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Virtual water in interprovincial trade with implications for China's water policy

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ABSTRACT

With increased social wealth and economic development, provinces in China have also faced serious water shortages. In this paper, we implemented a multi-regional input–output framework to evaluate the pressures posed by human consumption of water resources, as well as the water displacement in the thirty provinces of China. The most recent available multi-regional I/O data has been applied in the study. We found that some water scarce provinces were still net virtual water exporters (such as Ningxia, Hebei and Xinjiang), while some water deficit and developed regions such as Beijing and Tianjin relied heavily on external water sources. Further detailed analysis revealed that huge disparities of water intensities, export constitutions and consumption patterns all contributed to the virtual water transfers among provinces. With economic growth and urbanization taking place all over the country, less developed provinces may be locked in water intensive economies due to consumption from developed provinces, and some arid provinces may hardly support a harmonious development between the economy and water resource protection. In addition to enhancing water efficiency and promoting a green consumption-production system, we suggest that market-based water pricing and a nationwide virtual water compensation scheme be adopted by China's government.

1. Introduction

Since the 1980s, China has been facing water shortages due to increased water demands from urban industry, domestic consumption, and irrigated agriculture (Jiang, 2009). Therefore, the Chinese government has proposed several water policies to curb water consumption in production procedures (Minister of Water Resources, 2010; National Development and Reform Commission, 2005). Although water usage primarily occurs during the production processes inside a region, it is also shaped greatly by trade with other regions (Chapagain and Hoekstra, 2008; Čuček et al., 2012; Hoekstra, 2009). Thus, focusing only on the production processes may not be enough to deal with the problems of water scarcity. The monitoring and controlling of interregional water supplies and demands should also be attached with greater attention.

Evaluating virtual water has become a key approach to understanding how water resources are transferred among regions or countries, as well as their respective water consumption characteristics. Virtual water refers to water embodied in traded goods and services between regions or countries (Dietzenbacher and Velázquez, 2007; Hoekstra, 2003). Many researchers have analyzed the interregional virtual water flows, in order to understand water scarcity both in and out of China (Dalin et al., 2012; Hoekstra and Hung, 2005; Ma et al., 2006; Mekonnen and Hoekstra, 2011).

A growing number of virtual water studies have been conducted on multiple levels in China with many meaningful results (as listed in Table 1). At the sectoral level, the Agricultural and Food sectors proved to be the dominant part of interregional virtual water trades (Zhang and Anadon, 2014). At the provincial and basin level, Zhang et al. (2011, 2012) and Wang et al. (2013) found that Beijing highly relied on external virtual water supplies. In addition, the water consumption characteristics of Liaoning (Dong et al., 2013), Zhangye (Wang et al., 2009) and multi basins (Feng et al., 2012; Zhao et al., 2010) were analyzed. At the national level, many studies have found that virtual water was traded from North to South, from arid regions to wet regions in China (Guan and Hubacek, 2007; Ma et al., 2006; Zhang and Anadon, 2014). As paradoxical as it seems to

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Table 1
Review of Recent Virtual Water Research on China's domestic trade.

Paper	Target region	Year	Methods	Key findings
City level				
Wang and Wang (2009)	Beijing	1990–2007	IO	Beijing was a net importer of virtual water in primary and secondary industries, but an exporter in tertiary industries. The proportion of virtual water in secondary sectors has increased greatly.
Zhang et al. (2011, 2012)	Beijing	1997–2007	SRIO	Other provinces have increasingly supported Beijing's water footprint, controlling the growth of the internal WF might be more essential than importing external virtual water
Wang et al. (2013)	Beijing	2002–2007	SRIO	Beijing was a net virtual water importer, with deficits of 9.68 Gt in 2007, thus strategies such as adjustments in the industrial structure of virtual water importing should be adopted
Wang et al. (2009)	Zhangye	2002	SRIO	Zhangye was exporting large amount of virtual water in the form of Agricultural products, planners should consider both direct and indirect water consumption in policies
Province level				
Dong et al. (2013)	Liaoning	2007	SRIO	Although facing serious water scarcities, Liaoning still exported 2.68 Gt virtual water in 2007, thus the industrial and trade structure should be adjusted
Basin level				
Zhao et al. (2010)	Haihe river basin	1997–2007	SRIO	The basin was slightly importing virtual water through the trade of raw and processed food products
Mao and Yang (2012)	Baiyangdian		Ecological network analysis	This paper revealed ways to optimize the virtual water trade structure by adjusting the relationships among compartments
Feng et al. (2012)	Yellow river basin	2007	MRIO	All three reaches (the upper, middle and lower) are net virtual water exporters, the lower reach should increase the import of water intensive goods
Sub-region level				
Ma et al. (2006)	Northern and Southern region		LCA	North China annually exports about 52 Gt of water in virtual form to south China, which is more than the maximum proposed water transfer volume of the Water Transfer Project
Guan and Hubacek (2007)	Northern and Southern region	1997	IO	North China as a water scarce region exports about 5% of its total available freshwater resources while accepting large amounts of wastewater
Zhang and Anadon (2014)	Eight regions in China	2007	MRIO	China has a north-to-south net VWT pattern, re-shaping the water-trade nexus can be a significant complementary tool to address local water scarcity problems

be, water demand for production in arid regions, is found to be driven by consumption from other regions, leading to more unsustainable and uneven economic and environmental development. Based on these findings, previous literature proposed policy suggestions such as optimizing trade structures (Zhang and Anadon, 2014).

To date, there has been little analysis beyond conventional wisdom in the following important areas. **First**, in deriving the virtual water trade map inside China, previous studies have usually failed to take the level of water scarcity in the targeted province into consideration. To be more specific, due to the huge differences in water quantity, water availability and the population of each province, the ecological and economic impacts of virtual water exports from a water-rich province and a water-starved province might be significantly different even if the volume of exported water is exactly the same. Thus, it is more meaningful to weigh virtual water trade against water scarcity than to only calculate virtual water flows.

Second, although virtual water analysis provides a useful method of tracing water displacement across regional boundaries (Jeswani and Azapagic, 2011), it only provides a preliminary understanding of water utilization and policy (Wichelns, 2010). It is important to understand the driving forces to derive more details about the virtual water trade. Is it caused by geographical specialization or technological capacity? Are there other influential factors, such as economic development? By acknowledging the determining factors behind the virtual water trade, about a more accurate understanding of virtual water trade can be derived, and better policies aimed at relieving the interregional water imbalance can be developed.

Third, the current virtual water analyses have fallen short of contributing to meaningful policy suggestions. The seemingly attractive and compelling policy recommendations such as increasing virtual water imports from humid areas and optimizing trade structures have proven to be difficult to adopt. What practical water policies can be suggested for China? In order to address the water shortage problem in China, it is of paramount importance to conduct an interprovincial virtual water trade study that considers provincial water scarcity levels, the driving forces of water scarcity, and based on which, offer practical water management policy suggestions.

This paper is a quantitative analysis of how and why interprovincial water trade shapes the water resources for provinces, and what the implications of water trade are for water policy. We compare the virtual water trade of different provinces with the economic benefits and water resource conditions in Section 4, and we analyze the contributors to virtual water flows in China in Section 5. Finally, we discuss possible national and interprovincial water policies based on these calculations.

2. Methodology

There are various methods counting virtual water trade, including life cycle analysis (LCA), inter-region input–output model (IRIO), single-regional input–output model (SRIO) and multi-regional input–output model (MRIO). The advantages and disadvantages of these models have been discussed in Miller and Blair's book (2009). In order to calculate the virtual water flows among the provinces of China, we used a multi-regional input–output economic and water accounting framework in this study.