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Transaction Costs, Modes, and Scales from Agricultural to Industrial Water Rights Trading in an Inland River Basin, Northwest China

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Abstract: Water transactions from agriculture to industry have become an important means to address water scarcity and improve water economic efficiency. Transaction costs (TCs) are one of the main factors preventing water markets from forming or efficiently operating. To evaluate the level of transactions costs, we set the appropriate transaction modes for cross-sector lever water trading and evaluated the TCs from agriculture to industry in the Heihe River Basin (HRB), an inland basin in northwest China. We found that the ranges of transaction costs per m^3 of water ranged from 0.06 to 1.10 yuan, and the ratios of TCs to transaction prices ranged from 4.11% to 244.44%. The transaction scale should be more than 15,267 m^3 or 29,888 m^3 when the TC is at the lower or upper limit in the study area. When the transaction scales are set correctly, the range of the transaction costs will be in an acceptable range, and the proportion of TCs to transaction price will not exceed the 8% limit of the California Water Bank, which was employed as a comparison. The key restrictive factor of water trading in HRB may be the low transaction scale, followed by the high water TCs. The effects of improving water use efficiency in cross-sector trading could not neutralize the restrictions caused by the negative effects of small water demand transaction scales for undeveloped secondary industries in HRB. However, considering the industrial structure and development trends of the regional economy, the future driving force of water transactions across sectors likely lies in tertiary industries in HRB.

Keywords: transaction costs; water rights; transaction modes; transaction scales

1. Introduction

Water scarcity is an issue worldwide, affecting more than 40% of the global population—a proportion that is projected to increase [1]. Over 1.7 billion people are currently living in river basins where water use exceeds recharge [2]. Moreover, the water use ratio of the agricultural sector is high, exacerbating the water crisis on account of the lower general output per unit water use in agriculture. Because of the difficulties associated with developing a new water supply through engineering/technological means, water demand management measures, such as developing water markets for transactions, have often become key solutions to water availability issues [3–5]. This indicates that one major current problem for water resources worldwide is water management in the social system, rather than water availability in the natural water system. Water allocation can be undertaken through administered systems, market-based systems, or a combination of the two [6]. Meanwhile, water transactions conducted on a voluntary basis in water markets rather than as enforced by laws and regulations have become a primary means to reconfigure water sources in most developed countries [7].

Existing water transaction costs (TCs) are one of the key factors impeding the development and efficiency of water markets [8–10] and improvements in productivity [11–13]. Decreasing the water

TCs between transaction parties is a feasible way to increase the possibility of water trading and to ease the severity of water scarcity [14,15]. High TCs also impede the achievement of the intended goals of building good water trading markets and improving water-saving technologies, among other goals, in many water-stressed regions [16].

TCs were first discussed in the literature on economics by Coase [17]. Cheung [18], Williamson [19–21], and North [22] studied and developed the theory of TCs. According to Coase [17], TCs are the costs of using a price mechanism. Williamson [20] divided TCs into ex ante and ex post categories, according to the time at which the contract was signed.

Researchers may assign different categories or components of TCs, including water TCs according to different research aims [9,10,23–26]; for example, water TCs may include time invested in searching for appropriate partners with whom to form a contract [24] and in facilitating water transactions, the money paid for conducting these transactions, and other costs involved in completing the water trading, excluding the price of the water rights [14]. In practice, the measurement of TCs depends on the boundaries, the stages of evaluation, and the real situations of trading [10].

According to the life cycle of the water rights transaction, five kinds of TC are set out according to the following steps (Table 1). The first kind, institution costs (TC_1), is related to the institutional environment and transaction policies, which is the prerequisite to conducting the water transaction legitimately. At the same time, these costs are one-time costs that occur at the establishment of the water tradable system, or the costs that we refer to as investment at an earlier stage. According to different governance structures, technologies, water environments, and ways to use water, the remaining costs (TC_2–TC_5) are TCs that contracting parties and the local government have to pay for completing some transaction. These include implementation transaction costs (TC_2), transfer costs (TC_3), maintenance and monitoring costs (TC_4), and third-party effect costs (TC_5) [10].

Table 1. The components of water transaction costs.

Transaction Costs (TCs)	Components
Institution costs (TC_1)	Authentication of feasibility costs (TC_{11}) Rules and regulations construction costs (TC_{12}) Construction costs, such as new water conveyance facility input costs at an early stage (TC_{13}) Expanded personnel costs (TC_{14})
Implementation transaction costs (TC_2)	Information costs (TC_{21}) Negotiation costs (TC_{22}) Contract costs (TC_{23}) Costs for examination and approval by local governments (TC_{24}) Enforcement costs (TC_{25})
Transfer costs (TC_3)	Water delivery loss costs (TC_{31}) New water conveyance facilities costs for trading (TC_{32})
Maintenance and monitoring costs (TC_4)	Monitoring costs (TC_{41}) Seeking compensation costs (TC_{42}) Preventing infringement of third-party costs (TC_{43})
Third-party effect costs (TC_5)	Return flow costs (TC_{51})

The gaps in water use benefits between these parties of transactions are the important driving factors of water transactions. Usually, the water use benefits of the secondary or tertiary industries are higher than those of the agricultural sector. The potential of trading water between different sectors is much larger than within the agricultural sector [27,28]. One very important driving force behind water trading is the transaction from agricultural to industrial sectors for improving the benefits of water use. The big gap in water use benefits between these two sectors can also contribute to productive efficiency by incentivizing water-saving technologies since any conserved water can then be sold [29]. This means that the agricultural sector, having lower water use benefits, can act as the supply-side of water transactions; meanwhile, the industrial sector can be the demand-side and provide more added value to water use. However, the number of benefits gained depends on the costs spent on the transactions, the design of the water markets, and the transaction scales.

Even with the strong endogenous drive of potential benefits, the severity of water scarcity still makes the development of water markets prosperous in certain countries [30]. The United States and Australia have built market-based water rights trading to enhance flexibility and to reallocate water resources [31]. There are many water banks in the western United States, and the Australian state of Victoria issues water shares to promote water trading. In these countries, to better enhance water trading, water rights are usually separated from land rights. The water management department would assure trading information transparency to reduce water TCs. Meanwhile, the government would buy back some water rights to promote environmentally sustainable development in the very dry years. Chile and Mexico, both developing countries, also employ water trading systems [30].

China is among the countries worldwide that are confronted with water scarcity, especially in the northwest arid region. Government regulation is still the main channel through which water resources are distributed in China, and water market transactions are only the secondary means. The Ministry of Water Resources in China advocates the transaction of water rights through water markets. In the promotion of a "water-saving society" in Zhangye City of the Heihe River Basin (HRB), the first project of its type in China, maintaining a tradable water market is one of the most important specific measures. However, water rights trading among the whole county is currently low, with most of the transactions involving trade among farmers for agricultural use. Even in Zhangye City, the forerunner of building water markets, only one transaction, from agricultural irrigation districts to a heat energy plant enterprise, can be seen as a cross-sector transaction. In this study, we aimed to investigate whether the TCs are high enough to impede water rights trading or whether there is a lack of appropriate transaction modes.

To address these issues, it was necessary to set an appropriate transaction mode to clarify the possible existed transaction costs, and to evaluate the ex ante water transaction costs including return flow costs from agriculture to industry. In this paper, we chose Zhangye City in the HRB, the first saving-water society in China, as our case study area. We reviewed the relevant literature and conducted in-depth interviews with the staff of the water management departments to clarify the existing water TCs between agriculture and secondary industries in the current water system. We use a mechanism including participation constraint and incentive compatibility constraint to set the appropriate transaction mode, to determine an acceptable water transaction pricing, and to identify he range of the transaction scale, which would ensure that the owners of agricultural water rights would benefit more from participating in the transaction than not. We also investigated the sale of water rights to industry, rather than only trading within the agricultural department. Meanwhile, the industry bosses pay less to buy water rights from the agricultural sector than to purchase them from water supply companies. We aimed to identify a range of water TCs, to find appropriate ways to decrease TCs, and to provide policy suggestions for water management and the tradable water rights system in our study area and other arid regions in the world.

2. Materials and Methods

2.1. Study Area

The Heihe River, the second longest inland river in China, originates from the Qilian Mountain; it lies mainly in the Qinhai province and ends in Juyanhai Lake in Inner Mongolia. The study area, Zhangye City of Gansu Province, is located in the midstream region of the HRB, accounting for 95% of the cultivated land, more than 90% of the population, and 89% of the GDP of the entire river basin [32]. The city governs six counties: Ganzhou, Linze, Gaotai, Shandan, Minle, and Sunan Yugur. The first three counties are located in the corridor plains region and are the main agricultural irrigation areas that consume the most water in the midstream area of the HRB (Figure 1).

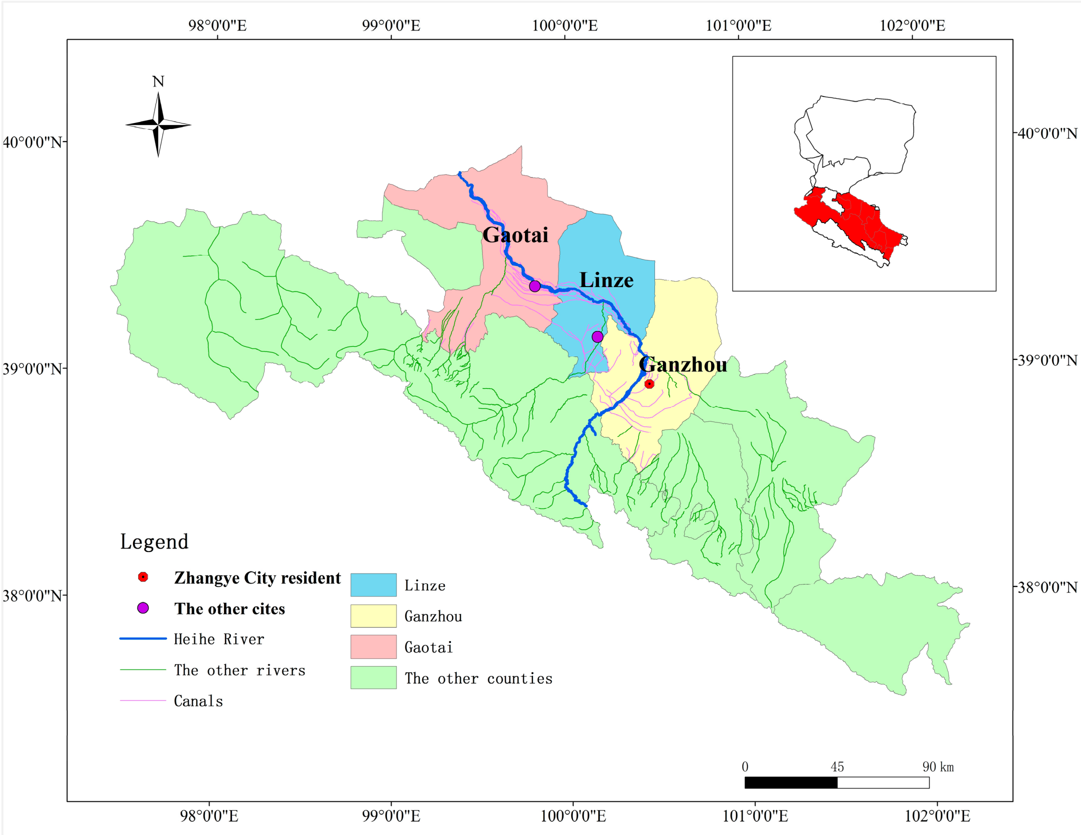

Figure 1. Map of study area in the Heihe River Basin.

Figure 2 shows the proportion of the output values and the proportion of water use attributed to each sector in Zhangye City from 2000 to 2014.

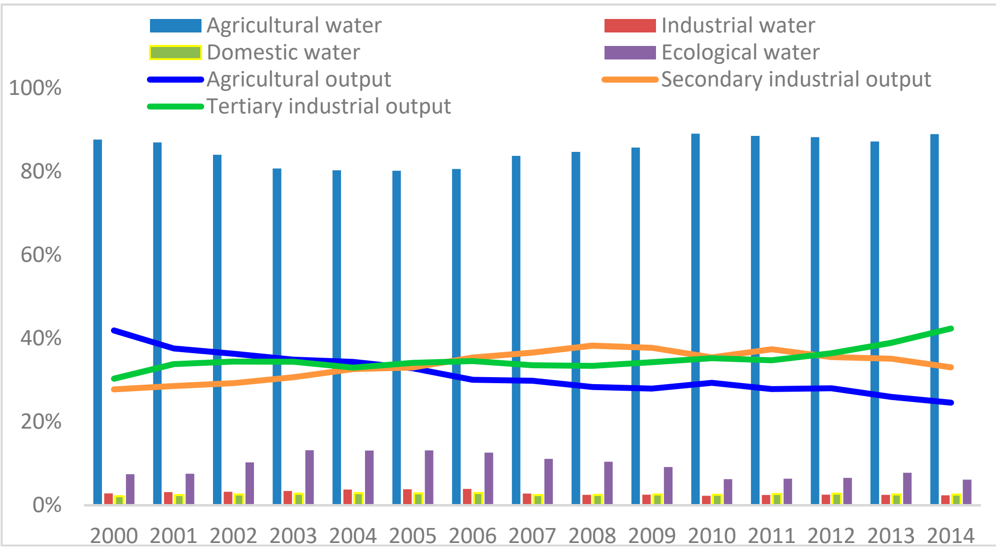

Figure 2. The proportion of the output values and the proportion of water use of each sector in Zhangye City, 2000 to 2014.

Both in output and water use, the agricultural sector played the most important role in Zhangye City before 2004. From 2006 to 2011, the output of secondary industries was higher than the other two sectors. From 2012, the output of tertiary industries exceeded that of secondary industries, mainly due to the prosperous tourism industry. The output values of the agricultural, secondary, and tertiary industries were 8.898, 11.968, and 15.337 billion yuan (RMB) in 2014 [33]. In Zhangye City, the proportion of agricultural water use exceeded 80% (Figure 2). The water use volumes of agricultural, secondary industrial, domestic, and ecological sectors, including surface water and groundwater, were 2.147, 0.057, 0.061, and 0.147 billion m^3 in 2014 [33]. About one quarter of the water consumption comes from ground water.

The net benefits of agriculture, secondary industries, and tertiary industries use per m^3 of water were approximately 4.14, 211.16, and 73.62 yuan, respectively. It is clear that the net benefit per m^3 of water used in secondary industries was the highest in Zhangye City during these years.

The output value of secondary industrial enterprises above a designated size was 6.659 billion yuan in 2014. The four top-ranking sectors of output values were the farm and sideline food-processing industry, the electricity and heat production and supply industry, the alcohol- and beverage-manufacturing industry, and the non-metal mineral product industry. The output value proportions of these four industries accounted for 76.9% of the whole of Zhangye City. The highest output value came from the farm and sideline food-processing industry, which accounted for 36.5% [33].

To alleviate the severe deterioration of ecosystems in the downstream areas of the HRB, the Chinese government implemented an ecological water diversion project at the end of the 20th century [34,35]. To accomplish the targets of ecological conservation and water saving, the Chinese government initiated two comprehensive programs in the HRB. The first program was the short- to mid-term governance program of the HRB, initiated in early 2001, by dividing water availability among regions based on quantitative targets [36]. In 2002, Zhangye City began the development of a water-saving society and a tradable water market, the first project of its type in China, which is the second program. During the implementation periods of the two programs, the government emphasized investments in building and improving water infrastructure, such as lining canals, and in the development of economic and institutional water resource management strategies, such as establishing a participatory water management system with clearly defined water use rights (WUR) and tradable water quotas [37].

2.2. Parties of the Transaction

The water transactions we analyzed involved two sectors: the buyers as the owners of the secondary industrial enterprises, representing the demand side, and the sellers as the owners of the agricultural water rights, representing the supply side of a water transaction.

Ganzhou County (the county of residence of Zhangye City) had the highest output value among the six counties, accounting for almost one third of that of the entire city [38]. Zhangye economic and technological development zones are located in Ganzhou County, where many industrial enterprises that consume considerable water are concentrated. There were 462 enterprises in the zone, and 24 of these enterprises were above the designated size.

The average output value per m^3 of water of secondary industrial sectors was from 25.99 yuan in 2000 to 211.16 yuan in 2014. The average output value per m^3 of water for agriculture ranged from 1.25 yuan in 2000 to 4.14 yuan in 2014. Although the output value of agriculture continuously increased by three-fold in 2014 from the value in 2000, the output value of the use of secondary industries was 20-fold greater than that of agriculture in 2000 and increased by 50-fold in 2014.

Through engineering/technological means, including developing new water management strategies and adjusting the composition of crop cultivation, Zhangye City has saved a substantial amount of water since 2002, especially in agriculture. The saved amount of water use was 0.2 billion m^3 every year from 2002 to 2009 [39]. With the development of secondary and tertiary industries, more agricultural water might be saved because many farmers might change their livelihoods to work in the city, such as in handicraft work, catering service work, and so on, and their farmland may be transferred or idled [10].

So, we found that it is easy to meet some basic requirements for trading water rights across sectors: the benefit of use per m^3 in the demand side industry is higher than that of the agricultural sector, but the potential for water-saving in agriculture, the supply side, is still huge.

2.3. Transaction Mode Setting

After the water market was built, the key problems of water trading from agriculture to secondary industries included the following: (1) how to gather the scattered water rights together from each farmer, as all volumes of water rights ownership were small in this study area; (2) how to obtain the sold water rights for the industries (do channels exist, or are new water conveyance facilities needed?); and (3) how to design an efficient transaction pricing mechanism.

This process requires government agencies to participate as agents. One reason for government involvement is to gather the scattered water rights together from farmer-sellers. The other reasons include to make sure the benefits of other third parties remain intact, and to examine and approve the water rights.

Considering the scattered distributions of industrial enterprises, completing a water transaction from an irrigation district to an enterprise requires pipe-laying or new channel construction, which adds to uncertainty for ex ante evaluation and increases new water conveyance facility costs for trading (TC_{32}).

Roughly estimating the TC_{32} from the nearest irrigation district to the Zhangye economic and technological development zone, pipe-laying would cost between 1.05 and 1.68 million yuan if using the different materials prices [40] of low-pressure or high-pressure piping after considering inflation, respectively. This expense is not cost-effective for a relatively small transaction. It is worth mentioning that because of improvements in irrigation facilities and their accessories during the projects of the short- to mid-term governance and building a water-saving society in Zhangye City, agricultural water rights trading must be easier in the corridor plain region of the HRB, i.e., in Ganzhou, Linze, and Gaotai Counties. Additionally, the conversion rate of surface water and underground water is more than 70% in the HRB [41].

Negotiations and auctions are the primary pricing mechanisms for water rights trading. Due to the considerable gap of outputs per water use between the agricultural and industrial sectors, the negotiation costs may be high and unclear due to repeated bargaining, which impedes water transactions. Auctions provide relatively open market settings and transparent price signals that reduce the extent of information asymmetry and agency costs among potential buyers. The gathering of traders using auctions minimizes the need for information searches, negotiations, and contracting [42]. Auctions as a transactional mechanism are common for the exchange of divisible goods, such as power systems, and general goods, such as public resources that have high information search and negotiation costs [43].

In this context, with the uncertainties of TC_{32} through pipes or channels and the reduction of loss via useless evaporation, increasing the transparency of the pricing mechanism, we set the transaction mode and conditions from agriculture to secondary industries to meet an incentive compatibility constraint and a participation constraint, as described below:

(1) Usually, a vast quantity of water rights required by an industrial enterprise per transaction requires many farmers to provide water together. To facilitate such a transaction, the Institution of Irrigation District would serve as a representative of these farmers to conduct water transactions and negotiate with the agents of the industrial enterprise.
(2) Considering the high conversion rates of surface water and underground water in this region, and using as a reference a water bank in Oregon, USA, agricultural surface water is poured into the ground aquifer (if the farmers sell the underground water in the well irrigation district, they reduce the relevant volume of water drawn), and then the buyer's industrial enterprise will pump groundwater from a new or original well. The change of water rights from available surface water to groundwater may provide the necessary water allocation through an appropriate

auction or by another transaction [44]. This setup reduces the construction costs involved with laying new pipe and reduces losses via evaporation [45].

(3) The transactions must be examined and approved by the local government to promote the registration of trading of water rights and issuance of water rights certificates.
(4) Both parties must install intelligent water meters for controlling the monitoring costs and transaction scales [45].
(5) Auctions are the only form for trading water rights between two sectors in this study.
(6) Making the assumption that water demand growth can be met by water supply companies in the future, the target of the water transaction from agriculture is to reduce purchase costs. The upper limits of the buyer enterprise's whole payments, including water prices and water TCs, should not exceed the prices of tap water to meet the incentive compatibility constraint.
(7) To meet the participation constraint for farmer sellers, the transaction price per m^3 of water should not be less than three times the current agricultural price (0.45 yuan/m^3), based on local management approaches of the upper limit of inner-agricultural water trading.

2.4. Transaction Costs and Their Determinants

The components of water transaction costs are shown in Table 1, including institution costs (TC_1), implementation transaction costs (TC_2), transfer costs (TC_3), maintenance and monitoring costs (TC_4), and third-party effect costs (TC_5) [10]. Given that the early inputs of the water rights transaction system in Zhangye City have been completed during the implementation periods of the above two programs, which means that institution costs (TC_1) have all been thoroughly accounted for by the Chinese government, we evaluated only the last four types of costs (TC_2–TC_5), without considering institution costs.

We calculated the other four TCs associated with agricultural water trading in Zhangye City, northwest China in our previous work [10]. The influences of water rights transactions at the cross-sector level are much different from those of water trading in agricultural sectors, including changes in water use stability and a greater return flow [46,47]. In this context, water rights transactions between two sectors are strictly regulated by the government. The examination and approval costs by the government (TC_{24}) and the third-party effect costs (TC_5) are important elements of water TCs in the context of cross-sector transactions. These costs cause larger obstacles for water rights trading from agricultural to industrial sectors, which require a greater trading scale to decrease the per m^3 water TCs in each transaction and to induce the different transaction modes from the transactions in inner-agriculture water trading.

Implementation transaction costs (TC_2) include information costs (TC_{21}), negotiation costs (TC_{22}), contract costs (TC_{23}), examination and approval costs by the local government (TC_{24}), and enforcement costs (TC_{24}).

As described above, auctions are the only form for trading water rights between two sectors in this study. Thus, we evaluated the costs of organizing an auction, including issuing information to the public, renting a location, and paying commissions to auction companies. These factors served as substitutions for information costs (TC_{21}) and negotiation costs (TC_{22}). Contract costs (TC_{23}) are the relevant travel expenses of both representatives, including the wage proportions of the agents and the paper costs of the final three contracts. According to the ruling institution, cross-sector water trading must provide supporting papers to third parties or obtain permission from relevant people. Therefore, the examination and approval costs by the local government (TC_{24}) include those relevant costs and the time invested in this step. Enforcement costs (TC_{25}) involve the time spent by the water administrator in identifying the sell volume of water that is returned to the aquifer. Then, the buyer enterprise draws the relevant water quantity after payments of the water price in advance.

Transfer costs (TC_3) include water delivery loss costs (TC_{31}) and new water conveyance facility costs for trading (TC_{32}). Due to the surface water returned to the aquifer, delivery loss can be neglected. The agricultural surface water must be added to the aquifer using a well, and then the industry enterprise draws water using a well. Some industrial enterprises have wells that can be used directly. Therefore, we account for the costs of digging one or two wells as TC_{32}, considering that the average service life of a well is 16.5 years [48].

Maintenance and monitoring costs (TC_4) include monitoring costs (TC_{41}), compensation-seeking costs (TC_{42}), and costs to prevent infringement by third parties (TC_{43}). Because intelligent water meters, which can measure the volume of water being added to and drawn from a well, are used for trading to avoid infringements, the TC_4 uses the costs of intelligent water meter installation as a substitution.

We analyzed the return flow costs (TC_{51}) in third-party effect costs (TC_5) using the preliminary computation results.

The total transaction costs are equal to the sum of TC_2, TC_3, TC_4, and TC_5. Except for TC_5, the other transaction costs ($TC' = TC_2 + TC_3 + TC_4$) are fixed for one transaction, while the return flow costs (TC_{51}) in third-party effect costs (TC_5) change according to the transaction scales of each trade.

2.5. Calculation for Pricing and Scales

With the integration of the transaction mode setting and conditions (2), (6), and (7), given the difference in water resource fees between surface and underground water and the spending electricity costs of pumping underground water, the highest water transaction price can be calculated by Formula (1). In this case, it is assumed that the transaction costs are paid by the industry enterprises (the added value of per m^3 of water consumption in industry is higher than that of agriculture).

$$P + TC < P_w - D_{wf} - E_c \tag{1}$$

P and TC are the transaction price and transaction cost per cubic water, respectively; P_w is the price per cubic meter of tap water; D_{wf} is the difference in water resource fees between surface and underground water; E_c is the electric charge of pumping one m^3 of underground water.

Additionally, because we consider the transaction to be cost-effective compared to purchasing water from the city tap water company, there is a minimum transaction scale to be met. The minimum transaction scale can be calculated by Formula (2).

$$TS \geq TC'/(P_w - P - TC_{51}) \tag{2}$$

TS is the transaction scale, and TC′ is the transaction cost without the return flow costs (TC_{51}).

2.6. Data Preparation

For this paper, we designed three types of surveys, including interviews with officers of the Zhangye City and Ganzhou County water management bureaus, interviews with staff from the Yingke Institution of the irrigation district, and a survey of an auction company in Zhangye City. The interview questionnaires for the officers included two parts to learn about: (1) the processes of water transactions, examinations, and approvals in Zhangye City; and (2) financial accounts. In addition, certain information or data could not be acquired because of ex ante evaluations, which were substituted by other materials. For example, the negotiation cost was substituted with the cost of organizing auctions. Part of the contract costs related to the travel expenses of the staff of the irrigation districts institute, for negotiating purposes, was substituted with travel expense constraints regulated by the Chinese government. Similarly, consulting fees from relevant agencies for determining the third-party effect on the water rights transactions were substituted with data pertaining to "fee standards of an environmental impact assessment service."

These surveys and interview questionnaires and the collection of financial accounts were completed by four researchers in 2015.

The interview questions posed to the officers of the Zhangye City and Ganzhou County water management bureaus were similar and involved water transaction matters in relevant managed confines, requests for examinations and approvals, staff time and labor invested in these businesses, and water administration monitoring and penalties. The auction company questionnaire surveyed costs for posting messages, renting auction space, and other relevant costs after receiving these delegations.

3. Results

3.1. The Range of Transaction Costs

There are very few cases of water trading at the trans-sector level in Zhangye City, especially from agriculture to industry. The collected materials indicate that most secondary industrial enterprises pump groundwater from their own wells and pay a small water resource fee if they have relevant water rights. A few enterprises use city tap water and pay a water rate at a price of 2.1 yuan/m^3. The specific data and the evaluated TCs are presented in Table 2.

Table 2. Water transaction costs from agriculture to industry in Zhangye City.

Transaction Costs	Valuation Range (yuan)	Data Source
Implementation transaction costs (TC_2)		
Information costs (TC_{21})	1000–2800	Surveys, publication costs
Negotiation costs (TC_{22})	2200	Surveys, cost of organizing auctions
Contract costs (TC_{23})	935–1135	Surveys, financial accounts, time spent and labor invested, documentation costs
Examination and approval costs by the local government (TC_{24})	2600–6075	Surveys, financial accounts, time spent and labor invested, documentation costs, design costs from designing institute
Enforcement costs (TC_{25})	216.67	Time spent and labor invested
Transfer costs (TC_3)		
Water delivery loss costs (TC_{31})	Almost 0	No surface evaporation
New water conveyance facilities costs for trading (TC_{32})	9090.91–18,181.82	The costs of one or two wells per year
Maintenance and monitoring costs (TC_4)		
Monitoring costs (TC_{41})	666.67–1333.33	The costs of one or two intelligent water meter installations per year
Compensation-seeking costs (TC_{42})		
Costs of preventing infringement by third parties (TC_{43})		
Third-party effect costs (TC_5)		
Return flow costs (TC_{51})	5.56–31.27 (yuan/10^3 m^3)	Calculation and references [10,49]
Total transaction cost without return flow costs (yuan) (TC′)	16,709.24–31,941.82	

Information costs (TC_{21}) use the costs of posting buying or selling information through media as substituted values. To reduce information asymmetry, one of the parties of the transaction issues the relevant information through the water affair information website, Zhangye City TV station, or Zhangye daily paper. Then, the auction company is commissioned to complete the water transaction and pricing. Negotiation costs (TC_{22}) are the costs of organizing an auction. Contract costs (TC_{23}) are the relevant travel expenses of both representatives from the buyer enterprise and the seller irrigation district, the wage proportion of the agent, and the paper costs of the final three contracts. Enforcement costs (TC_{25}) depend on the forms involved in obtaining the water. Given enforcement feasibility, we set the buyer enterprise to pump groundwater from the well; the seller irrigation district reduces this water quantity and recharges underground aquifers (water banks for groundwater).

Usually, these transactions are for long-term water rights trading, and the buyer enterprises gain water rights from water markets. Then, enterprises obtain water rights certificates, pay water resource fees in advance, and pump the water. The reasons we set this form are to reduce new water conveyance facilities' investment costs for trading (TC_{32}), to eliminate water delivery loss costs (TC_{31}), and to increase the likelihood of trading, especially if the two sides are separated by a large distance. In general, there is no new canal investment, but one or two well input costs. A new well costs approximately 15×10^4 yuan at the local level, with an average service life of 16.5 years. Therefore, the cost of one well is 9090.91 yuan per year.

Monitoring costs (TC_{41}), compensation-seeking costs (TC_{42}), and costs to prevent infringement by third parties (TC_{43}), can simply be substituted by the costs of installing an intelligent water meter. The intelligent water meter's operating principle is payment in advance of usage. Total purchasing amounts can be controlled by the water management bureau according to water rights certificates. Therefore, the installation of intelligent water meters can avoid infringement and the breaking of contracts.

Without return flow cost, total transaction costs are between 16,709.24 and 31,941.82 yuan for one transaction.

The irrigation flow losses ranged from 15.56% to 36.27% in different crops in Ganzhou County [10]. The different industry return flow ranged from 5% to 10% according to previous research [49]. Therefore, the return flows ranged from 5.56% to 31.27% as the limits when water trading occurred from agriculture to industry. We employed the current agricultural water price in the corridor plain region (0.1 yuan/m^3) to calculate the return flow costs (TC_{51}). Based on our preliminary computation results [10], it is clear that these costs range from 5.56 to 31.27 yuan/10^3 m^3.

3.2. Water Transaction Pricing

Based on the highest permitted trading price of water transactions in agriculture, three times the current agricultural water price (the agricultural water price in the Huazhai irrigation district in Ganzhou County was 0.15 yuan/m^3, and that in the remaining irrigation districts was 0.1 yuan/m^3), we set the lowest water trading price at 0.45 yuan/m^3 to meet the participation constraint for farmers, as well as to sell agricultural water rights to industries rather than just trading within the agricultural sector. Without sewage charges, the price of tap water was 2.1 yuan/m^3 during our accounting period. Considering that industry enterprises can obtain tap water through normal pipelines under the current circumstances, rational buyers would not accept a new trading water price of more than 2.1 yuan/m^3.

Given the difference in water resource fees between surface and underground water, and considering the electricity costs of pumping underground water, the highest water transaction price can be calculated by Formula (1). In our calculation period, P_w was 2.1 yuan/m^3, D_{wf} was 0.05 yuan/m^3, and E_c was not higher than 0.5 yuan/m^3 in Ganzhou County. Therefore, we easily found the upper limit of water transaction pricing, including a TC per m^3 of water of 1.55 yuan/m^3. So, the water transaction price from agriculture to industry should be between 0.45 and 1.55 yuan/m^3 in the study area.

3.3. Transaction Scales

As described above, without calculating the return flow cost, the total transaction costs are fixed for one transaction, meaning that larger transaction scales can achieve a smaller per m^3 water transaction cost. Additionally, when the transaction scale reaches a certain level, the rate of contribution of returning flow cost per m^3 becomes more and more important. Under current irrigation conditions, the irrigation returning flow cost per m^3 of water is fixed; however, the other transaction costs (TC′) per m^3 of water would decrease as the transaction scale increases.

To meet the participation constraint and incentive compatibility constraint, we used Formula (2) to calculate the minimum transaction scale. When P was 0.45 yuan/m^3 and TC_{51} was 5.56 yuan/10^3 m^3, we obtained a minimum transaction size of 10,160 m^3 and 19,422 m^3, respectively, when the TC′ takes the different values in Table 2. Moreover, we considered the maximum transaction scale at 300,000 m^3 based on the maximum annual usage of local enterprises.

3.4. Transaction Costs from Agriculture to Industry

The TC′ (transaction costs per trading without returning flow costs) are affected by the means of transaction and the process of trading. At the same time, the transaction scale does not affect the entire TC′ but can change the transaction cost per m^3 of water, which would decrease with the increasing transaction scale.

Figure 3 shows the transaction costs from the agricultural sector to secondary industries in Zhangye City based on the above description and calculation. The results show that (1) when the transaction scale is small, especially below 50,000 m^3, the curve is steep, which means that the transaction cost per m^3 of water decreases rapidly with the increase of the transaction scale; (2) the differences in TC (or TC′) between the upper and lower limits decrease as the transaction scale increases (for example, the difference in TC is from 1.52 yuan to 0.08 yuan as the transaction scale increases from 10,160 m^3 to 300,000 m^3); (3) the upper limits of TC′ are more than the lower limits of TC when the transaction scale is small. However, with the increase of the transaction scale, the difference in the above two variables decreases. Although the first variable (the upper limit of TC′) is higher than the last one in Figure 3, as the transaction scale increases, the latter will become greater than the former. This is because, under the current irrigation conditions, the irrigation returning flow cost per m^3 of water is fixed; however, the other transaction costs (TC′) per m^3 of water would decrease as the transaction scale increases.

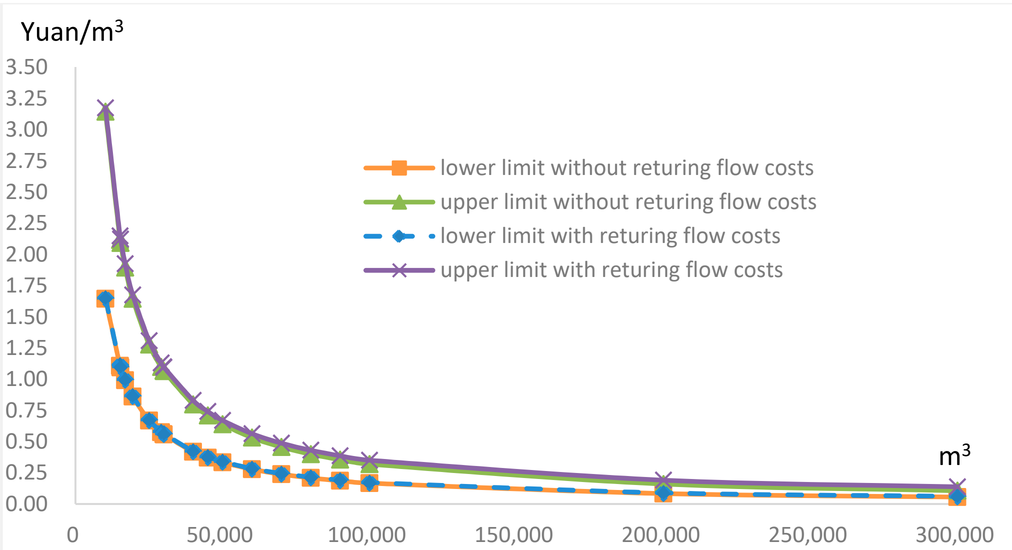

Figure 3. Transaction costs per m^3 of water from agriculture to secondary industries in Zhangye City.

Table 3 shows the upper and lower limits of TCs of different transaction scales and the highest acceptable transaction price under these limits.

As noted above, to conclude a transaction for both sides, the transaction price per m^3 of water should be between 0.45 and 1.55 yuan. Therefore, the transaction scale should be more than 15,267 m^3 or 29,888 m^3 when the TC is at the lower or upper limits, respectively. At the same time, given the cost-effectiveness for both parties, the ranges of transaction costs per m^3 of water are from 0.06 to 1.10 yuan. The total payments include the transaction price, and transaction costs range from 0.51 (0.06 + 0.45) to 1.55 yuan.

It is clear that the TCs ranged from 3.94% to 70.97% of total payments. Moreover, the ratios of TCs to transaction price ranged from 4.11% to 244.44%. When the transaction scale was 300,000 m^3, the TCs were lowest (0.06 m^3), the transaction price was highest (1.49 yuan), and we obtained the smallest ratio of TC to transaction price. However, the greatest ratio was present on the transaction scale at 15,267 (29,888) m^3 when the transaction price was 0.45 yuan and the TCs were highest.

Table 3. Transaction costs and the limits of water transaction pricing (yuan/m^3).

Transaction Scale (m^3)	Lower Limit of TC	Upper Limit of TC	P_1	P_2
10,160	1.65	3.18	−0.10	−1.63
15,267	1.10	2.12	0.45	−0.57
19,422	0.87	1.68	0.68	−0.13
25,000	0.67	1.31	0.88	0.24
29,888	0.57	1.10	0.99	0.45
30,000	0.56	1.10	0.99	0.45
40,000	0.42	0.83	1.13	0.72
45,000	0.38	0.74	1.17	0.81
50,000	0.34	0.67	1.21	0.88
60,000	0.28	0.56	1.27	0.99
70,000	0.24	0.49	1.31	1.06
80,000	0.21	0.43	1.34	1.12
90,000	0.19	0.39	1.36	1.16
100,000	0.17	0.35	1.38	1.20
200,000	0.09	0.19	1.46	1.36
300,000	0.06	0.14	1.49	1.41

Note: P_1 indicates the upper limit of the transaction price when the TC is lowest; P_2 indicates the upper limit of the transaction price when the TC is highest.

4. Discussion

There are four basic requirements to meet for water trading across sectors: (1) a sound tradable water system, including a legal and institutional environment; (2) at least one water rights supplier; (3) at least one buyer with buying power; and (4) trades that are cost-effective for both sides, which is to say that they have acceptable transaction costs.

In real terms, the first requirement has been met because the water rights transaction system has been completed in Zhangye City by the government. According to the above calculation, the total water TCs can be controlled in an acceptable range to meet the participation constraint and incentive compatibility constraint when transaction modes are appropriate and transaction scales reach a greater volume. Compared to the transactions completed in inner-agriculture water trading, the return flow costs (TC_{51}) and the new water conveyance facilities costs for trading (TC_{32}) in cross-sector transactions would be greater in general. Roughly estimating the TC_{32} from the nearest irrigation district to the potential buyers in Zhangye City, pipe-laying alone would cost at least 32 times the calculated TCs without this pipe-laying cost. If the transaction mode does not use the underground water quasi-bank, the water transaction from agriculture to industry in the current condition could hardly meet the requirement of being cost-effective, even with only the new water conveyance facilities cost being considered as the trading cost.

In the current state, about 25% of water consumption originates from the ground water of the whole city, while ground water constitutes about 77% of industrial water use. Moreover, in Ganzhou, Gaotai, and Linze, the total industrial water use is sourced from ground water. Therefore, we set a transaction mode as suitable for the most inland arid region for water transactions at the cross-sector level, using an existing water bank as a reference. The buyer's industrial enterprise pumps groundwater from a new or original well, while the agricultural supply side pours water into the ground aquifer or reduces the relevant volume of water drawn. Through this transaction mode, the transaction costs of TC_{32} are reduced considerably, and evaporation due to water delivery can be effectively restrained. However, with the development of a water-saving society, newly established farmland can lead the original pressure on surface water to be replaced with a heavier dependence on groundwater sources [37]. So, even with the high conversion rates of surface water and underground water in this region, this transaction mode may be suitable for the main agricultural areas along the Heihe River.

It was emphasized that the benefit gaps of the trading parties were the most important driving force facilitating water transactions. In the current situation, the net benefit per m^3 of water used in secondary industries was still the highest in Zhangye City. This means that if there is a demand for water rights trading in secondary industries or even tertiary industries, the third requirement can be met. Besides, the demand for water rights is important as it may affect the scales of each transactions. So, the key restrictive factor may be the transaction scales, especially in the first stage of the water market. In some arid regions, such as our study area, with a mature water market in which the TCs could be controlled over a particular range, water transactions are rare, even though the two sectors exhibit large differences in water use efficiency. The effects of improving water use efficiency through cross-sector trading could not neutralize the restrictions caused by the negative effects of small water demand transaction scales. Therefore, it is important to note that a water transaction from agriculture to industry should involve an adequately large transaction scale.

For buyers representing secondary industries, taking no technological advances into account—i.e., assuming that the water consumption per 10,000 yuan GDP remained unchanged (47.36 m^3 in 2014 in the industrial department of Zhangye City)—the new water increment would be approximately 5,000,000 m^3 annually from 2015 to 2020, as the growth rate of the industrial output value is set conservatively at 8%. Prorating the water increment to the 183 industrial enterprises above the designated size, the new water increment of each enterprise would be 16,860 m^3, which meets an appropriate transaction scale at the lowest transaction costs but which would require a lower transaction scale at the highest transaction costs.

In fact, besides the secondary industries considered above, tertiary industries could also represent potential buyers of water transactions in Zhangye City. Based on a growing trend among all industries and the policies of industrial development in the vulnerable ecosystem in northwest China, tertiary industries re developing well, especially the vigorous growth of the tourist industry in Zhangye City. The growth rate of tertiary industries was 19.14% in 2012, and the total water use of these industries was almost 2.2×10^8 m^3. The output value of these industries reached 10.64 billion yuan, and has since grown higher than that of the secondary industries in the region. The output value of tertiary industries reached 15.34 billion yuan in 2014, and the growth rate was 17.25% in the whole of Zhangye City. In the same year, the growth rate of output value of the 69 service enterprises in tertiary industries above the designated size was 25.5%, which was greater than that of 2013 [33]. Assuming that the growth rate of the output value would conservatively be 15%, that the water consumption per 10,000 yuan GDP remained unchanged (135.84 m^3 in 2014), and that the number of relevant enterprises would reach 200 in Zhangye City, the new water increment would be roughly estimated as 350,700 m^3 per enterprise annually from 2015 to 2020. The water demand quantity is huge compared to the smallest transaction scale. Moreover, if these enterprises cannot obtain water from water supply companies, the endogenous demand for water transactions from agriculture to tertiary industries would be very high, considering the higher output per m^3 of water use in tertiary industries. Besides, excluding the return flow costs (TC_{51}), the water TCs do not differ greatly between the transaction from the agricultural sector to tertiary industries vs. secondary industries.

For the suppliers, there is a huge potential to save water in the agricultural sector. Since building up a water-saving society in 2002, Zhangye City has saved substantial amounts of water using the means of engineering, technology, water system reform, and the adjustment of crop structures. The volume of water saved was 0.2 billion m^3 annually from 2002 to 2009 [39]. In fact, the phenomenon of cultivated land continuously expanding in Zhangye City [37] proves that there are substantial amounts of water that can be used to trade, because when saved water cannot be utilized or bought by another department, it is used to irrigate new reclaimed land [10].

Furthermore, with the development of tertiary industries, more and more farmers will take on new livelihoods in town to earn more money than possible when engaging in agriculture. Water-saving practices will increase as a result of farmland transference, intensive management, and even the abandonment of farmland without water irrigation.

The gap of TCs from agriculture to industry is great in Zhangye City under different circumstances, especially with different transaction scales. Larger transaction scales result in cheaper transaction costs per m^3 of water. However, water demand in secondary industries in Zhangye is not sufficient, and the service industry is developing very well; these factors are likely to be driving forces of water transactions in the future.

5. Conclusions

The TCs ranged from 3.94% to 70.97% of total payments, and the ratios of TCs to transaction prices were from 4.11% to 244.44% in our study area. As the transaction scale increases, the TCs decline gradually. When the scales are set correctly, the proportion of TCs will not exceed the 8% limit, set by the California Water Bank as a comparison [50]. Moreover, the minimum ratio of 4.11% (TC/trading price) is lower than the value reported in Chile, i.e., 7% [51], and lower than the average small fraction (6%) of each American state [23]. When the scales are not set correctly, this proportion can reach so high that it would hinder the conclusion of a transaction. So, the transaction scale needs to reach an appropriate economic scope. According to our calculation, the transaction scale for a trade of water rights from the agricultural sector to an industrial enterprise should be more than 15,267 m^3 or 29,888 m^3 when the TC is at the lower or upper limit, respectively.

Each cost component has lower and upper limits because of certain reasons and ex ante evaluation. In addition, the transaction scale affects the final results. Therefore, advanced design and choice of transaction modes are very important to reduce the TC. In order to make these costs acceptable, each component cost should not be too high. To realize the reduction of water TCs, we can use an appropriate underground water bank to facilitate water trading and to reduce the costs of new water conveyance facilities and invalid evaporation. Furthermore, we can install intelligent water meters to reduce the maintenance and monitoring costs, and choose water managers in irrigation districts as agents to negotiate with the buyers to reduce the negotiation costs, among other measures. We can also employ practices tested by other developed countries, such as isolating the water rights from farmland completely and issuing some water shares to make water trading more easily, developing the dissemination channels of water market information maturely, and so on.

The key factors restricting water trading may be the low transaction scale, followed by the high water TCs. The effects of improving water use efficiency in cross-sector trading could not neutralize the restrictions caused by the negative effects of small water demand transaction scales, especially in northwest China, which is characterized by undeveloped industry and a vulnerable ecological environment.

Therefore, to activate the water market across sectors, increasing the water demand, i.e. increasing the transaction scale is a top priority. Considering the industrial structure and development tendency of regional economic development, the future driving force of water transactions across sectors will likely be tertiary industries in the arid region of northwest China. Finally, we hope that the methods of reducing transaction costs as well as setting appropriate transaction modes and scales will serve as a reference for studies of water transactions in other arid regions around the world, and that the results provide valuable suggestions regarding water system management by local governments.

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