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Analyses of impacts of China's international trade on its water resources and uses

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Abstract

This study provides an insight into the impact of China's international trade of goods and services on its water resources and uses. Virtual water flows associated with China's international trade are quantified in an input-output framework. The analysis is scaled down to the sectoral and provincial levels to trace the origins and destinations of virtual water flows associated with the international trade. The results reveal that China is a net virtual water exporter of $4.7 \times 10^{10}\ m^3\ year^{-1}$, accounting for 2.1% of its total water resources and 8.9% of the total water use. Water scarce regions tend to have higher percentages of virtual water export relative to their water resources and water uses. In the water scarce Huang-Huai-Hai region, the net virtual water export accounts for 7.9% of the region's water resources and 11.2% of its water uses. For individual sectors, major net virtual water exporters are those where agriculture provides raw materials in the initial process of the production chain and/or pollution intensity is high. The results suggest that China's economic gains from being a world "manufacture factory" have come at a high cost to its water resources and through pollution to its environment.

1 Introduction

International trade between countries entails flows of virtual water, i.e., the water used for the production of traded products (Allan, 1993; Hoekstra and Hung, 2005; Yang et al., 2006). An inflow of virtual water through trade reduces the pressure on domestic water resources, whereas an outflow of virtual water adds to the pressure. With the world markets crammed with "made in China" products on the one hand and the increasingly severe water stress and pollution endured in most parts of China on the other, the impact of China's international trade of goods and services on its water resources and uses warrants a scrutiny.

There is a large literature on the investigation of the role of virtual water trade in addressing water scarcity and in redistributing water resources (virtually). Studies on the relevant issues have hitherto mostly concerned with agricultural products due to their high water intensity in production and large share in total water use. For instance, Yang and Zehnder (2002) estimated the volume of virtual water embedded in food imports into the countries in the southern Mediterranean region. They highlighted that food imports were imperative for compensating water resources deficiency in these countries. The major components of the virtual water flows were investigated at the global level by Zimmer and Renault (2003). This analysis was further refined by Hoekstra and Hung (2005). They quantified the volumes of virtual water flows between nations related to international crop trade and analyzed virtual water balance in relation to national water needs and water availability. Yang et al. (2006) assessed the efficiency of the water use embodied in the international food trade from the perspectives of exporting and importing countries. Hoekstra and Chapagain (2007) and Chapagain and Hoekstra (2008) examined the water consumption in individual countries with distinction of internal and external water sources. The results show that worldwide, about 16% of the water use is for the production of goods and services that are for export.

Recent years have seen some studies extending the assessment of virtual water flows associated with the international trade to all the sectors of an economy. Zhao et al. (2009) quantified China's virtual water trade for each individual sector using an input-output model. They found that China as a whole is a net virtual water exporter, although the agricultural sector is a net importer. Using the similar approach, Dietzenbacher and Velazquez (2007) assessed the virtual water embodied in the trade of 25 sectors in the Andalusian economy system and the findings reveal Andalusia as a net virtual water exporter. So far, however, studies on virtual water flows associated with international trade of all the sectors in a national economy remain few.

There are a number of gaps lying in the previous studies of virtual water flows associated with the international trade. One is the overwhelming focus on agricultural products and little attention to other sectors of an economy. Secondly, most of the

HESSD
8, 3543–3570, 2011

studies have been conducted at the country level or for a single region. For a country like China which is vast in territory and uneven in water resources distribution, treating the country as a whole overlooks the regional variations in water endowments and the impacts of virtual water trade on regional water resources and uses. A sub-country study is more pertinent to reflect the specific local conditions and regional water problems. Thirdly, the hitherto studies generally lack the specification of the origins of the virtual water export and the destinations of the virtual water import for a given country. The specification of the origins/destinations of the virtual water export/import is important for identifying the prominent regions influencing national virtual water trade patterns and the regions where water resources and uses are significantly affected by their trade patterns.

This paper aims to quantify the virtual water flows associated with China's international trade of goods and services in a framework of input-output model. All the economic activities in the national economy are considered in the assessment. The analysis is scaled down to the provincial level to specify the impact of virtual water trade of individual economic sectors on water resources and uses across regions. The results of this study help a better understanding of China's water problems and provide scientific references for supporting policies to alleviate the negative impact of its international trade on water resources and uses in different regions.

2 Data and methodology

2.1 Data

The main data foundation of this study is the 2002 regional input-output tables of 30 provinces, autonomous regions and municipalities in mainland China. Tibet is not included due to data unavailability. For simplicity, these 30 administrative entities are all called provinces in this study. In the original provincial input-output table, there are 60 sectors including 5 primary sectors, 25 secondary sectors and 30 tertiary sectors. In

HESSD

8, 3543–3570, 2011

Analyses of impacts of China's international trade

Z. Y. Zhang et al.

this study, considering the sector correspondence between regional input-output tables and the data of sectoral direct freshwater use, the 60 sectors are aggregated into 20 sectors, including 1 primary sector, 16 secondary sectors and 3 tertiary sectors (Table 1). The national average sectoral direct freshwater uses for a monetary unit of production are from Zhao et al. (2009).

In this study, water use in industrial sectors is defined as the freshwater intake during the whole production process. In agriculture, water use is the irrigation water supply to the field. Water use defined here differs from water consumptive use which refers to water consumed (hence no longer available for other uses) during the production processes. In both agriculture and industrial sectors, part of the water is returned to the natural water systems through percolation and/or drainage and wastewater discharge. The return flow is not considered in this study because of the lack of data on the return rate and the pollution intensity of wastewater in individual sectors.

In this study, water resources and water uses concern only blue water, i.e., the surface and ground water. Soil moisture, the so-called green water is not considered. The definition of blue and green water follows that by Falkenmark and Rockström (2006). The exclusion of green water is mainly for the content consistency of water use across economic sectors. Except for the agricultural sector and the sectors where agriculture provides raw materials in the production processes, all the other sectors use exclusively blue water, which has the possibility of choosing alternative water sources and thus the opportunity cost is high in relation to green water. Green water use is typically 60–80% of the water use in the agricultural sector; if green water is not utilized for plant growth it mainly evaporates and is lost for local use. Including green water in water use accounting greatly increases the share of agricultural water use in total water use. Mixing blue and green water in the analysis could derive misleading conclusions in assessing the efficiency in water resources utilization across regions and among different sectors.

HESSD
8, 3543–3570, 2011

2.2 Methodology

2.2.1 The basic mathematical structure of the input-output model

Input-output table/model, firstly developed by Leontief (1941), represents the monetary transactions of goods and services among different sectors of economic system. It provides a technique to specify how the substances flow among sectors through supplying inputs (including water) for the outputs (where the virtual water is embedded) in the economic system. Since the information on interconnections and interdependences of economic units are essential to the determination of the virtual water content of a product, the input-output model is a practical tool in the virtual water trade estimation.

The basic mathematical structure of the input-output system consists of n linear equations as shown in Eq. (1), depicting how the productions of an economy depend on inter-sectoral relationships and final demand.

$$x_i = \sum_{j=1}^{n} x_{ij} + y_i \tag{1}$$

Where n is the number of economic sectors; x_i is the total output of sector i; x_{ij} is the inter-sectoral monetary flows from sector i to sector j. y_i is the final demand of sector i.

The direct input refers to the input provided by a sector for the production of another sector in the last stage of the production chain and it numerically equals to the elements of the inter-sectoral flow matrix (i.e., x_{ij} is the direct input from sector i to sector j). The direct input coefficient α_{ij} indicates the amount of input from sector i required to increase one monetary unit output of sector j (Eq. 2).

$$\alpha_{ij} = \frac{x_{ij}}{x_j} \tag{2}$$

HESSD
8, 3543–3570, 2011

Therefore, Eq. (1) can be rewritten so as to include the direct input coefficient α_{ij}:

$$x_i = \sum_{j=1}^{n} \alpha_{ij} x_j + y_i \tag{3}$$

Equation (3) can be shown as follows in matrix notation:

$$\mathbf{X} = \mathbf{AX} + \mathbf{Y} \tag{4}$$

Where **X**, **A** and **Y** are respectively the matrixes of output, direct input coefficients and final demand.

Assuming the matrix **A** of direct input coefficients is constant, it is possible to change Eq. (4) into a demand-driven format:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}, \quad B = (\mathbf{I} - \mathbf{A})^{-1} = [b_{ij}] \tag{5}$$

Where $(\mathbf{I} - \mathbf{A})^{-1}$ is known as Leontief inverse matrix; b_{ij} denotes how much output of sector i is required to meet one monetary unit of the final demand of sector j. Thus, the link between final demand and corresponding direct and indirect production has been built up with Leontief inverse matrix as the bridge.

2.2.2 Direct water use coefficient (DWUC) and total water use coefficient (TWUC)

In order to combine the monetary trade with the associated water use, the essential step is to derive DWUC, the amount of direct water intake to produce one monetary unit of output, representing the direct or the first round effects of the sectoral interaction in the economy (Bouhia, 2001; Hubacek and Sun, 2005). DWUC can be expressed as Eq. (6).

$$\mathbf{W} = [\omega_j], \quad \omega_j = \frac{w_j}{x_j} \tag{6}$$

HESSD
8, 3543–3570, 2011
Analyses of impacts of China's international trade
Z. Y. Zhang et al.

Where **W** is the matrix of DWUC (measured in $m^3/10^4$ Yuan in this study); ϖ_j is the DWUC of sector j; ϖ_j is calculated by dividing the freshwater use of sector j w_j by total output of sector j x_j (in monetary term).

TWUC δ_j, an indicator of the total water consumption throughout the whole production chain, can be achieved by multiplying DWUC ϖ_j with the Leontief inverse matrix $[b_{ij}]$.

$$\mathbf{D} = [\delta_j], \quad \delta_j = \sum_i \varpi_i \times b_{ij} \tag{7}$$

Where **D** is the matrix of TWUC, which links the monetary product trade with their corresponding total amount of water use.

2.2.3 The water use to meet domestic final demand

The water use to meet domestic final demand can be obtained by multiplying TWUC with final demand:

$$\mathbf{T} = \left[t_j^S\right], \quad t_j^S = \delta_j^S \cdot y_j^S \tag{8}$$

Where **T** is the matrix of water use for domestic final demand; t_j^S is the water use for final demand of sector j in region S; δ_j^S is the TWUC of sector j in region S; y_j^S is the final demand of sector j in region S.

It is worth noting that water use for domestic final demand of a province or a sector in this study is equivalent to water footprint defined by Hoekstra et al. (2009), but excluding the green components and return flows.

HESSD
8, 3543–3570, 2011

2.2.4 Virtual water trade accounting

In the virtual water trade analysis, the virtual water export can be obtained through Eq. (9).

$$\mathbf{U} = \left[u_j^S\right], \quad u_j^S = \delta_j^S \times e_j^S \tag{9}$$

Where $\mathbf{U}$ is the matrix of the virtual water export; u_j^S is the virtual water export of sector j in region S; δ_j^S is the TWUC of sector j in region S; e_j^S is the export of sector j in region S.

The regional input-output tables used in this study are characterized as import-competitive table. The underlying assumption is that the import is competitive with domestic supplies and thus can be incorporated into domestic supplies of final demand as well as the intermediate demand. The import consisting of the two parts can be expressed as:

$$m_j^S = m_j^{S(\mathrm{in})} + m_j^{S(\mathrm{f})} \tag{10}$$

Where m_j^S is the total import of sector j in region S; $m_j^{S(\mathrm{in})}$ is the import for the intermediate demand of sector j in region S; $m_j^{S(\mathrm{f})}$ is the import for the final demand of sector j in region S. The two parts are determined using a distributing coefficient β_j^S.

$$\beta_j^S = \frac{y_j^S}{\sum_{i=1}^{n} x_{ji}^S + y_j^S} \tag{11}$$

Where β_j^S is the distribution proportion of the final demand part in the total import of sector j in region S; y_j^S is the final demand of sector j in region S; $\sum_{i=1}^{n} x_{ji}^S$ is the intermediate demand of sector j in region S.

HESSD
8, 3543–3570, 2011

Thus, $v_j^{S(\mathrm{f})}$, the virtual water imported for final demand, can be obtained by multiplying the import incorporated in final demand $m_j^{S(\mathrm{f})}$ with the corresponding TWUC δ_j^S as shown in Eq. (12).

$$v_j^{S(\mathrm{f})} = \delta_j^S \cdot m_j^{S(\mathrm{f})} \tag{12}$$

While the virtual water imported for intermediate use and consumed by domestic final demand can be derived through Eq. (13):

$$v_j^{S(\mathrm{in})} = \delta_j^S \cdot m_j^{S(\mathrm{in})} \cdot \eta_j^S \tag{13}$$

Where η_j^S is an adjusting coefficient derived as an adjusting coefficient derived as the proportion of the outcome of final demand minus export over the final demand of final demand, representing that only a portion of virtual water embodied in intermediate input will be used for domestic final demand.

The virtual water import with the two parts can be obtained as:

$$\mathbf{V} = \left[v_j^S\right], v_j^S = v_j^{S(\mathrm{in})} + v_j^{S(\mathrm{f})} \tag{14}$$

Where $\mathbf{V}$ is the matrix of virtual water import; v_j^S is the virtual water import of sector j in region S; $v_j^{S(\mathrm{in})}$ is the virtual water import for intermediate demand of sector j in region S; $v_j^{S(\mathrm{f})}$ is the virtual water import for final demand of sector j in region S.

3 Results

3.1 Virtual water import and export in individual sectors

DWUC reflects the direct water intensity at the last stage of production chain, whereas TWUC reflects the water intensity throughout the whole production chain. Using

HESSD
8, 3543–3570, 2011

Eqs. (6) and (7), DWUC and TWUC for each sector are calculated. The virtual water import and export in each sector are derived by multiplying the import and export values with TWUC.

TWUC is higher than DWUC in all the sectors. This is expected because DWUC only accounts for the water use at the last stage of the production chain, whereas TWUC is the accumulated water use in the whole production chain.

Sector 1 (agriculture) has the highest water-intensity, with DWUC of 1307.3 $m^3/10^4$ Yuan and TWUC of 1692.3 $m^3/10^4$ Yuan. This is followed by Sector 16 (electricity, gas and water production and supply) where DWUC and TWUC are 814.1 $m^3/10^4$ Yuan and 1042.6 $m^3/10^4$ Yuan, respectively. It is noticed that the difference between DWUC and TWUC in these two sectors are relatively small in comparison to the differences in other sectors. The high DWUC indicates that the direct water use is the major form of water use in Sector 1 and Sector 16. In contrast, most manufacturing industry sectors have large indirect water consumption. For manufacturing sectors like Sector 3 (food and tobacco processing), Sector 4 (textile goods), Sector 5 (wearing), Sector 6 (sawmills and furniture) and Sector 10 (non-metal mineral products), the shares of the direct water use in the total water use of the whole production chain are lower than 5%. Hence, over 95% of the water use in these sectors occurred in an indirect way, i.e., in the previous processing stages prior to the final stage.

The total amount of virtual water import is 5.4×10^{10} m^3 $year^{-1}$, whereas the total virtual water export is 1.0×10^{11} m^3 $year^{-1}$. Hence, China turns out to be a net virtual water exporter of 4.7×10^{10} m^3 $year^{-1}$ in view of the whole national economy.

For individual sectors, the virtual water trade balance varies. Sector 1 (agriculture), Sector 8 (petroleum processing), Sector 12 (machinery and equipment) and Sector 16 (electricity, gas and water production and supply) are the net importers of virtual water. The other 16 sectors are net exporters.

Sector 4 (textile goods), Sector 5 (wearing), Sector 14 (electric equipment, telecommunication equipment), Sector 18 (wholesale and retail trade and passenger transport)

HESSD
8, 3543–3570, 2011

and Sector 11 (metal smelting and products) are the five major net virtual water exporters (Fig. 1). These sectors are the mainstay industries in China, greatly contributing to China's role as the "world manufacturing factory". Their total net virtual water export amounts to 4.1×10^{10} m^3 $year^{-1}$, or 87% of the total net virtual water export of the country.

The ratio of the net virtual water export to water use for domestic final demand indicates how the water use is distributed between domestic demand and external (abroad) demand (export). At the national level, the ratio is 10.4%, indicating that a considerable amount of water use in China is for the production of goods and services for export.

Sector 4 (textile goods) has the highest ratio of net virtual water export to water use for final demand, 337.9% (Fig. 2). This suggests that the textile goods are mostly exported to other countries. Besides, Sector 7 (paper and products), Sector 11 (metal smelting and products) and Sector 5 (wearing) are also of high ratios, respectively 112.7%, 87.1% and 76.2%. Sector 8 (petroleum processing) is the major net virtual water importer with the ratio of −342%. Petroleum, an important intermediate material for industries, is badly needed to support the continuous economic growth in China. The domestic production is far short to meet the demand. The dependence on import is large and increasing over the years.

3.2 Regional variations in virtual water trade

With significant discrepancies in natural conditions and economic development levels among regions, the virtual water trade patterns also appear to show spatial variations. Table 2 provides the quantity of virtual water trade of individual provinces associated with their international trade of final products.

Except for Jiangxi and Hubei, all the other provinces are net virtual water exporters. Guangdong is the largest net virtual water exporter with the net virtual water export of 1.4×10^{10} m^3 $year^{-1}$, accounting for 29% of the total net virtual water export of China. Zhejiang, Jiangsu, and Shandong are also important virtual water exporters, accounting for the total net virtual water export of 18%, 11%, and 19%, respectively.

HESSD
8, 3543–3570, 2011

With two exceptions, all other provinces are net virtual water exporters (Fig. 2, Table 2). Some provinces have very high ratios, implying an export oriented economy. The ratio of Zhejiang is 36%, the highest among all the provinces. Generally, the provinces in the Eastern Coastal area of China have relatively higher ratios, consistent with their roles as the major contributors of the national economy and export in China.

3.3 Sectoral virtual water trade in selected water scarce provinces

As a large country, water resources endowments vary across provinces. Provinces in the north in general are water scarce. It is interesting to take a closer look at the virtual water trade patterns of the water scarce provinces to gain some insights into the impact of the international trade on their water resources. Figure 4 shows the major exporting sectors in 4 extreme water scarce provinces, Beijing, Tianjin, Hebei, and Shandong. The net virtual water export in these 4 provinces accounts for 15.1% of the total net virtual water export of China, whereas the sum of their water resources is only 2.2% of the national total.

Figure 4 presents the share of the first 5 major net virtual water exporting sectors in total net virtual water export in the selected provinces. Apart from Sector 4 and Sector 5, (textile and wearing sectors) there are significant variations in other major sectors in the selected provinces. They reflect the sectoral specialization in these provinces. For example, the net virtual water export in Beijing mainly concentrates in the sectors related to services (Sector 18 and Sector 19). In Tianjin, Sector 14 (electrical goods and communication equipments) and Sector 8 (petroleum processing) have large shares in net virtual water export. The large net virtual water export in Sector 8 corresponds to Tianjin's role as one of the most important petroleum production bases in China. Tianjin's advantage in port transportation conditions facilitates the export of petroleum products. In Shandong, the net virtual water export is highly concentrated in the five major exporting sectors. The share of the remaining sectors is −6%, meaning that the net virtual water import in these sectors offsets 6% of the net virtual water export in the province.

HESSD
8, 3543–3570, 2011

4 Discussion

4.1 The scale of virtual water export and impact on domestic water resources

The results reveal that China is a net virtual water exporter. Given the total water resources of 2.2×10^{12} m^3 year^{-1} (average of 2002–2009), the net virtual water export is about 2.1% of the total water resources of the country. This is seemingly a small percentage. However, not all the water resources of the country are accessible because of geographical, topographical and other barriers. This is particularly the case for the abundant water resources in the southwest part of the country, which are generally not accessible for other regions. Looking into individual regions, the situation differs largely. In the Huang-Huai-Hai region (the HHH region), which is extremely water scarce, the net virtual water export is about 7.9% of the water resources of the region. 17.5% of China's net virtual water export is from this region. Hence, the impact of China's international trade on its water resources is much more significant when reviewed at the regional level (Table 3).

It should be pointed out that a country or region's international trade occurs for multiple reasons, including economic development, political motivation, social consideration, historical trend, natural endowments (apart from water), technology, etc., rather than the water resources concern only. Even for the water sufficient regions, it is imprudent to claim that virtual water export is laudable because of the needs to consider trade-offs between the economic well-being and the state of the environment. The results from this study indicate that it is important to incorporate virtual water trade into the strategic water and trade planning in China, particularly for the regions with server water scarcity.

4.2 Impact of the international trade on water uses

According to the Chinese statistics, the total water use in China is 5.5×10^{11} m^3 year^{-1}. The net virtual water export of 4.7×10^{10} m^3 year^{-1} accounts for 8.9% of the total water

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

HESSD

8, 3543–3570, 2011

Analyses of impacts of China's international trade

Z. Y. Zhang et al.

use. In other words, 8.9% of the water use in China is for the production of goods and services for export. For individual provinces, variations are significant (Fig. 5). It is noticeable that some water scarce provinces, such as Beijing, Tianjin, Jiangsu, Shandong, have large shares. In Tianjin, an extremely water scarce area, 63% of the water use is "exported" in the form of virtual water. In Beijing and Shandong, the shares are 17.9% and 20%, respectively. Hence, the virtual water export in these provinces has significant impact on their water uses. With strong export-driving growth mode, it is expected that water demand will continue to increase, putting further pressure on their already stressed water resources.

The total water use for meeting the domestic final demand in China is 4.5×10^{11} m^3 year^{-1} based on the data in 2002 (Table 1) and the total water use is approximately 5.5×10^{11} m^3 year^{-1} in 2002 (China Statistical Bureau, 2003). The gap is 1.0×10^{11} m^3 year^{-1}. This means that China uses about 24% more water than that required by its people for the final demand. Subtracting the net virtual water export of 4.7×10^{10} m^3 year^{-1}, there is a missing amount of 6.1×10^{10} m^3 year^{-1} in the national water balance. This is about 10.9% of the total water use of the country. The "missing" water may be partly attributed to the return flow, treated water and water loss during the supply and use. Even when the statistical errors and lumping errors are considered, the unproductive losses are still expected to be significant. Hence, reducing losses in the overall water management and water supply system could make a significant contribution to the alleviation of water stress in China.

4.3 Sectoral scrutiny

The net virtual water export is highly concentrated in Sector 4 (textile goods), Sector 5 (wearing), Sector 14 (electrical goods and communication equipments) (Fig. 1). The three sectors account for 63% of total net virtual water export of the country. These sectors are typically labor intensive, which employ a large number of rural migrant workers. In terms of water use, Sector 4 and Sector 5 are rather water intensive with high TWUC in their whole production chain. As shown in Sect. 3.3, the share of these

HESSD
8, 3543–3570, 2011

sectors is rather high in water scarce provinces. The results suggest that the international trade patterns and structure of the whole country and individual provinces have been shaped mainly by other factors, rather than water resources endowments.

The study finds that the agriculture sector is a net importer of virtual water at the national level, which is consistent with the results in other studies (Hoekstra and Hung, 2002; Zhao et al., 2009). However, it is not the case for all the provinces. Our study reveals that provinces like Fujian, Anhui, Hubei, Hunan, and Sichuan are net exporters in the agricultural sector.

It is worth noting that Food and tobacco processing, Textile, and Wearing are typical downstream industries of agriculture, i.e., using raw materials from agriculture in the initial stage of their production processes. Although the agricultural sector is a net importer in China, its downstream industries are not (Table 1). The situation suggests that part of the imported virtual water from agriculture is re-exported through the exports of products in the downstream sectors.

The international trade partners in China contribute to its sober water situation not only in quantity, but also in quality. The wastewater discharge from Food and tobacco processing, Textile, and Wearing, Paper and products, and Metal smelting and products and Smelting process accounts for 53% of China's total industrial wastewater discharge (China Statistical Bureau, 2009). Small scale and low technology are the common features of enterprises in these sectors, and they are notorious for releasing heavily polluted waste water often without any treatment (Wang et al., 2008). In essence, China is exporting a large amount of virtual fresh water to other countries while at the same time keeping heavily polluted water to itself. The results suggest that China's economic gains from being a world "manufacture factory" have been attained at a high cost to its water resources and through pollution to its environment.

4.4 Concluding remarks

It is worth noting that our estimate of the total net virtual water export of China is almost double of the volume estimated by Zhao et al. (2009), which was 2.4×10^{10} m^3 year^{-1}

HESSD
8, 3543–3570, 2011

in 2002. The difference stemmed primarily from the regional discrepancy incorporated in the assessment process. Regional discrepancy in TWUC was not considered in Zhao's study, while partly considered in ours as specified in Eq. (9) to Eq. (14). Besides, Zhao's result was obtained based on the national Input-output table, whereas this study is a provincial-level analysis using the provincial IO tables in which the regional technology variations are embodied. This difference indicates the importance to take into consideration the regional discrepancies in the virtual water trade assessment.

Despite the effort to incorporate regional discrepancies, some limitations remain. Due to data constraint, the assessment does not fully differentiate the regional discrepancy in water use efficiency. As shown in Eq. (7), the regional TWUC variation consists of regional technology variation reflected by Leontief inverse matrix $[b_{ij}]$ and regional water intensity variation reflected by DWUC ω_j. In this study, the national average DWUCs for individual sectors are used for all the provinces due to the unavailability of provincial DWUC data. This substitution may cause overestimations of the virtual water embodied in the products from the water use efficient provinces as well as underestimations of the virtual water embodied in the products from the water use inefficient provinces. Therefore, the lacking information makes it difficult to exactly quantify the overall impact on the national virtual water trade figures.

This study is a first attempt to use the input-output model to investigate the virtual water flows associated with China's international trade of goods and services with regional specifications. The accounting process used here adopts some assumptions due to data constraint. Improvements would need a more reliable data base on the regional disparity of water use efficiency containing also information on return flows and waste water treatment.

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HESSD
8, 3543–3570, 2011

Analyses of impacts of China's international trade

Z. Y. Zhang et al.

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◂◂ | ▸▸
◂ | ▸
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

References

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HESSD
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Z. Y. Zhang et al.

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Table 1. Detailed results of sectoral virtual water trade accounting.

	Sectors	DWUC	TWUC (average)	Virtual water export	Virtual water import	Net virtual water export	Water use for final demand
		ω_j	δ_j	u_j	v_j	$u_j - v_j$	t_j
		$m^3/10^4$ Yuan	$m^3/10^4$ Yuan	10^6 m^3 $year^{-1}$	10^6 m^3 $year^{-1}$	10^6 m^3 $year^{-1}$	10^6 m^3 $year^{-1}$
1	Agriculture	1307.3	1692.3	8039.5	11 322.8	−3283.4	148 993.8
2	Coal mining and processing	31.6	229.9	354.9	5.5	309.4	661.8
3	Food and tobacco processing	32.1	758.0	6199.1	3790.5	2408.6	64 690.7
4	Textile goods	30.4	563.4	13 824.2	1164.3	12 659.9	3747.1
5	Wearing	5.5	419.2	9575.1	1034.5	8540.5	11 202.8
6	Sawmills and furniture	2.7	452.9	3118.2	547.5	2570.7	4065.8
7	Paper and products	90.0	429.9	3849.0	882.6	2966.4	2631.5
8	Petroleum processing	24.8	308.2	1085.9	2718.9	−1633.0	477.6
9	Chemicals	47.5	353.4	7511.0	4557.9	2953.1	6527.7
10	Non-metal mineral products	22.6	533.6	3084.8	830.2	2254.6	4051.0
11	Metal smelting and products	40.7	614.3	9207.3	4610.9	4596.4	5279.2
12	Machinery and equipment	4.7	220.6	2845.8	6614.6	−3768.7	18 321.4
13	Transport equipment	5.8	217.2	1584.5	1572.3	12.1	5179.5
14	Electric equipment, telecommunication equipment	3.1	207.3	14 051.7	5856.4	8195.3	11 436.5
15	Other manufacturing	4.9	249.8	3362.9	2002.6	1360.3	2997.1
16	Electricity, gas and water production and supply	814.1	1042.6	67.3	3956.3	−3889.0	15 216.4
17	Construction	4.5	227.6	192.7	144.1	48.5	61 042.1
18	Wholesale and retail trade and passenger transport	39.7	188.4	7074.9	379.9	6694.9	13 113.6
19	Restaurant and hotel	170.1	639.6	2186.8	21.6	2165.2	16 703.4
20	Other services	23.2	168.3	3825.6	2359.8	1465.8	50 715.1
	Total			101 041.1	54 413.3	46 627.8	447 054.2

DWUC: direct water use coefficient; TWUC: total water use coefficient.

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

HESSD

8, 3543–3570, 2011

Analyses of impacts of China's international trade

Z. Y. Zhang et al.

Table 2. Virtual water trade at the provincial level (10^6 m^3 $year^{-1}$).

	Provinces	Virtual water export 10^6 m^3 $year^{-1}$	Virtual water import 10^6 m^3 $year^{-1}$	Net virtual water export 10^6 m^3 $year^{-1}$
1	Beijing	2104.1	1515.6	588.5
2	Tianjin	2384.0	1004.4	1379.6
3	Hebei	1788.9	1024.7	764.2
4	Shanxi	779.7	294.0	485.6
5	Inner Mongolia	637.5	344.4	293.1
6	Liaoning	6124.4	5546.5	577.9
7	Jilin	1272.7	626.4	646.3
8	Heilongjiang	1098.6	1003.4	95.2
9	Shanghai	7626.4	4933.0	2693.4
10	Jiangsu	13 189.7	7912.7	5277.0
11	Zhejiang	10 668.2	2157.8	8510.4
12	Anhui	1177.5	484.6	693.0
13	Fujian	6202.7	2359.9	3842.8
14	Jiangxi	579.3	585.2	−5.9
15	Shandong	10 674.3	6358.6	4315.7
16	Henan	1641.8	1037.6	604.1
17	Hubei	851.2	1266.8	−415.6
18	Hunan	751.2	495.5	255.7
19	Guangdong	26 146.5	12 489.5	13 657.0
20	Guangxi	598.5	387.4	211.2
21	Hainan	364.5	128.9	235.6
22	Chongqing	500.7	414.6	86.2
23	Sichuan	1072.4	458.9	613.5
24	Guizhou	298.3	244.0	54.3
25	Yunnan	696.3	430.9	265.3
26	Shaanxi	657.9	362.3	295.7
27	Gansu	301.7	211.1	90.6
28	Qinghai	57.0	19.0	38.0
29	Ningxia	131.1	66.3	64.8
30	Xinjiang	663.9	249.2	414.7
	Total	101 041.1	54 413.3	46 627.8

HESSD
8, 3543–3570, 2011

Analyses of impacts of China's international trade

Z. Y. Zhang et al.

Title Page
Abstract Introduction
Conclusions References
Tables Figures
◀◀ ▶▶
◀ ▶
Back Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

Table 3. Net virtual water export and water resources in different regions.

Regions	Provinces	WR/cap m^3/person	WR 10^6 m^3 $year^{-1}$	NVWE 10^6 m^3 $year^{-1}$	NVWE/WR (%)
The HHH region	Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan	331.4	103 251.4	8137.8	7.9%
Northeast	Liaoning, Jilin, Heilongjiang	1195.7	128 114.4	1319.3	1.0%
The Yangzi river basin	Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan	1022.7	204 453.0	17 173.8	8.4%
South	Fujian, Guangdong, Hainan	2543.5	736 770.5	17 569.6	2.4%
Southwest	Guangxi, Chongqing, Sichuan, Guizhou, Yunnan	3157.6	782 195.3	1230.5	0.2%
Northwest	Inner Mongolia, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang	2197.9	256 101.2	1196.8	0.5%
	Total	1737.4	2 210 885.7	46 627.8	2.1%

HESSD
8, 3543–3570, 2011

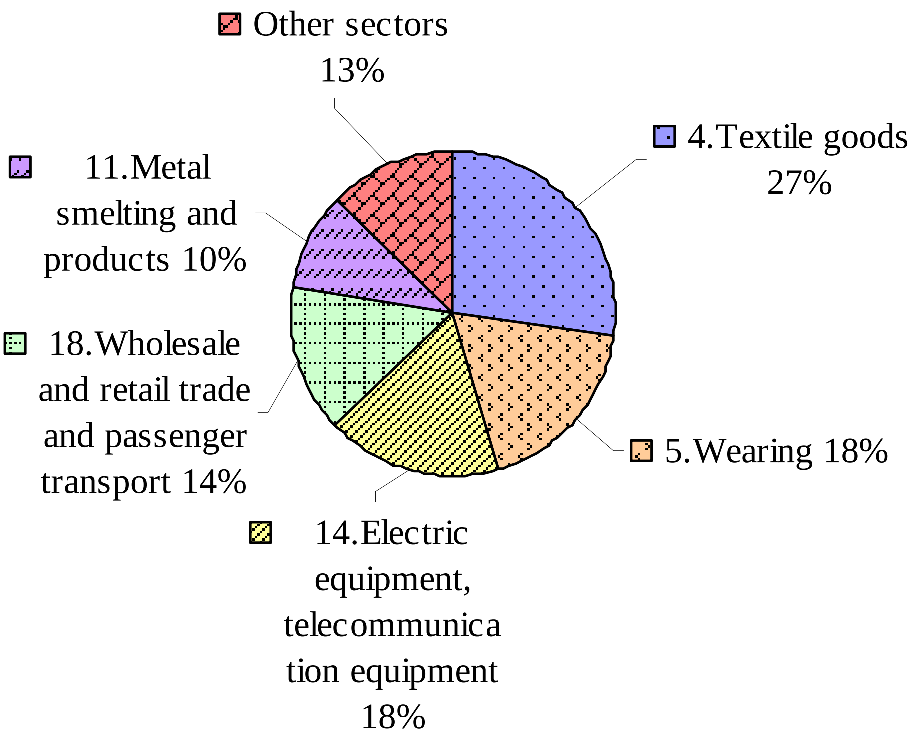

Fig. 1. Shares of the major net virtual water exporting sectors in total net virtual water export.

HESSD
8, 3543–3570, 2011

Analyses of impacts of China's international trade

Z. Y. Zhang et al.

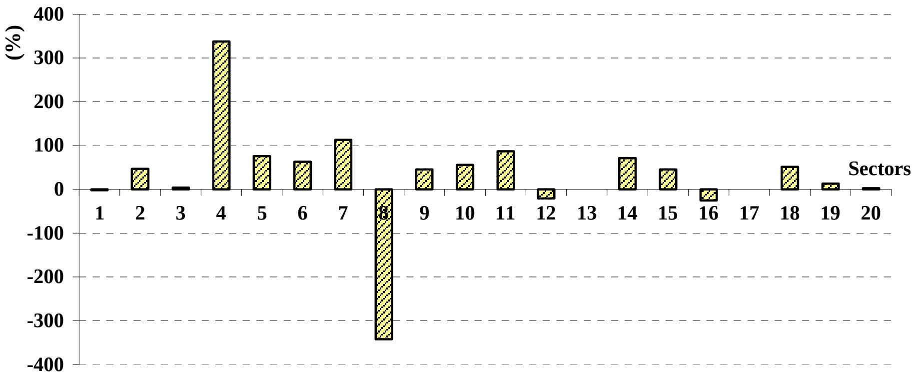

Fig. 2. Ratios of net virtual water export to water use for domestic final demand in different sectors.

HESSD
8, 3543–3570, 2011

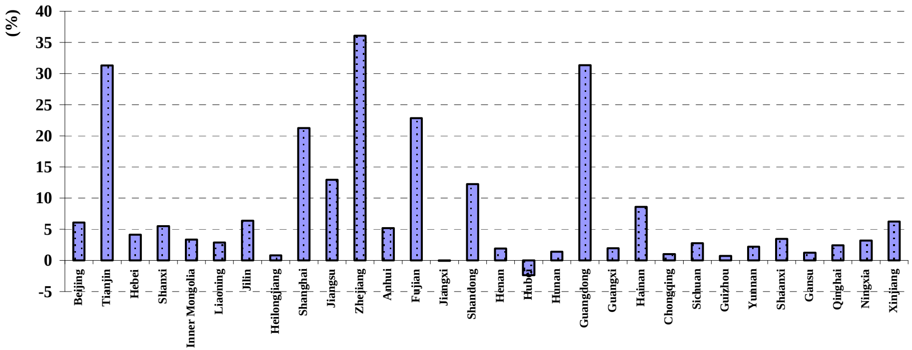

Fig. 3. Ratios of net virtual water export to water use for final demand in individual provinces.

HESSD
8, 3543–3570, 2011

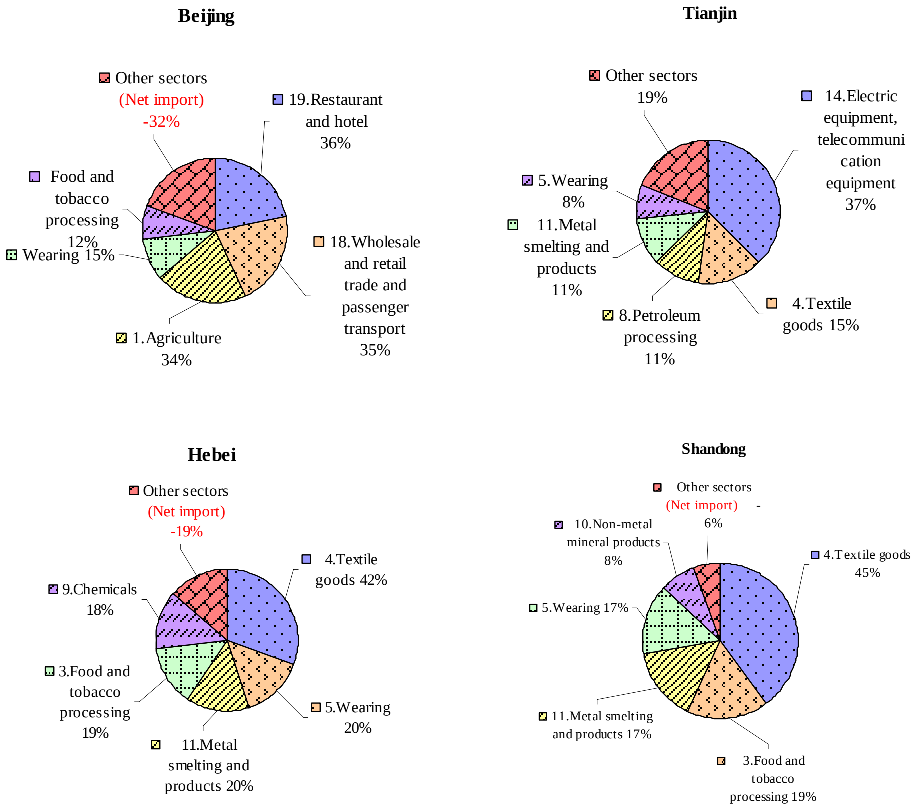

Fig. 4. The major net virtual water exporting sectors in the selected water scarce provinces.

HESSD
8, 3543–3570, 2011

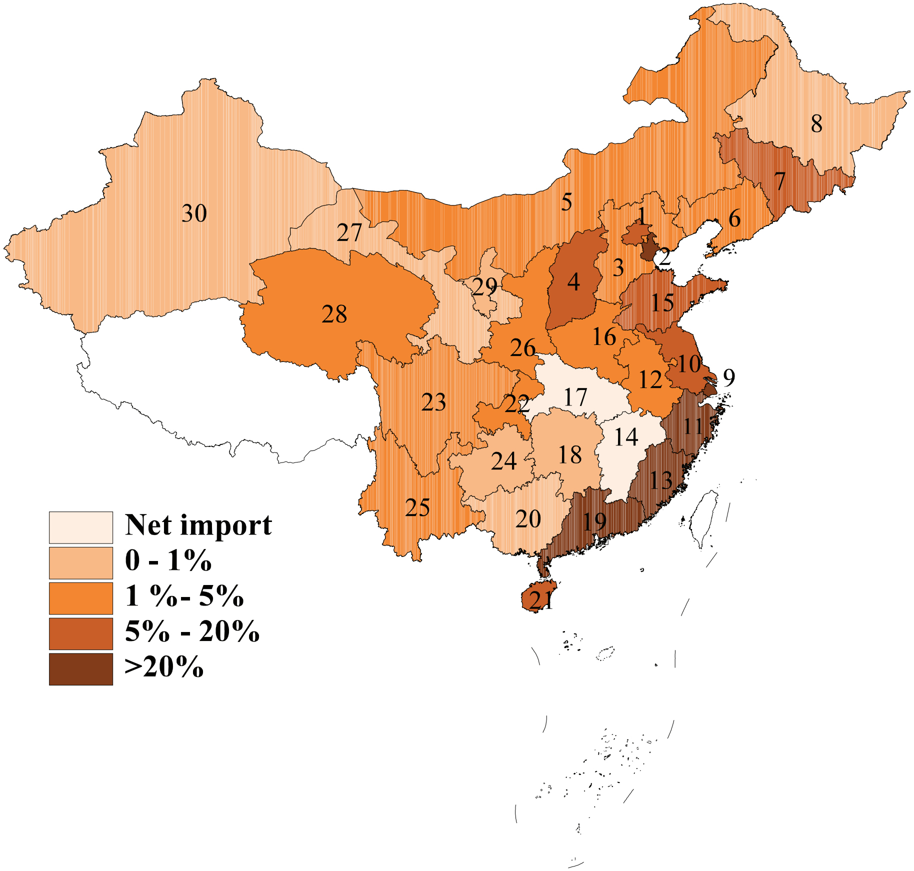

Fig. 5. Share of net virtual water export in total water use in different provinces.

HESSD
8, 3543–3570, 2011

Analyses of impacts of China's international trade

Z. Y. Zhang et al.