



# Agricultural water rights trading and virtual water export compensation coupling model: A case study of an irrigation district in China



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## ABSTRACT

Water rights trading is an effective way to promote efficient water allocation. The implementation of agricultural water rights trading can promote water saving, but may reduce the agricultural production scale in irrigation districts. Compensation for crop virtual water export can increase the benefits of agricultural water use, so as to enhance the competitiveness of economic benefit for agricultural production. This paper analyzed the relationship between agricultural water rights trading and virtual water export compensation, then a bi-level programming model was established with multiple objectives. The model was applied in Hetao irrigation district by using enumeration method. The changes of new water use of different users, benefits of irrigation district and water users with different water prices were analyzed and the optimization schemes were selected. Results show that the model through adjusting price variables including both water rights trading price and virtual water compensation price to optimize the allocation of agricultural water quantity saved among different water users, which at the same time makes both the irrigation management administration and water users get more benefit. The optimized scheme can raise the willingness of water saving in irrigation district, and enhance the competitiveness of agricultural water user against non-agricultural water user. This study provides a new method and scientific basis for the water resource management agency in their policy making.

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## 1. Introduction

Half of the arable land in China is irrigated, consuming high volumes of water, while producing 75% of the grain and 90% of the cotton, vegetables and other crops consumed by the country (Cao et al., 2015). Irrigation districts have been playing an increasing important function for ensuring china's agricultural production, food safety and social economic development (Sun et al., 2013). The dominant challenge for agricultural water resources management is how to secure water to meet grain production demand for water resources (Misra, 2014). To achieve substantial increases in

food production on the limited water resources, it is necessary to break the bottleneck of agricultural production, by promoting the efficient use of irrigation water (Falkenmark and Rockström, 2004; Morison et al., 2008; FAO, 2015). Increasing water demand due to population growth, irrigation expansion, industrial development and ecosystem improvement calls for the efficient, economic and sustainable management of water resources in irrigation district (Speelman et al., 2010; Garrick et al., 2013; Bekchanov et al., 2015; Zhang and He, 2016).

Water rights trading is a way to promote more efficient water allocation. Chile has become the world's leading example of the free-market approach to water law and water resources management, the textbook case of treating water rights not merely as private property but also as a fully marketable commodity (Bauer, 2004; Bekchanov et al., 2015). Implementing irrigation water rights trading can play an important role in market allocation, and promote water savings in irrigation district (Howe and Christopher, 2003; Yoo et al., 2013). In the example of the Yellow River rural

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farmer water rights trading, the water savings from agriculture is used to meet industrial production demands. Water rights trading improves the efficiency of water use and is considered an important way to solve the water shortage problem in the future. However, although the transfer of water rights can promote water saving in agriculture, it has failed to alleviate agricultural water pressure. There is also a risk when water is diverted from agriculture or ecological environment, especially during dry years (Zhao et al., 2004).

As one type of agricultural production areas, irrigation district in China is the main virtual crop water export district. Virtual water embedded in the crop product transferred with crop between regions. The virtual water trade represents the volume of water that is embedded in the traded commodities (Allan, 2003; Hoekstra et al., 2011; Vanham, 2013). Since the concept of virtual water has been proposed, many studies focused on the accounting of the virtual water trade and its effect on regional water resources use which lacks a substantive application in water management (Chapagain et al., 2006; Chapagain and Hoekstra, 2008; Aldaya et al., 2010). Although the Chinese government continues to increase financial subsidies, it has not yet introduced mandates on the efficiency of agricultural water-related subsidies. This has led farmers to focus solely on crop management, and to pay no attention to water saving. Through providing financial compensation for virtual water export from irrigation district will increase the benefit of irrigation district. Water resources, as a special commodity, cannot simply rely on the role of market allocation (Wang, 2012; Bekchanov et al., 2015; Rivera et al., 2016). Compensation for the virtual water export of crops can make up for the water efficiency policy gaps in agricultural subsidies. It will promote water savings during agricultural production and increase the competitiveness of agriculture.

In the system of agricultural water right transfer and virtual export compensation, government water management departments and the water users are independent entities and decisions will be made by each. Not only do they have the right to independently make a decision but they are also influenced by other policy-makers. This is in line with bi-level programming for policymakers and decision maker requirements, so a bi-level programming is used to establish agricultural water right transfer and virtual water output compensation. A bi-level programming problem has a hierarchical structure in which an upper-level and a lower-level decision maker. Both levels need select their strategies to optimize their objective functions. Decision maker in the upper-level knows how the lower-level decision maker would react to a given upper-level decision and acts accordingly. On the other hands, lower-level decision maker can act only according to given decisions of upper-level problem (Maher et al., 2001). Lv et al. (2009) introduced bi-level planning in water resources allocation based on the master-slave relationship between water resources management and water users, treating the initial allocation of water rights and water resources as a decision variable for the water resources management department. They indirectly control and guide the quantity of water in water rights trading markets from water users. Liu and Luo (2012) established a bi-level model for planning signalized and uninterrupted flow intersections in an evacuation network. Yu et al. (2015) proposed a bi-level programming model to solve the design problem for bus lane distribution in transport networks. Results showed that the bi-level programming performs well in aspect of reducing travel time costs for all travelers and balancing transit service level.

In order to coordinate economic, environmental benefits, food security as well as improving water allocation efficient. This paper first analyzes the relationship between agricultural water rights trading and virtual water export compensation. It then establishes a coupling model between irrigation water rights trading and crop

virtual water export compensation. And the benefits of irrigation district and water users with different prices were analyzed and the optimization schemes were selected by using this model.

## 2. Material and methods

### 2.1. Study area and data sources

The Hetao irrigation district is one of the three largest irrigation districts in China, with an irrigated area of  $5.74 \times 10^3$  km<sup>2</sup> (Zhang et al., 2011). The annual precipitation is below 200 mm, and the annual average evaporation is more than 2000 mm. Hetao irrigation district is a major agricultural production region in Inner Mongolia. Water diverted from the Yellow River is the major source for the study area, and the annual diversion of water from the Yellow River is approximately 5 Gm<sup>3</sup>. Increased cultivated acreage in recent years along with rapid urbanization and industrial expansion has resulted in greater competition between agriculture and other sectors for water resources (Sun et al., 2016).

The socioeconomic data, such as GDP, population, Per Capita Water Use, were taken from the "Inner Mongolia Statistical Yearbook" (Inner Mongolia Statistical Bureau, 2013). The hydrologic data were provided by the water authority in Bayannur (Water Authority in Bayannur, 2013).

## 3. Theory of agricultural water rights trading and virtual water export compensation

Agricultural water rights trading is a system where irrigation district management administration and the top water users maximize their benefits in a water-saving game: how much water can be converted to industrial, tertiary industrial or ecological purpose, or can be used to increase the irrigation area and meet the growing demand for grain. In the game, each of the participants is rational individual decision maker, and will pursue each of their own interests at the same time. They will conflict with other individual's decisions and collective interests. Although the trading of water rights can promote agricultural irrigation district management and help to generate high economic benefit, there is a limited price tolerance from farmers. Thus, even though crop production cannot meet the country's grain needs, irrigation district management still wishes to transfer water to the high profit sector through agricultural water rights, putting agricultural water use at a disadvantage in the water rights trading game.

Compensation for crop virtual water export follows the "who benefits, will compensate" principle. Farmers and irrigation district management administration can both seek to have their own interests carried out. Virtual water import region alleviate the pressure on water resources, allowing more water and land to be put into the secondary and tertiary industries of the area in order to obtain a higher economic return. The mechanism and process of virtual water compensation is as follows: to maintain and gain higher benefit, firstly, virtual water import region should propose a compensation strategy. Secondly, after evaluating the irrigation districts' benefit, the administration agency of the irrigation should invest for water saving reconstruction and encourage farmers' crop production according to the compensation strategy made by virtual water import district. At last, in order to get more virtual water compensation, farmers in the irrigation should expand the irrigation area using the saved water and increase the crop yield accordingly to pursue higher virtual water export and higher virtual water compensation. In this way, virtual crop water export compensation is carried out at different levels to stimulate water conservation, and furthermore to promote agricultural production. Through implementation of the above measures, virtual water compensation can

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