (1991) found that 86% of the households in eastern Uttar Pradesh purchased water for irrigation services. In central and western Uttar Pradesh 65% of farm households purchased irrigation services. Shah et al. (2006) showed that the share of sample villages reporting activity in local groundwater irrigation service markets varies from 9% to 100%, and that more than 50% of villages in India have groundwater irrigation service markets. Strosser and Meinzen-Dick (1994) and Meinzen-Dick (1996) found that markets for irrigation services from groundwater are widespread in Pakistan.

Despite the interest on groundwater markets there has been a noticeable absence of measuring the impacts of this new phenomenon on agricultural production and incomes in rural communities. Yet there are important research questions. For example, farmers who participate in markets for irrigation services might use less water per hectare if they must pay a higher price for water than those who have their own tubewells. Because they use less water farmers who utilize groundwater markets might not irrigate sufficiently, and their yields might be lower than those obtained by farmers who own tubewells or obtain water from a collective well. Using multivariate analysis, Meinzen-Dick (1996) found that groundwater irrigation service markets adversely affect the income of some users and negatively affect income distribution.

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0378-3774/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.agwat.2010.05.015

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There might also be positive effects from the emergence of irrigation service markets. If there is no collective well, and if farmers cannot afford their own wells, irrigation service markets can provide farmers with access to groundwater, thus enabling them to achieve higher yields. Shah and Ballabh (1997) found that water buyers obtained higher yields than water sellers in all six villages in their sample in North Bihar in India.

However, much early work on irrigation service markets is focused only on South Asia. More importantly, many empirical analyses have not controlled the unobserved (or unmeasurable) factors that can affect both the increased availability of irrigation service markets and the outcomes, such as higher yields. Researchers studying the impacts of groundwater markets must isolate the net effects of the markets on the outcomes of farmers. The results observed in earlier studies might be attributed to the challenge of isolating causes and effects, particularly when considering differences in regions and study areas.

With increasing water scarcity and declining groundwater tables, understanding the impacts of the ways that farmers access irrigation services from groundwater has become an important policy issue in China. Therefore, the goal of this paper is to measure the impacts of the changes in the ways that farmers access irrigation services on water use, yields and income. We begin by assuming that farmers who irrigate obtain higher yields and earn higher incomes, which is consistent with results in Huang et al. (2006). We then ask: does it matter "how" people obtain access to groundwater?

2. Data

The data for this study come from the China Water Institutions and Management survey (CWIM), conducted by Center for Chinese Agricultural Policy (CCAP), Chinese Academy of Sciences (CAS) and University of California, Davis in December 2001 and 2004. Four separate survey instruments were created and implemented—one for farmers, one for tubewell managers, one for canal managers, and one for village leaders. Enumerators collected data and information from 338 households, 110 tubewell owners, 68 canal managers and 80 village leaders in 80 villages of three provinces (Hebei, Henan and Ningxia Provinces). Since there is almost no groundwater irrigation in Ningxia Province and not all villages in Hebei and Henan Provinces have groundwater irrigation, only some of the data from Hebei and Henan Provinces are used in this study (100 households in 35 villages). Located on the North China Plain, the two provinces face serious water shortages and have the highest extent of groundwater irrigation in China. About 78% of the irrigated area is supplied by groundwater.

The questionnaires included the questions regarding the village's land and water resources, the evolution of tubewell ownership, socio-economic conditions, and government policies and regulations. During the survey we asked farmers, detailed questions about the three main ways in which they access groundwater: from one's own tubewell, from collective tubewells and purchasing water from private tubewell owners (henceforth, from *groundwater markets* or *irrigation service markets for groundwater*). In order to obtain relatively accurate measures of water use volume, our interviews included all different stakeholders involved in the irrigation process, including farmers, water managers and village leaders. Additionally, information was collected on crop production and revenues by plot and by crop for each cropping season.

The CWIM survey was conducted in two rounds, in 2001 and 2004. Because wheat is a key crop in Hebei and Henan Provinces, we selected wheat as the crop for which we explore the impacts of irrigation service markets from groundwater on water use and production. Importantly, using a single crop eliminates differences in water use due to the differences in the demands of each crop.

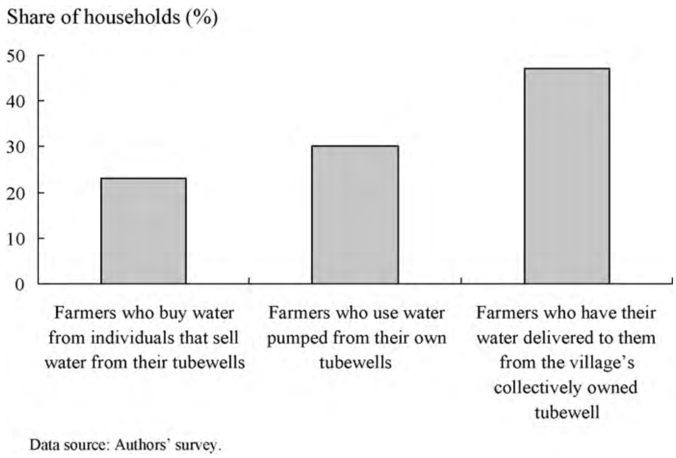

Fig. 1. Alternative ways of gaining access to groundwater for sample farmers on the North China Plain, 2004.

3. Access to groundwater and water use, yields and income

Each of the three ways to access groundwater are all important for farmers on the North China Plain. 47% of households gained access to irrigation from collective tubewells in 2004 (Fig. 1). The number of households buying water through markets (23%), however, was less than the number of households gaining irrigation from their own tubewells (30%—Fig. 1).

3.1. Impact on crop water use and yields

Groundwater markets on the North China Plain could reduce crop water use. For example, if farmers buy groundwater through markets to irrigate wheat, water use per hectare is 3241 m^3, 9% lower than those farmers who use water from their own tubewells (3571 m^3) (Fig. 2, panel A). In addition, the level of water use through markets was also 11% lower than relying on collective tubewells.

These results are consistent with the findings when we only compare access to irrigation services *within our sample villages*. Within one village, when comparing the two types of farmers, those farmers relying on their own tubewells use 12% more water than farmers buying water from markets. In addition, those farmers using collective tubewells had 35% higher water usage than farmers who purchase water from groundwater markets.

Why farmers who buy water use less water? One reason may be that farmers who purchase water pay more for their water. If so, they would have an incentive to reduce water use. Compared with farmers depending on their own tubewells or collective tubewells, farmers irrigating crops through irrigation service markets for groundwater have higher outlays for their water (Fig. 3).

Similar to the analysis above, the most accurate way to compare water prices among farmers who gain access to groundwater in different ways is to compare the water prices within a single village. Water buyers pay more than other farmers who do not depend on groundwater irrigation service markets. Because of this, it is reasonable to expect that farmers who purchased their water on groundwater markets will use water differently and produce different yields (and possibly earn different levels of income) than other farmers (Wang et al., 2007).

Because of this, crop yields fall slightly with the decrease in water use of farmers buying water from irrigation service markets for groundwater. For example, if farmers irrigated wheat with water purchased from groundwater markets, per hectare wheat

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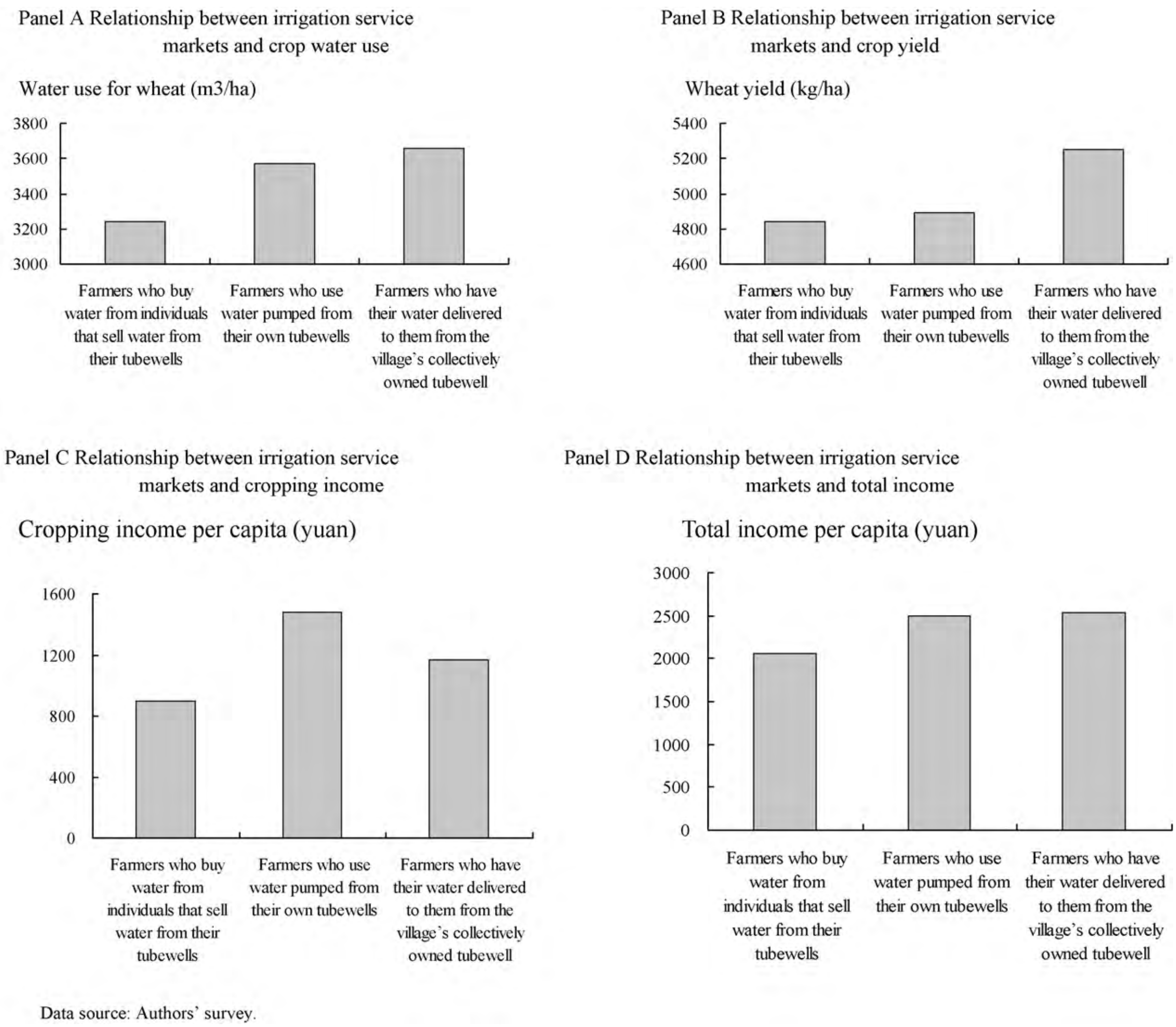

Fig. 2. Relationship between alternative ways to gain access to groundwater and water use, yields and income of sample farm households on the North China Plain.

yields are lower – though not significantly – than those farmers irrigating from their own tubewells (1%) or those depending on collective tubewells (8%) (Fig. 2, panel B). Within the same village, the same results show that wheat yields of water buyers are lower but not significantly so.

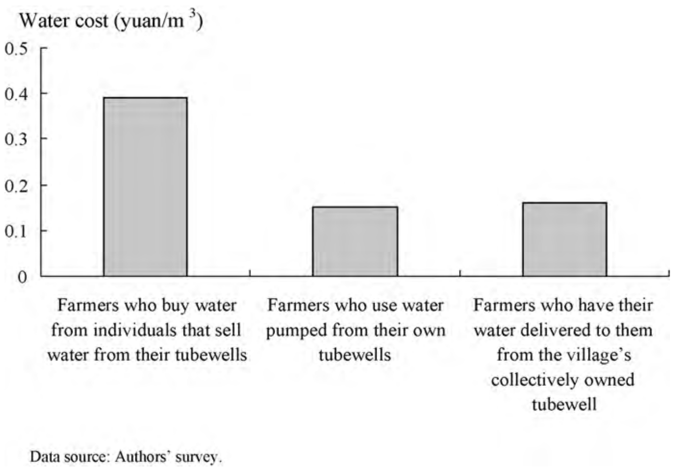

Fig. 3. The cost of water (per cubic meter) that gain access to groundwater through different ways on the North China Plain.

3.2. *Impact on farmer income*

Irrigation service markets for groundwater possibly have a negative effect on the income of farmers who buy water from groundwater markets. For example, per capita cropping income for water buyers is 902 yuan, 61% of that of tubewell owners (1482 yuan) and 77% of that of farmers getting irrigation from collective tubewells (1168 yuan) (Fig. 2, panels C and D). Within the same village, the impact of differences between cropping incomes of those relying on groundwater markets with other farmers shows consistent results.

Although interesting, our descriptive analysis has shortcomings. The effects of other variables on farmer income are not controlled for. Therefore it is too early to conclude that irrigation service markets for groundwater have any significant effects on water use, yields or income. A multivariate analysis is necessary to better understand the relationship between the ways in which farmers access groundwater, and farmer yields and income.

4. Multivariate empirical model and results

4.1. *Multivariate approach*

In order to identify the impact of the various ways of accessing groundwater on crop water use, crop yields and farmer income,

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we utilize a set of econometric models. The specification of our equations employs a number of control variables from other studies (Meinzen-Dick, 1996; Fujita et al., 2001; Meinzen-Dick et al., 2002; Wang et al., 2006). The first econometric model to measure the effect of the ways of accessing groundwater on water use can be written as

$$w_{ijk} = \alpha + \beta B_{ijk} + \gamma C_{ijk} + \delta Z_{ijk} + \varepsilon_{ijk} \quad (1)$$

where w_{ijk} represents water use per hectare for the ith wheat plot of household j in village k. The variables on the right hand side of Eq. (1) explain crop water use. B_{ijk} and C_{ijk}, our variables of interest, measure the ways in which farmers gain access to groundwater for irrigation. If farmers irrigate their plots by buying water from groundwater markets, B_{ijk} equals 1; otherwise, it equals 0. Similarly, C_{ijk} equals 1 if farmers irrigate their plots by pumping water from collective tubewells and equals 0 otherwise. If farmers pump groundwater from their own tubewells, both B_{ijk} and C_{ijk} equal 0. In other words, the plot on which a farmer uses his/her own tubewells for irrigation is the base case.

We also include Z_{ijk}, a set of control variables, to represent other factors that affect water use. Specifically, the first category of control variables includes two variables to assess the effects of the village's production environment on crop water use. We include variables measuring the share of irrigated area serviced by groundwater and the degree of water scarcity in the village measured as a dummy variable. The second category of variables controls for household characteristics, including age and education of the household head. Finally, our model also includes variables that control for plot characteristics, including plot area, the plot's soil type and the distance of the plot from the home. The symbols α, β, γ and δ are the parameters to be estimated and ε_{ijk} is the error term.

While it is possible to estimate α, β, γ and δ with Ordinary Least Squares (OLS), in Eq. (1), there could be an endogeneity problem that biases the attempt to measure the true relationship between water use per hectare and access to groundwater. The fundamental problem is that there could still be other unobserved factors that affect both water use and access to groundwater. In order to estimate the parameters in Eq. (1) consistently when the explanatory variables B_{ijk} and C_{ijk} are endogenous, we use an instrumental variable (IV) approach to solve the problem. To do so, prior to estimating Eq. (1), we regress a set of variables measuring the access to irrigation access, B_{ijk} and C_{ijk}.

$$B_{ijk} = \lambda_1 + \rho_1 IV + \varphi_1 Z_{ijk} + \mu_1 \quad (2)$$

$$C_{ijk} = \lambda_2 + \rho_2 IV + \varphi_2 Z_{ijk} + \mu \quad (3)$$

where the predicted value of B_{ijk} and C_{ijk} from Eqs. (2) and (3), $\hat{B}_{ijk}$ and $\hat{C}_{ijk}$, would replace B_{ijk} and C_{ijk} in Eq. (1). Eqs. (2) and (3) also include Z, which are measures of the other exogenous variables (which are the same as those in Eq. (1)—e.g., measures of the village's production environment and the household's and plot's characteristics).

The IV approach is only valid if the variables in the IV matrix in Eqs. (2) and (3) have two properties: (a) the IV variables must be uncorrelated with the error term of Eq. (1); and (b) they must be partly correlated (as a group) with the endogenous explanatory variable. The key instrumental variables in Eqs. (2) and (3) are two variables that measure the way in which policy markers have intervened into China's groundwater markets (in village k). The first variable, *fiscal subsidies for tubewells*, is a dummy variable that is equal to one if there was a program of fiscal investment in the village that targeted tubewell construction (and zero otherwise). This government program, run by the local Bureau of Water Resources, is primarily targeted at individuals. The second instrumental variable, *bank loans for tubewells*, is also a dummy variable to control for whether or not there was a program through banks that gives preferential access to low interest rate loans for investing in tubewells. Unlike the fiscal subsidy program, most bank loan programs targeted local villages and leaders, and loans were typically used for investment into collective wells.

Both our field work and regression results suggest that the choice of the instrumental variables (IVs) is satisfactory. First, officials in the local Water Resources Bureaus told us that these government programs were implemented on a fairly random basis; village leaders and farmers almost never were aware that they could influence these programs. Personal relationships (between officials governing over subsidy/loan programs and village leaders) often were one of the most significantly cited basis for giving a grant or a loan to a villager or village leader (Luo and Kelly, 2004). In other words, our two instrumental variables, fiscal subsidies and bank loans for tubewells, are logically exogenous and should have no independent effect on water use, except through the influence on the way in which farmers gain access to groundwater.

Second, our IVs are partially correlated with the endogenous variables (B_{ijk} and C_{ijk}). The regression coefficients of our IVs are statistically significant in the regression results of Eqs. (2) and (3)—Table A1, columns 1 and 2, rows 1 and 2). In other words, our IVs are correlated with the decision of farmers to select how to obtain access to groundwater to irrigate. In summary, we can say we have basically solved the problem of endogeneity.

In order to answer the question of whether the emergence of groundwater markets affects crop yields, we use the following econometric model:

$$Q_{ijk} = a + bW_{ijk} + cX_{ijk} + dZ_{ijk} + e_{ijk} \quad (4)$$

where Q_{ijk} represents the yield of wheat from the ith plot of household j in village k (which comes from our household survey). In Eq. (4), yields are explained by the variable of interest, W_{ijk}, which measures water use per hectare, X_{ijk}, which measures other inputs to the production process, and Z_{ijk} which holds other factors constant, including characteristics of the production environment of the village, household and plot. Agricultural production inputs include measures of per hectare use of labor (measured in man days), fertilizer (measured in the expenditure of fertilizer per hectare) and expenditures on other inputs, such as the level of the fees paid for custom services. The control variables for the village, household and plot characteristics are the same as for Eq. (1). We also added a variable that represents production shocks, measured as the farmer-estimated yield reductions percentage on a plot due to floods, droughts or other "disasters". The symbols a, b, c and d are the parameters to be estimated and e is the error term.

The impact of the emergence of groundwater markets on crop yields is measured through the water use variable. For example, if the regression results from Eq. (1) show that buying water from groundwater markets will motivate farmers to reduce water use, and if production responds positively to water use (from the regression results of Eq. (4)), then we can deduce that buying water from irrigation service markets for groundwater will reduce yields.

In order to measure the effect of groundwater markets on income, we also specified the following econometric model:

$$y_{jk} = \pi + \sigma B_{jk} + \omega C_{jk} + \psi Z_{jk} + \xi_{jk} \quad (5)$$

where y_{jk} represents either cropping or total income per capita for household j. Our interested variables, B_{jk} and C_{jk}, are the same as in Eq. (1). Z_{jk}, is a set of control variables affecting farmer income. Specifically, the first category of control variables measuring the village's production environment is the same as in Eqs. (1) and (4). The second category of control variables represents household characteristics, including age and education of the household head and the size of the arable land of the household (measured on a per capita basis). The symbols, π, σ, ω and ψ, are the parameters to be estimated and ξ is the error term.

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Table 1
Regression analysis of the impact of the emergence of irrigation service markets for groundwater on crop water use, crop yield and farmer income.

	Log of water use per hectare for wheat	Log of wheat yield per hectare	Cropping income per capita	Total income per capita
Irrigation service markets for groundwater				
Buying water from private tubewell (1 = yes; 0 = no)	−0.340		84.249	−718.512
	(1.65)*		(0.05)	(0.34)
Using water from collective tubewell (1 = yes; 0 = no)	−0.424		2,305.948	861.595
	(0.97)		(1.51)	(0.44)
Production inputs				
Log of water use per hectare		0.022		
		(0.44)		
Log of labor use per hectare		−0.066		
		(1.37)		
Log of fertilizer use per hectare		0.134		
		(2.49)**		
Log of value of other inputs per hectare		0.105		
		(2.40)**		
Production environment				
Share of village irrigated area serviced by groundwater	−0.315	0.148	437.095	169.110
	(1.18)	(1.22)	(0.74)	(0.23)
Village water scarcity indicator variable	0.155	0.014	−102.536	−215.973
	(1.82)*	(0.30)	(0.34)	(0.56)
Household characteristics				
Age of household head	0.051	−0.002	22.576	54.391
	(0.83)	(0.11)	(0.31)	(0.60)
Age of household head, squared	−0.001	0.0001	−0.053	−0.384
	(0.95)	(0.25)	(0.07)	(0.37)
Education of household head	−0.014	0.003	−59.787	42.633
	(0.67)	(0.31)	(1.19)	(0.67)
Area of plot	−1.088	−0.371		
	(1.91)*	(1.66)*		
Number of plots per household	−0.003			
	(0.17)			
Population of household	0.063			
	(1.74)*			
Arable area per capita of household			9,412.560	6,123.917
			(3.69)***	(1.89)*
Plot characteristics				
Loam soil	−0.004	0.040		
	(0.03)	(0.70)		
Clay soil	0.069	0.115		
	(0.61)	(2.13)**		
Distance to home	−0.163	−0.097		
	(1.26)	(1.91)*		
Water saving technology				
Share of surface or underground channel	−0.275			
	(2.26)**			
Flood irrigation (1 = yes; 2 = no)	−0.108			
	(0.98)			
Production shocks				
Yield reduction due to production shocks		−0.015		
		(10.44)***		
County dummy	–	–		
Constant	7.932	6.860	−2,017.856	−644.721
	(6.12)***	(9.20)***	(1.19)	(0.30)
Observations	120	140	200	200
Chi^2	55.80	176.20	42.21	24.75
R^2	0.37	0.61	0.10	0.09

Note: Absolute value of *z* statistics in parentheses.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

In order to estimate the parameters in Eq. (5) consistently when the explanatory variables B_{jk} and C_{jk} are endogenous, we use the same IV strategy as used for estimating Eq. (1).

4.2. Results

4.2.1. Impact on crop water use and yields

In estimating Eq. (1) with the survey data, the econometric estimation performs well (Table 1, column 1). Several of the coefficients of the control variables have the expected signs and are statistically significant. For example, we find that after holding constant other factors, households using high shares of water saving technologies (plastic piping—either above ground or underground) use less water per hectare.

The econometric estimation also performs well when estimating the impact of the emergence of irrigation service markets for groundwater on crop yields (Eq. (4)—Table 1, column 2). The *R*-square statistic of the OLS version of the equation is 0.61. In addi-

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tion, as in the estimation of Eq. (1) above, several coefficients of the control variables have the expected signs and are statistically significant. For example, the coefficient on the production shock variable is negative and significant (Table 1, column 2, row 21).

Importantly, our results show that water use decreases for farmers who buy water from groundwater markets compared with farmers who have their own tubewells or use collective wells. The coefficient of the variable measuring the emergence of groundwater markets is negative and significant (Table 1, column 1, row 1). Hence, farmers who buy groundwater from private tubewell owners use less water for wheat than tubewell owners. Interestingly, the coefficient of the variable for collective tubewells, although negative, is not significant (column 1, row 2). Such results are consistent with our descriptive statistics.

So what is causing this? One explanation is that farmers who buy water through groundwater markets have greater incentives to reduce crop water use because they pay more for water (as seen in the discussion above). Tubewell owners are willing to use more water, because the cost per unit is smaller.

We did not include 'Water Price' in the Water Use model (Table 1, column 1) due to concern regarding multicollinearity. Specifically, we were concerned that "Water Price" and "Irrigation service markets for groundwater" were highly correlated, as private water sellers systematically sold water at higher price levels. Table A2 shows that water price has a significantly negative impact on water use.

In contrast, although water use per hectare falls for farmers who buy water from groundwater markets, yields do not fall significantly. The coefficient on the water use variable, while positive, is not significant (Table 1, column 2, row 3). However, when farmers buy water from irrigation service markets, they reduce water use per hectare (column 1, row 1). These two results suggest that, after holding other factors constant, even though farmers who buy their water from groundwater markets use less water, wheat yields are not negatively affected. Observations during our field work suggest that farmers purchasing water may waste less water.

Table A1
First stage regression analysis of impact of irrigation service markets for groundwater on crop water use, crop yield and farmer income.

	If buy water from private tubewell (plot level)	If use water from collective tubewell (plot level)	If buy water from private tubewell (household level)	If use water from collective tubewell (household level)
Instrument variable				
Dummy of fiscal subsidies for tubewell investment	4.015	−0.394	0.179	−0.050
	(3.01)***	(1.06)	(2.14)**	(0.52)
Dummy of bank loans for tubewell investment	−1.420	1.004	−0.013	0.216
	(1.39)	(1.85)*	(0.13)	(1.83)*
Production environment				
Share of village irrigated area serviced by groundwater	−2.964	0.231	−0.221	−0.057
	(1.83)*	(0.28)	(1.44)	(0.32)
Village water scarcity indicator variable	−0.105	−0.045	0.113	−0.088
	(0.18)	(0.14)	(1.65)*	(1.10)
Household characteristics				
Age of household head	1.889	−0.144	0.019	−0.008
	(2.41)**	(0.78)	(0.91)	(0.34)
Age of household head,squared	−0.020	0.001	−0.000	0.000
	(2.34)**	(0.63)	(0.60)	(0.13)
Education of household head	−0.103	0.086	−0.007	0.026
	(0.84)	(1.33)	(0.61)	(2.08)**
Area of plot	−1.984	−3.102		
	(0.83)	(2.16)**		
Number of plots per household	−0.330	0.057		
	(3.01)***	(1.14)		
Population of household	0.636	−0.027		
	(2.13)**	(0.22)		
Arable area per capita of household			−0.676	−1.020
			(1.77)*	(2.30)**
Plot characteristics				
Loam soil	−3.031	0.716		
	(3.10)***	(1.73)*		
Clay soil	−0.940	0.343		
	(1.33)	(0.88)		
Distance to home	0.972	−0.673		
	(1.33)	(2.14)**		
Water saving technology				
Share of surface or underground channel	2.644	−0.106		
	(2.54)**	(0.27)		
Flood irrigation (1 = yes; 0 = no)	−1.725	−0.183		
	(2.37)**	(0.49)		
County dummy	–	–		
Constant	−43.833	3.665	−0.019	0.781
	(2.54)**	(0.91)	(0.04)	(1.56)
Observations	120	130	200	200
Chi	90.27	53.62	22	20

Note: Absolute value of *z* statistics in parentheses.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

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4.2.2. Impact on income

The emergence of irrigation service markets for groundwater on the North China Plain does not have a negative effect on income. In the cropping income and total income equations, the coefficients on the groundwater market variable are not statistically significant (Table 1, columns 3 and 4, row 1). Hence, when holding other factors constant, compared with tubewell owners (and farmers who buy water from collectively managed wells), the income of farmers who buy water from groundwater markets will not be lower.

These results can be extended. In another paper we found that irrigation service markets for groundwater in China have provided better (and new) access to groundwater for poorer farmers. In our sample, households purchasing water from irrigation service markets for groundwater are poorer than households owning their own tubewells and selling water (Zhang et al., 2008). We conclude that irrigation service markets for groundwater on the North China Plain have made positive contributions to improving the welfare of the poor in rural areas.

5. Conclusions

Many farmers on the North China Plain purchase water from private owners of tubewells. Many of these farmers pay more per cubic meter for their water than farmers who have their own tubewell or those with access to water from collectively owned wells. This situation generates concern that farmers who gain access to water through emerging groundwater markets might use less water and, as a consequence, produce lower yields and earn less income.

Our results suggest that farmers who buy water from local groundwater markets use less water than farmers who have their own tubewells or use collective tubewells. However, yields do not diminish. In addition, there is no measurable negative effect on income. Our findings imply that as water in China becomes scarcer, and water efficiency must be increased, allowing the emergence of markets for groundwater may be an effective way to provide irrigation services.

With the results of Zhang et al. (2008), our results show that leaders should consider supporting privatization and encouraging the development of groundwater markets. Such developments might reduce water demands without reducing either production or incomes. Generally, when farmers pay more for water they exert effort to save water while maintaining current yields.

We consider this research to be a starting point for additional work on the subject of water savings in agriculture. Further studies are needed to better understand the linkages between farm-level objectives, water prices, irrigation methods, and hydrology. The emergence of private water sales from tubewells presents an additional, interesting dimension to an already challenging research agenda.

Acknowledgements

The authors would like to thank Steve Beare, Amelia Blanke, Anna Heaney, Mark Giordano, Tushaar Shah, Aditi Mukherji, Liu Yang, Karen G. Villholth and Jorge García for their insights and helpful suggestions. We also appreciate the comments from two anonymous reviewers and the editorial assistance of Elaine Yu. We acknowledge financial support from the National Natural Sciences Foundation (70733004; 70925001) in China, State Key Laboratory of Resources and Environmental Information System, Challenge Program (CPWF-61), Knowledge Innovation Program of the Chinese Academy of Sciences (KSCX1-YW-09-04), and the Alcoa Foundation's Conservation and Sustainability Fellowship Program. We also acknowledge the support of the Program of China Women Economists.

Appendix A.

See Tables A1 and A2.

Table A2
Regression analysis of the relationship between water use and price.

	Log of water use per hectare for wheat
Water price	
Water price (yuan/m^3)	−1.011
	(4.70)***
Production environment	
Share of village irrigated area serviced by groundwater	0.108
	(0.54)
Village water scarcity indicator variable	0.133
	(1.82)*
Household characteristics	
Age of household head	0.037
	(1.20)
Age of household head, squared	−0.0004
	(1.10)
Education of household head	−0.020
	(1.27)
Area of plot	−0.249
	(0.69)
Number of plots per household	−0.005
	(0.38)
Population of household	0.065
	(2.27)**
Plot characteristics	
Loam soil	−0.137
	(1.43)
Clay soil	−0.053
	(0.59)
Distance to home	−0.110
	(1.37)
Water saving technology	
Share of surface or underground channel	−0.314
	(3.30)***
Flood irrigation (1 = yes; 0 = no)	−0.071
	(0.76)
County dummy	–
Constant	7.639
	(11.97)***
Observations	140
Chi^2	86.63
R^2	0.44

Note: Absolute value of *z* statistics in parentheses.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

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