IRRIGATION AND DRAINAGE
Irrig. and Drain. **64**: 193–204 (2015)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.1901

IRRIGATION MANAGEMENT REFORM IN NORTHERN CHINA: CASE STUDIES IN SHANXI PROVINCE†

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ABSTRACT

Irrigation in northern China is exposed to declining groundwater resources and institutional issues. As a response, authorities have developed measures that include differentiated resource allocation and charging, collective and individual water rights, a block pricing system, prepaid access to water, and real-time monitoring of resource and use. This paper analyses this alternative management model and its implications at the farm and system levels, using institutional, technical and economic analyses of case studies from Qingxu County, northern China.

The results show that the prepaid system helps solve cost-recovery, free-riding, agency and resource overuse problems. All water fees are prepaid, therefore fully collected. However, while most operation and maintenance costs are covered, personnel costs are covered in only one case, due to low water fees. The agency problem is also addressed by the continuous monitoring of water resources. Water use value is high compared to actual water fees, owing to high maize yields and reasonable use of supplemental irrigation. This indicates potential for a water price increase, if needed. This paper shows that the new management system at the county level epitomizes China's whole rural financial reform and the realignment of local water institutions with public administrative layers. It finally discusses achievements, pending questions and limitations for long-term impacts. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS: irrigation management reform; governance; water rights; water value; groundwater; northern China

Received 9 February 2014; Revised 23 September 2014; Accepted 24 September 2014

RÉSUMÉ

L'irrigation en Chine du Nord souffre d'un déclin des ressources en eaux souterraines et de problèmes institutionnels. En réponse, les autorités ont développé des mesures qui incluent l'allocation et la tarification différenciées de la ressource, des droits d'accès individuels et collectifs, une tarification par paliers, l'accès à l'eau par prépaiement, et un suivi en temps réel des consommations et de la ressource. Ce papier analyse ce modèle alternatif de gestion et ses implications sur les systèmes et les exploitations, mobilisant l'analyse institutionnelle, économique et technique du cas sous étude dans le comté de Qinqxu, dans le nord de la Chine. Les résultats montrent que le système de prépaiement aide à résoudre les problèmes de recouvrement, de resquille (free-riding), d'agence et de surexploitation de la ressource. Tous les usages sont prépayés et donc collectés. Cependant, alors que la plupart des couts d'opération et de maintenance sont couverts, les couts de personnel sont couverts dans un seul cas seulement, en raison du bas prix de l'eau. Les problèmes d'agence sont aussi traités grâce au suivi continu des usages et de la ressource. La valeur d'usage de l'eau est élevée comparée à son prix, en raison de rendements en maïs élevés et à un usage raisonnable de l'irrigation d'appoint. Une augmentation du prix de l'eau est donc potentiellement envisageable, si nécessaire.

Ce papier montre que ce nouveau système de gestion à l'échelle du comté reflète finalement les réformes de la finance rurale en Chine, et le réalignement des institutions locales de gestion de l'eau avec les niveaux administratifs existants. Il discute finalement les points positifs, les questions en suspens, et les limites d'un tel système sur le long terme. Copyright © 2015 John Wiley & Sons, Ltd.

MOTS CLÉS: réforme de la gestion de l'irrigation; gouvernance; droits d'eau; valeur d'usage; eau souterraine; Chine

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INTRODUCTION

The groundwater revolution was made possible by advances in pumping technology in the 1960s, in semi-arid regions of Asia (Barker and Molle, 2006); in northern China, groundwater has become the main water resource. The region increasingly faces water stress and declining quantity and quality of water resources (Cai, 2010). The overexploitation of groundwater for irrigation has long been identified as a critical issue (Zaisheng, 1998; Yang *et al*., 2003; Webber *et al*., 2008; Sun *et al*., 2009; Cai, 2010), although opinions have differed on the causes, the actual responsibility of farmers, and possible solutions.

According to water legislation of the People's Republic of China (2002), water resources are state property. In practice, the government works on behalf of the state to exercise power over water rights (Dajun, 2010). However, as effective control is often lacking, and the government's administrative structure does not operate at village level, groundwater resources in rural areas are de facto open resources, leading to overexploitation.

The question of whether irrigation systems should be regulated and managed by public authorities or left to self-governance by farmers has been vigorously debated worldwide over the last 50 years, with contrasting justifications, experiences, policies and outcomes. China has just experienced the same debates, trends and policy shifts in recent times, with some specificities (He, 2007; Huang *et al*., 2010).

Overall, the role of the state in economic life has greatly decreased since the 1980s. From 2005, agricultural taxes and fees were no longer collected. As a consequence, the so-called 'collective production fees', such as irrigation fees paid by farmers, were no longer compulsory. Collective production fees used to be the source of funding for services for rural communities such as irrigation facilities or financial support to cope with droughts and floods. The lack of funding and the withdrawal of the public sector have weakened the provision of such services to farmers.

The Chinese government has been promoting local actions and governance so that local organizations and stakeholders take over and compensate for these losses of services. In the irrigation sector, the Ministry of Water Resources, the National Development and Reform Commission and the Ministry of Civil Affairs recommended the development and strengthening of water user associations (WUAs) (2005). WUAs and contracting arrangements have replaced traditional institutions of collective management at the village level over the past decade in many places (Huang *et al*., 2010). Overall, such reform is similar to the global irrigation management transfer (IMT) process. In many cases, local collective action and self-governance in irrigation did not materialize (The China Irrigation District Association, 2005). Huang *et al*. (2010) showed that, while WUAs generally improved overall performance of irrigation systems in terms of maintenance expenditure, the timeliness of water deliveries, and the rates of irrigation fee collection (at least during the early stages), they failed to achieve broad-based participation, ownership and support of farmers.

Most reasons evoked for the shortcomings of Chinese WUAs in the long term are common to other situations, particularly the poor condition of irrigation facilities and the limited capacity for self-governance and organization. Physical, social and human capital at the farmer level was insufficient for promoting the development and application of local collective action and self-governance (Vermillion *et al*., 2006). In addition, relationships between local stakeholders and the government and relationships between local stakeholders posed institutional problems.

From a political economy viewpoint, He (2007) analysed the typical agent–principal problems (or agency dilemma) that existed with regard to access to and use of groundwater. The author highlighted the diverging interests and the information asymmetry that existed between the public authorities and farmers. As the agent, farmers' groups had access to more information than the authorities (the principal) with regard to actual water extraction. It became impossible for the government to control or enforce water access and use or to motivate village committees (the agent) to act in the best interests of others (government, the entire society, other village committees or user groups, other irrigation systems) rather than in its own. Such agency problems are particularly acute when activities that are useful to the principal are costly to the agent, as is the case in this situation, as the water rights and allocation system needs to be based on sound, upgraded infrastructures, metering and monitoring facilities, and enforcement systems, all of which incur high costs that the farmer cannot afford and that the principal no longer covers. Furthermore, farmers would forgo the benefits of unlimited access and use of groundwater resources if they were to strictly abide by the water rights system.

The other problem is local, as free-riding became inherent to irrigation systems after government-managed agricultural taxes and fees (collective production fees) were no longer collected. Irrigation fees are no longer compulsory, and newly autonomous local water user associations often failed to recover them. Furthermore, the operation costs incurred by the allocation and monitoring of the water rights system were too high for the farmers (Cai, 2010). Under such circumstances, farmers were hardly motivated to contribute. Xing-zuo and Xue-feng (2008) stated that free-riding had become a common feature in irrigation in China and a source of problems in the construction, operation and maintenance (O&M) of irrigation facilities.

In view of the limitations of both models (i.e. full public management vs farmer self-management), there is now a wide recognition that radical and mutually exclusive solutions are hardly viable, especially in the context of developing countries (Backeberg, 2006; Vermillion *et al.*, 2006; Vidal *et al.*, 2006). Xue-feng and Xing-zuo (2006) suggested that, while farmers should be involved in irrigation management and financing, the government should also intervene in water use monitoring and regulation. He suggested that a mechanism of cooperation between authorities and village committees be fostered. Recent reforms were aligned with these ideas, as an attempt to address the issues of farmers' sustainable use of groundwater, collection of water fees, and ultimately to solve the free-riding and agency problems. With these aims, China has recently launched local pilot experiments of an alternative model of joint government–farmer irrigation management, with institutional, technical and economic dimensions.

The present paper first describes the context and the different specific features of such experiments, on a case study basis. It then investigates their institutional, technical and economic implications. Ultimately, the paper aims at assessing the overall sustainability and possible replicability of such experiments at a larger scale. The cases under investigation are three villages located in Qingxu County, Shanxi Province, northern China.

METHODOLOGY AND STUDY CASES

General set-up

The research relied mostly on primary data and information. Key informant interviews were used to collect detailed information on the governance system at the county, water user committee (WUC) and farmer levels. Semi-structured questionnaires and in-depth interviews were used to collect crop production data, detailed information on water supply costs, and cases from officials and farmers. The research combined qualitative and quantitative methodologies; institutional analysis relied mostly on local informants' views and information, and secondary literature; economic and technical analyses was based upon data and figures collected during interviews, and in local available grey literature.

Case study villages and Qingxu County

Qingxu County is a traditional agricultural county in Shanxi Province located in northern China. Shanxi has a dry continental climate; scarcity of water resources limits agriculture.

The total population of Qingxu County is 340 000, 250 000 of whom live in 193 rural villages. The average yearly net income per capita was US$1407 in 2010. The arable land covers 28 000 ha. The irrigated area is 24 535 ha, half of which uses groundwater. In recent years, total annual water use in Qingxu was 55.4 million m^3, 82% of which was groundwater. Before 2004, the average annual groundwater withdrawal was 59.4 million m^3. A sustainable yearly extraction was estimated at 44.1 million m^3; hence, an excess of 15.3 million m^3 was used during this time period. Overuse led to an average decline of 1.6 m yr $^{-1}$ in the groundwater table. As a result, irrigation wells had to be dug deeper and water yields decreased (Qingxu County Water Resource Bureau, 2011).

The main crops grown in Qingxu are maize and wheat. The average annual rainfall of 425 mm is concentrated in the summer months, and the average evaporative demand is 975 mm, which makes rainfed farming almost impossible. Irrigation water is pumped from wells and conveyed by canals and pipes to the fields. Surface irrigation (near-flooding) is widely practised.

The three villages surveyed are Qingdepu, Xihuaiyuan and Xiaowang; they have a water user committee (WUC) for each. The total populations are 1847, 1820 and 1535, respectively. All three use groundwater resources for irrigation and the total irrigation command areas are 280, 304 and 254 ha, of which 195, 274 and 186 ha are registered under the new governance system, respectively. Most farming families own between 0.5 and 1 ha. Most farmers grow irrigated open-field maize; Xiaowang farmers also grow vegetables in greenhouses.

Assessing the use value of water

Neoclassical economic theory predicts that, in a competitive market, the economic value of a good corresponds to its market price, which reflects individuals' willingness to pay for that good. In the case of northern China, however, there is no irrigation water market per se; users are charged according to the electricity requirements for extracting groundwater, and the electricity charges (prices) are low, varying and arbitrarily determined at each village level, as shown in the following sections. So, due to the lack of a water market, valuation techniques must be used (Agudelo, 2001; Speelman *et al.*, 2008). The residual imputation method (RIM), based upon farm-level data, has been implemented to assess the marginal value product (MVP or use value) of water, as a proxy to their willingness to pay for irrigation water (as done in Agudelo, 2001; Speelman *et al.*, 2008; Perret *et al.*, 2013). Although RIM has its well-known limitations, which have been discussed in detail by Agudelo (2001), Renzetti (2002) and Speelman *et al.* (2008), it was considered the most suitable technique to estimate water values for the small irrigation schemes under study of northern China.

In RIM, the total value of output (produce value, or gross income, or total value product (TVP)) is allocated among each of the resource and production factors (inputs) used in the production process of one given cropping system, the budget of which must be quantified. If appropriate, nondistorted prices can be assigned (presumably by market forces) to all resources but one, the remainder of TVP is imputed to the remaining (or 'residual') input. This method is most suitable when the residual claimant (water in our case) presumably contributes a large fraction of TVP (Agudelo, 2001). Such a condition seems to be met in arid northern China, where irrigation is an inescapable condition for production.

Primary data were collected via detailed structured questionnaires, which were given to 51 farmers; 14, 14 and 23 in Qingdepu, Xihuaiyuan and Xiaowang respectively. MVP of water was calculated on the maize crop, because it was the main irrigated crop in all three villages, on the largest areas. Ultimately, 44 questionnaires were retained for MVP analysis, since 12, 13 and 19 farmers in Qingdepu, Xihuaiyuan and Xiaowang respectively were able to provide accurate and reliable information about their maize cropping systems, budgets and water consumption.

The costs of most production factors have been considered, including seeds, mineral and organic fertilizers, pesticides and agrochemicals, plastic film for mulching, and land. Capital costs (infrastructure, machinery) were excluded because of poor accuracy and incompleteness of data. Labour costs were included based on labour requirements and fees (according to local labour markets), even though most farmers actually only resorted to unpaid family labour.

Details for RIM calculations may be found in Agudelo (2001) and Speelman *et al*. (2008).

P_W, the use value of irrigation water, can be estimated as follows:

$$P_W = \left[\mathrm{TVP}_{Y} - \sum_i (\mathrm{MVP}_i \times Q_i)\right] / Q_W \quad (1)$$

where P_W is the shadow price, or marginal net benefit imputed to irrigation water per unit of water input, or the irrigator's maximum willingness to pay per unit of water for the given crop;

$\sum_i (\mathrm{MVP}_i \times Q_i)$ refers to the total costs of production; MVP_i may be expressed as the input's observed market values P_i, Q_i is their respective quantities used
TVP_Y is the market price paid to farmers at farm gate for product Y, times the yield obtained Q_Y,
P_W is the shadow price of water, or use value of irrigation water,
Q_W is the amount of irrigation water used to reach the given production Q_Y.

RESULTS AND DISCUSSION

The role of government

'Government' refers here to the line of nested public organizations involved in water policy and administration, i.e. the provincial Water Resources Department, the county-level Water Resource Bureau, and the township government.

Initial physical capital development. At inception, Qingxu County constructed a series of facilities and set up relevant hardware and technology. First, the remaining old canals were replaced with pipes. Total investment per ha ranged between US$1000 and 2000 in each village. The county provided approximately 50% of these costs; farmers contributed 10–20% (mostly in labour); other sources included donations by village heads (Qingdepu) and rents from collective land (Xihuaiyuan and Xiaowang).

Second, a regulated system of water supply to farmers based on prepaid integrated circuit (IC) cards was set up; the IC card system is used for the prepayment of water fees by farmers, water access and use control, and the metering/recording of consumption; charging is volumetric. In the equipped pilot systems, the IC card system operates as follows: farmers who wish to use irrigation facilities and access irrigation water must acquire a card at the local office of the WUC, under the guidance of the Water Resource Bureau. This IC card functions like a debit card. Farmers must top up the card with virtual pumping units based upon a given pricing system. The IC card is then used in field card-readers to release water. The flow starts when the card is inserted in the reader and loaded with pumping units; the flow stops when the card is removed or empty. During each operation, pumping units are deducted from the balance. When empty, the card has to be topped up again.

Third, a real-time monitoring system was developed based on the above-mentioned electronic system and dedicated staff; it is based on a remote control system, and volumetric and water level measurements were made with a network of 60 gauging and observation sites; all sites were internet connected to a central server and monitored in real time by the County Water Resource Bureau.

Renewed policies on water rights. Qingxu County issued a series of policies establishing a water rights system. A first document was issued by the Qingxu County Government (2004b) on water resource allocation; it describes the four-level water rights allocation method: (i) the basis and principles for water resource allocation, (ii) the rules and regulations for water resource allocation, (iii) the water resource allocation plan, and (iv) the measures for implementing this policy.

Another document describes the water resource quota management approach (Qingxu County Government, 2004a). It includes: the basis and principles for quota determination, and the respective quotas for industrial, agricultural and domestic water use. Finally, a third document (Qingxu County Government, 2004c) established the water block pricing system for all sectors (the 'price ladder'). All three policies form a water rights system that stipulates allocation priorities, scheduling, quotas and pricing.

Water rights allocation: a four-level system. In line with these new policies, the Water Resource Bureau of Qingxu County is responsible for the administrative allocation of water rights. In 2002, groundwater water resources supply and demand in Qingxu County were assessed, including total availability, potential demand (cropped areas) and water distribution. These data may be reassessed based on changes in resource availability, use and demand. A four-level water rights system was established. Such a system sets up annual quotas and allocates water among (i) sectors, (ii) townships, (iii) villages, (iv) wells and water users. Table I shows the organizations in charge of allocation at the different levels. Quotas are allocated for an indefinite period of time; they will not be revised by the Water Resource Bureau unless significant change is observed in water resource availability.

Water pricing mechanism. The Pricing Bureau of Qingxu County is responsible for water pricing in all sectors except agriculture. Its objectives were to influence water users' behaviour through proper pricing, to raise fiscal revenues, and to bring fairness and equity to resource allocation among sectors. In particular, price differentiation was established for the different sectors based on differentiated use value. For example, very profitable car wash businesses consume significant amounts of water; they are categorized as 'special industry' and their water price is set at US$2.4 m^{-3}, plus a water resource fee of US$0.24 m^{-3}. This sector is therefore charged the highest price among the sectors (Table II).

A block tariff was also set up. If water use exceeds the annual quota by up to 30%, the price is 50% higher than the base price. If water use exceeds the quota by 30–50%, the

Table I. Four-level water right system in Qingxu County

Level of water right allocation	Authority for water right allocation
Allocation among sectors	County Water Resource Bureau
Allocation among townships	County Water Resource Bureau
Allocation among villages/WUC	Township government[a] or County WRB
Allocation among wells and water users	Village committee or WUCs

[a]Following the agricultural tax reform, the township as a governance level in China has been weakened due to decreased fiscal revenue, and some township functions have been transferred to the county level.
Data source:Water Resource Bureau of Qingxu County.

Table II. Water price per sector in Qingxu County (US$ m^{-3})

	Domestic use	Industry	Administration and services	Special industry
Water price	0.28	0.4	0.43	2.4
Water resource fees	0	0.24	0.24	0.24

Data source:Water Resource Bureau of Qingxu County, 2010.

price is doubled (100% higher). If water use exceeds the quota by more than 50%, the price is tripled (200% higher). Table II shows the water tariff that applies to the different sectors, except for irrigation, in Qingxu County.

Farmer mobilization and capacity building. Before rural finance reform and the establishment of the new water rights system, farmers paid for irrigation water on a cropped area basis. Water quotas, volumetric tariffs, prepayment for water, and the block pricing system were new to most of these farmers. At the onset of irrigation management reform, the Water Resources Bureau of Qingxu County held meetings with village heads to collect and understand their views about the changes. The most enthusiastic villages were selected to pilot the testing and implementation of the new water rights system.

Training started with training of trainers, focusing on village heads, party secretarie and WUC leaders. Secondly, these leaders conducted training for farmers. Thirdly, the Water Resources Bureau conducted technical training for village technicians on the new system (i.e. quotas, IC cards, water rights card) and O&M aspects.

Irrigation governance at the village level

Establishing water user committees. The Water Resource Bureau required that each of the 80 villages that used groundwater irrigation establish a water user committee (WUC) to implement the new system. The WUC is responsible for maintaining the irrigation system, collecting water fees, and implementing the quota mechanism. The WUC sets the price for the village irrigation and uses the water fees to cover the maintenance costs of the irrigation system (Table III). Each WUC includes a leader (often the village head), a deputy, accountants, technicians and farmers' representatives. WUC heads are elected for three years by all of the farmers in each village. The WUC and farmers' representatives develop and discuss the water rights system at the village level or the 'irrigation management set of rules'; it stipulates quotas, the price ladder, intended expenditure for water fees collected within quotas, and intended expenditure for water fees off-quotas, and is made public and displayed on a large board in the WUC office (Table III).

Table III. Water pricing specifications in the surveyed villages (in 2012)

Specifications	Unit	Qingdepu	Xihuaiyuan	Xiaowang
Total quota	$\times 10^3 m^3$	700	980	500
Quota per mu (0.067 ha)	m^3	240	240	180
Water lifting efficiency	$m^3 kWh^{-1}$	1.4	1.8	1.5
Price within the quota	US$ kWh^{-1}	0.091	0.072	0.101
Price for quota exceedance up to $+450 m^3$/ha	US$ kWh^{-1}	0.123	0.096	0.109
Price for quota exceedance of more than $+450 m^3 ha^{-1}$	US$ kWh^{-1}	0.131	0.112	0.128
Expenditure of the within-quota water fees		Electricity + salary + maintenance		
Expenditure of the over-quota water fees		50% for repair costs, 50% for developing new water resources		

Data source: authors' fieldwork (2012).

Regulations and policy implementation at the village level. The County Water Resource Bureau provided the information on the new regulations to users in the form of templates with similar structures for all villages but different contents. The templates outlined the following contents:water quota allocation, water price, water fee collection process, and the intended use of water fees (Table III). Water quotas per village differed depending on water demands and resource availability.

Water fees would primarily be used to cover electricity costs related to pumping and lifting, and the personnel costs (salaries) related to management, and maintenance of the irrigation facilities. Fifty per cent of the revenue related to quota exceedance would be used to cover electricity, personnel and repair costs; the remaining 50% would be used to develop new water resources.

As shown in Table III, in Xiaowang village, the water quota was 2700 $m^3 ha^{-1}$ or 1800 kWh, as 1 kWh provides for 1.5 m^3 of irrigation water; the price within the quota was set at US$0.101 kWh^{-1}. If consumption exceeded the quota by up to 30 $m^3 mu^{-1}$ (1 mu = 0.067 ha; that is 450 $m^3 ha^{-1}$ or a quota exceedance of 16.6%), the price was raised to US $0.109 kWh^{-1} (or an increase of 8% over the base tariff). In Qingdepu village, the water quota was set at 3600 $m^3 ha^{-1}$ or 2550 kWh, as 1 kWh provides for 1.4 m^3 of irrigation water; the price within the quota was set at US$0.091 kWh^{-1}. If consumption exceeded the quota by up to 30 $m^3 mu^{-1}$ (that is 450 $m^3 ha^{-1}$ or a quota exceedance of 12.5%), the price was raised to US$0.123 kWh^{-1} (or an increase of 35% over the base tariff). These two examples show that the relationship between price elasticity and quota exceedance differs markedly between villages. Maize farmers in Qingdepu and Xihuaiyuan benefited from higher base quotas but faced sharper price increases in the case of water use exceedance than vegetable farmers in Xiaowang, who had a markedly lower quota but faced a lower price increase for use exceedance.

The irrigation block tariff structure is also more lenient towards overconsumption than that applied in other sectors; in other words, the elasticity of price to quota exceedance is lower in irrigation than in other sectors. According to Table III, a farmer in Qingdepu who uses his quota of irrigation water (i.e. approximately 3600 $m^3 ha^{-1}$) would have to pay for 2550 kWh, that is US$233, or US$0.065 m^{-3}, which is significantly lower than the price for all other sectors (Table II).

Establishing the water access card system: an example. As an example, Figure 1 shows the water rights card of a farmer from Xiaowang village and records of irrigation water consumption from 2010. The water rights are set at 120 kWh of pumping power per mu; pumping efficiency is 1.5 $m^3 kWh^{-1}$, which amounts to total water rights (individual quota) of 180 $m^3 mu^{-1}$ (2690 $m^3 ha^{-1}$). This farmer's household has 1.03 ha (15.4 mu) of irrigated lands, resulting in total water rights (individual quota) of 1848 kWh (equivalent to 2772 m^3).

In 2010, this farmer first purchased 1300 kWh of irrigation water at the price of US$0.088 kWh^{-1}(0.55 yuan kWh^{-1}). He benefited from a lower price than the normal price (US$0.101 kWh^{-1}); the discounted price was a reward for the farmer's positive behaviour in implementing the family planning policy (decision made by the WUC). He also bought more water within his quota limit [1848 − 1300 = 548 kWh] at the normal base price. Beyond the quota, in line with the price ladder, the farmer purchased 308 kWh at US$0.109 kWh^{-1} and 244 kWh at US$0.128 kWh^{-1}.

Recovery of costs: principles and realities

O&M costs, including personnel costs, are supposed to be covered by payments made by farmers when purchasing irrigation water under the IC card-based charging system. The funds raised are managed by the WUC.

Table IV summarizes the costs incurred in the surveyed villages in 2012. In Qingdepu, personnel included two pipeline maintenance staff members and one electrician. The

User No.:	***2050***	*Name:*	***Li Jingang***
Irrigation area	*1.03ha*	*Quota (water right)*	*120*15.4 kWh*
Irrigation schedule:			
Date	*Quantity kWh*	*Price US$/kWh*	*Remark*
2010, April, 14	*1000*	*0.088*	*Discounted price*
2010, May, 17	*300*	*0.088*	
	214	*0.101*	*Normal price*
2010, June, 15	*334*	*0.101*	*= Quota*
	154	*0.109*	*< Quota +30m³/mu*
2010, June, 25	*154*	*0.109*	
	244	*0.128*	*> Quota+30m³/mu*

Data source: authors' fieldwork (2012), translated from Chinese.

Figure 1. Example of a Water Right Card of farming household in Xiaowang village

Table IV. Personnel, operation and maintenance costs in surveyed villages (2012)

		Qingdepu	Xihuaiyuan	Xiaowang
Electricity cost	US$/kWh	0.069	0.069	0.069
Personnel costs	US$	3848	3687	7375
Maintenance costs	US$	6413	3206	4810

Data source: authors' fieldwork (2012).

Table V. Recent changes in irrigation base water prices in the surveyed villages (pumping-electricity equivalent, within quota) in US$ kWh $^{-1}$

	Qingdepu	Xihuaiyuan	Xiaowang
2010	0.072	0.088	0.101
2011	0.085	0.096	0.101
2012	0.091	0.072	0.101

Data source: authors' fieldwork (2012).

managers of the IC card system and water fees are the WUC heads who are paid by the government when also village leaders. Personnel in Xiaowang include the manager of the IC card system, the accountant, a cashier, pipeline and well maintenance staff, an electrician, and other irrigation staff. Other costs include the cost of electricity for pumping and maintenance costs. The electricity company charges the WUC directly; the average electricity price is US$0.069 kWh^{-1} and depends on overall consumption. Maintenance costs include the maintenance of wells, pumps, main pipes, transformers and lines.

As shown in Table III, the block pricing system is aimed primarily at covering salaries and O&M costs, including electricity; repairs and the development of new resources may also be partly covered if some farmers exceed their respective quotas. The WUC is supposed to set up the block pricing system to meet these aims, assuming the full collection of prepaid fees.

Table V shows the recent changes in irrigation pricing decided by the WUCs for 2010, 2011 and 2012. Water tariffs increased gradually in Qingdepu and remained fixed in Xiaowang. In contrast, water tariffs dropped significantly in 2012 in Xihuaiyuan. These cases illustrate the flexibility of the pricing strategy at the WUC level.

In Xihuaiyuan, the WUC head agreed to the farmer representatives' wishes to lower the price of water (regardless of the O&M cost recovery objective) to please the farmers and win local elections as village head. In Qingdepu, the newly elected WUC (and village) head is a businessman who committed to personally providing the necessary funds to cover any non-covered O&M costs. Furthermore, both Xihuaiyuan and Xiaowang village benefited from rent revenue from village collective lands and used these funds to support irrigation O&M and maintenance costs.

From Table IV, the required base water price (up to quota use) was calculated to be US$0.09, 0.082 and 0.106 kWh^{-1} (in 2012) in Qingdepu, Xihuaiyuan and Xiaowang, respectively, if all personnel, operation and maintenance costs (including electricity) were to be covered under a scenario of full quota use. Interestingly, the WUC in Qingdepu gradually increased its base water price to meet that objective in 2012; in Xihuaiyuan, the base water price exceeded this objective in 2010 and 2011 and then dropped in 2012. In Xiaowang, the stable base water price was not able to balance the budget.

Table VI shows the actual water consumption that was recorded in the three villages surveyed. All three villages used more water in 2011 than in 2012 due to drier conditions. It is

Table VI. Water consumption (10^3 m^3) in the surveyed villages in 2011 and 2012

	Qingdepu	Xihuaiyuan	Xiaowang
Quota	700	980	500
2011			
Actual total consumption	574	648	765
Consumption between quota and +450 m^3 ha^{-1}	0	0	83.3
Consumption beyond quota +450 m^3 ha^{-1}	0	0	182
2012			
Actual total consumption	504	558	750
Consumption between quota and +450 m^3 ha^{-1}	0	0	83.3
Consumption beyond quota +450 m^3 ha^{-1}	0	0	167

Data source: authors' fieldwork and calculations (2012).

Table VII. The balance of revenue from water fees and O&M costs in the surveyed villages (year 2012) (units: US$)

	Qingdepu	Xihuaiyuan	Xiaowang
Revenue			
Expected revenue from full quota use	45 500	39 200	33 667
Actual revenue from use within quota	32 760	22 320	33 667
Actual revenue from use beyond quota	0	0	20 278
Actual total revenue	32 760	22 320	53 945
Costs			
Electricity pumping costs	24 840	21 390	34 500
Personnel costs	3 848	3 687	7 375
Maintenance costs	6 413	3 206	4 810
Total costs	35 101	28 283	46 685
Balance after electricity is paid	7 920	930	19 445
Balance	*−2 341*	*−5 963*	7 260

Data source: authors' fieldwork and calculations (2012).

worth noting that the two WUCs where farmers grew mostly open-field maize under irrigation used less water than allowed by their quota: 82 and 66% of the quota in 2011, and 72 and 57% in 2012 in Qingdepu and Xihuaiyuan, respectively. The main reason for these two villages water consumptions being less than their quota is the change of planting structure to less water using open-field crops. In Xiaowang, vegetable production under greenhouse conditions required more water than allowed by the quota (153% of quota in 2011 and 150% in 2012); in both years, consumption exceeded the two thresholds of the price ladder. Such behaviour was illustrated at the individual level by the case presented in Figure 1. It seems that vegetable farmers in Xiaowang were confident that additional fees paid for extra water would be offset by the benefits of higher value production.

WUC revenues from irrigation water sales (Table VI) were compared with the costs listed in Tables IV and V. Table VII shows the match between O&M costs and revenue from water fees (within and beyond quotas) in the surveyed villages in 2012.

Tables VI and VII reveal key features of farmers' water use and important outcomes of the block pricing system in the three WUCs surveyed.

In villages where maize was the main irrigated crop (i.e. Qingdepu and Xihuaiyuan), farmers (collectively) used approximately 20–40% less water than allowed by their quotas. For at least two consecutive years (2011–2012), it appeared that groundwater overexploitation could be contained. Farmers refrained from overuse, even when water prices were very low (in Xihuaiyuan). It is likely that charging for water use on a prepaid basis was effective.

In contrast, greenhouse vegetable farmers in Xiaowang exceeded their quota allowance by approximately 50%. It seems that the expected benefits from vegetable production surpassed the extra costs of high water consumption at higher prices. In addition, these farmers consumed water across the entire price ladder, even in excess of the 30 m^3 mu^{-1} (450 m^3 ha^{-1}) allowance. It seems that this intermediate threshold did not provide enough deterrence to limit the exploitation of water resources. Vegetable farming might be profitable enough to require rethinking the quota and water price system in Xiaowang. Under current pricing, the price elasticity of demand for irrigation water is low. Higher prices for excessive use might be required if groundwater water use needs to be limited. The village water quota per area in Xiaowang was the lowest of all three villages, which might explain the quota exceedance.

Water consumption at the village level resulted in different revenues and cost recovery situations. In Qingdepu and Xihuaiyuan, farmers used far less water than the amounts allocated by quotas, which resulted in low revenue from water fees and lower electricity costs for pumping. However, in both cases, electricity costs were covered. In Qingdepu, personnel costs and part of the maintenance costs were covered by water fees, while in Xihuaiyuan, none of these fees were covered because of the low price of water.

In Qingdepu, the village committee and WUC leader, as a businessperson, committed to providing private funds. In Xihuaiyuan, rent revenue from village collective lands was supposed to supplement the budget. Further details could not be obtained during the survey. In both cases, the combination of low water prices and low water use resulted in low revenue, which prevented full recovery of maintenance costs, let alone further resource development. As discussed above, the WUC of Qingdepu set the base water price to cover all costs under quota use conditions. As a result, lower consumption by farmers resulted in a revenue gap and an unbalanced budget due to fixed costs (personnel and O&M costs).

In Xiaowang, higher water use for greenhouse vegetable production and higher water prices resulted in higher revenue for the WUC. All costs were covered, and the remaining funds provided for water resource development. As discussed previously, this WUC had set a relatively low base water price that did not allow for recovery of costs under strict quota use conditions. The extra income resulted from the extra use of water by farmers.

Water use value

Table VIII sums up the techno-economic performance of maize cropping observed in the three villages surveyed. Maize yields are strikingly similar between farms and villages, and also quite high (approximately 6 t ha^{-1} of dry grain equivalent); labour-intensive cropping in small plots, with high fertilization and supplemental irrigation, may explain such performance. Also energy use for irrigation water pumping is homogeneous, with no significant difference between villages. Production cost is the feature that differs most and significantly between villages. While certain costs are similar between villages (i.e. seed, agrochemicals), others differ markedly (e.g. higher organic fertilization, and lower machinery and labour costs in Xiaowang). With higher yields and lower production costs, Xiaowang has significantly higher net income, 1900 US$ ha^{-1}, or approximately twice that achieved in the other two villages.

Energy used for pumping has been translated into water volumes, according to pumping specifications (Table III). Table IX reports these figures, which show that water use ranges between 360 and 390 mm in the three villages, with no statistically significant difference. Maize is grown between May (sowing) and October or November (harvesting), and benefits from summer precipitation (approximately 350 mm). However, due to very high evaporative demand (approximately 700 mm during the maize cropping season), supplemental irrigation is necessary, especially in the early stages.

Table VIII. Techno-economic performance of maize cropping systems in sample farms of the surveyed villages in 2013

		Total costs (US$ ha^{-1})	TVP (US$ ha^{-1})	Net income (US$ ha^{-1})	Yield* (kg ha^{-1})	Energy use (kWh ha^{-1})
Xiaowang	Average	1 810^{a}	3 710^{a}	1 900^{a}	10 800^{a}	2 410^{a}
N = 19	St. dev.	486	535	803	1 560	1 440
Xihuaiyuan	Average	2 180^{b}	3 210^{b}	1 030^{b}	9 690^{a}	2 160^{a}
N = 13	St. dev.	308	489	569	1 400	1 540
Qingdepu	Average	2 620^{c}	3 540^{ab}	922^{b}	10 600^{a}	2 710^{a}
N = 12	St. dev.	445	655	804	1 450	1 330

*Maize cobs are harvested fresh, dehusked, at approximately 30% moisture content; yields expressed in dry grain mass equivalent are therefore approximately 60% of the values indicated in the table.
[a,b,c]values of variables (averages) for each column with no superscript in common are significantly different at $P < 0.05$ (according to *t*-test).
Data source: authors' fieldwork in 2013 and own calculations.

Table IX. Irrigation performance and comparison of use value (shadow price or MVP) and actual price of irrigation water in the surveyed villages

		Water use (mm)	CWP* (kg m^{-3})	MVP (US$ kWh^{-1})	MVP (US$ m^{-3})	Water price** (US$ kWh^{-1})
Xiaowang	Average	361^{a}	1.60^{a}	1.09^{a}	1.64^{a}	0.101–0.128
N = 19	St. dev.	216	0.71	0.68	1.02	–
Xihuaiyuan	Average	389^{a}	1.58^{a}	0.74^{b}	1.33^{b}	0.072–0.112
N = 13	St. dev.	277	1.06	0.64	1.15	-
Qingdepu	Average	379^{a}	1.59^{a}	0.55^{b}	0.77^{b}	0.091–0.131
N = 12	St. dev.	186	1.02	0.61	0.85	–

*CWP: Crop water productivity, expressed in kg of dry grain per cubic metre of evaporated irrigation water.
**Water price data refer to the range of prices in each village's price ladder, according to consumption and quota (min–max) (Table III).
[a,b,c]values of variables (averages) for each column with no superscript in common are significantly different at $P < 0.05$ (according to *t*-test).
Data source: authors' fieldwork in 2013 and own calculations.

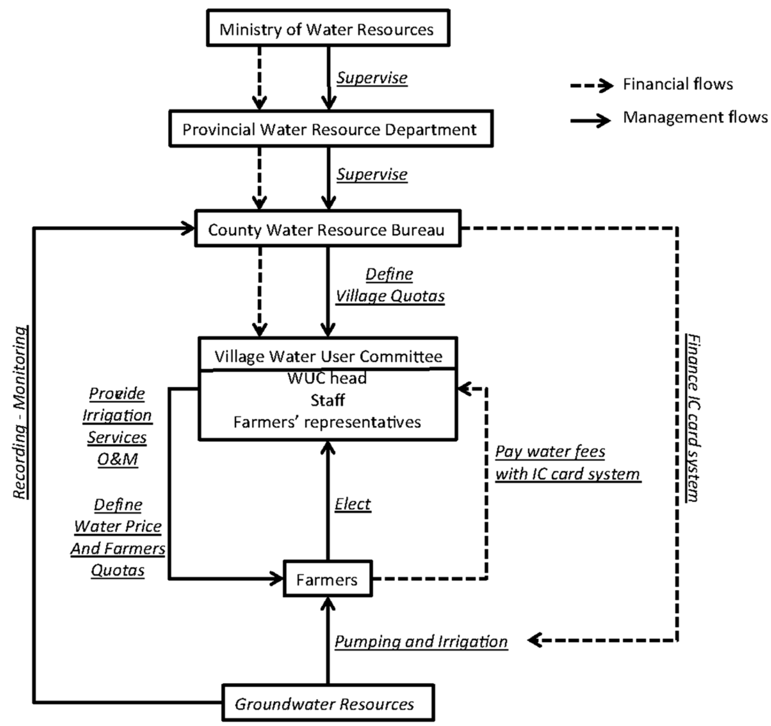

Figure 2. Schematic of the governance system in the irrigation sector of the case study villages of Northern China

In spite of such homogeneity in water use, and due to marked differences in net income, the use value of water is markedly different between villages; Xiaowang has a significantly higher MVP, at US\$1.64 m^{-3}, followed by Xihuaiyuan (1.33) and Qingdepu (0.77). For validation, cropping budgets and water use results were translated into crop water productivity (CWP, as the ratio between marketable yield in kg dry grain, and actual evapotranspiration water in cubic metres), and compare with the figures found by Doorenbos and Kassam (1979) and Zwart and Bastiaanssen (2004). Assumptions for calculations included dry grain mass equivalent per harvested cob (0.6 kg kg^{-1}) and irrigation field efficiency at 70% of raw supply (pumped water) in maize cropping. Table IX reports our CWP calculations and compares with existing sources. CWP in all three villages is very homogeneous, approximately 1.6 kg m^{-3}, because of similar yields and water pumping features. Doorenbos and Kassam (1979) modelled CWP for maize and found values ranging between 0.8 and 1.6 kg m^{-3}. Zwart and Bastiaanssen (2004) reviewed several CWP sources from northern China, with results ranging between 1.26 and 3.33 kg m^{-3}.

Table IX also compares MVP figures, expressed as per kWh, with the current prices. In all three villages, water use values, reflecting the willingness to pay of farmers, are approximately tenfold the current price charged to farmers. This means that irrigation water is well underpriced as compared to farmers' net return from water use, and that farmers would have, on average, the capacity to pay higher charges in all three villages. Such evidence is drawn from analysing maize cropping only, due to the limited number of other cases. Maize is arguably one of the crops that value irrigation water least due to its low market value. Higher-value crops, such as open-field or greenhouse vegetables, are likely to have higher MVP of water.

CONCLUSION

In an attempt to restore sustainable groundwater use, authorities in Qingxu County established a regulated water access mechanism and a joint framework for governmental and farmer governance. Under this framework, the government contributes to the construction of irrigation facilities and the implementation of institutional settings and mechanisms (water rights and access, control, monitoring and enforcement). Consequently, farmers pay for irrigation water and services through an innovative prepaid water charging system. Qinqxu County promoted and supported the development of WUAs, also known as water user committees (WUCs).

Local farmers' participation in irrigation management includes: (i) the election of the WUC head and farmer representatives; (ii) the rules of irrigation management to be approved by the assembly of farmer representatives; (iii) the transparency and monitoring of the irrigation management. Irrigation management rules, quotas, the price ladder, intended expenditure for water fees collected within and off-quotas, are all made public and displayed on a large board in the WUC office.

As shown in Figure 2, the reformed governance system in the irrigation sector in Qingxu County featured two new main dimensions.

First, financial reform was enacted whereby water services are now covered by contributions from farmers on a user-(pre)paid basis. The IC card system was set up with public investment at high cost. With a fee collection rate of 100%, this card system solved the free-riding problem and the lack of financial contribution by farmers. Pumping (electricity) costs and most maintenance costs were covered in all cases studied. However, full personnel and O&M cost recovery was only achieved in one village, Xiaowang, which managed to cover all costs, with surplus, in 2012. This was due to water use beyond quota, yielding higher revenue. Everywhere, government contributions continued in the form of investment in water-saving technologies (piping) and continuous support (training, funding). Results on water use value in maize cropping show a high MVP of water compared to the water fees that apply, owing to high yields and reasonable use of supplemental irrigation. Farmers can pay water charges, which could even be increased a little, if necessary, to better cover irrigation service costs and ensure sustainability.

Second, a realignment of institutional relations within the governmental administrative structure was achieved (as shown also by Mollinga *et al*., 2006). Indeed, the hierarchical line of command and funding that exists in Chinese administration now overlaps the irrigation governance system, from the province down to the village level.

In the new system, the village WUC plays a central role, interfacing between government agencies and farmers, setting water fees and individual quotas, allocating funds, collecting water fees, and providing irrigation services to farmers. Although commonalities do exist between the internationally broadly defined water users' associations and the WUCs, there are also key differences: the WUC head is commonly the ruling village head, usually a powerful, influential and respected person, and not always a farmer. In addition, the WUC makes decisions related to the water pricing system, the use and allocation of water fees, or the decision to resort to other public (collective land rent) or private (donations, vote-buying by the head) sources of funds to support irrigation. This results in an original but questionable mix of private–public interests and financial and political partnerships.

From a political economy viewpoint, such practices may be questioned and considered to be clientelism and paternalism. However, local informants stated that this mix of public and private interests and the dominant position of the head of the WUC led to a 'triple win' situation that satisfied all stakeholders (the government, farmers and the WUC head).

In spite of these justifications, the long-term sustainability of such arrangements is unclear. In Xihuaiyuan, the revenue from water fees did not cover salaries or O&M costs, while the use of collective land rents cross-subsidized irrigation costs. In Qingdepu, private funds were meant to compensate for budget gaps in a vote-buying manoeuvre. First, the direct link between farmers' contributions and the irrigation service is broken; farmers currently only pay for electricity costs. The WUC staff is not dependent on or accountable to farmers, but rather to the WUC (especially its head). Second, while costs that are not covered are known, there is no clear indication of how much the private financial contribution of WUC head will be and how long it will last.

Yet again, in spite of the above-discussed limitations and uncertainties, all stakeholders in the irrigation sector in Qingxu County considered that the reform had been successful and believed that it achieved more than previous experiences of both government- and farmer-managed irrigation. First, under the newly established system, farmers pay for groundwater use, and 100% of fees are collected. Second, pumping costs (the main O&M cost incurred) are internalized and fully covered by water fees. Third, groundwater use is monitored and apparently contained in most cases. Fourth, although fraught with some local political interference, the WUC operates with real decision-making power and autonomy, with differentiated solutions according to needs.

As the case study shows, the WUCs have yet to adjust prices and pricing strategies to farmers' actual willingness and capacity to pay for irrigation water. Farmers' WTP is much higher than current charges. There is room for water fee adjustments, in order to ensure long-term quality of irrigation service and the system's sustainability. The price elasticity of demand for irrigation water by farmers seems to relate to their cropping strategies and potential income. The WUC must pay attention to these factors and conduct more research on farmers' crop budgets and income. Finally, in light of the high cost incurred by the IC card system and because of the need for continuous public support (large repairs and further facility updates), such endeavours might not be suitable or acceptable in all counties.

ACKNOWLEDGEMENTS

This research has been funded by the National Social Science Foundation of China (project num. 11CJY059) and by the FAO project 'Study on the Analysis of Sustainable Water Resource Use in Asia' (num. GCP/RAS/241/JPN). The authors express their sincere gratitude to Professor Shen Dajun and Associate Professor Lv Zhiwang who provided valuable comments on early versions of the paper.

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