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Original Research

Research on China's Domestic Trade of Virtual Water from the Perspective of Value-Added Trade

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Abstract

From the perspective of value-added trade, this paper divides the virtual water consumption and trade in different provinces of China into five major paths according to the input-output relationship. In 2012 and 2015, most provinces' water resources were implicitly used in the final products to meet the local demand. In addition, the volume of virtual water trade in the complex domestic value chain is greater than that in the traditional domestic trade value chain and the simple domestic trade value chain. In both years, judging from the sum of virtual water trade volumes in the three major value chains, there is virtual water net inflow in Beijing-Tianjin and the northern, eastern and southern coastal areas, and virtual water net outflow in the northeast, central and northwest areas. In the course of this research, the virtual water net outflow turned into net inflow in the southwestern area.

Keywords: virtual water trade, value-added trade, input-output model, China

Introduction

Water is the source of life, essential to production and the foundation of ecology. Water resources are not only important for the flood control and the water and food supply, but also essentials to guarantee the economic and ecological security. In China, the water resources are indispensable to the production of all industries. However, the limited supply of water resources, together with the uneven distribution in time and space dimensions, has led to serious supply-demand imbalance that exists nowadays in China. The virtual water trade strategy is an innovative idea to alleviate this problem, according to which those water-deficient countries (regions) could import industrial and agricultural products or service from water-rich countries (regions) to replace their own production [1].

Since Allan [1] came up with the concept of virtual water trade, some scholars have done research on how to calculate it. Hoekstra and Hung [2] first studied the calculating method of virtual water trade in agricultural products such as grain, and pointed out that the key to calculating the virtual water trade volume of agricultural products is to use the Penman formula to calculate the virtual water content. Chapagain and Hoekstra [3] further proposed the method to calculate the virtual water trade in living animals and related products, which adds up the animals' water consumption at each growth stage, and when it comes to the product, it comprehensively weights the value factor and the scale factor of the product. After that, many researchers used the above method (which can be called "the product

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tree method") to conduct empirical research on the virtual water trade in agricultural products in various countries, such as Zhang et al. [4] that researched the agricultural virtual water trade of China from 2001 to 2013 and pointed out that the virtual water trade in China has shown a downward trend in exportation but an upward trend in importation. Antonelliet al. [5] calculated the virtual water trade in agricultural products among EU countries from 1993 to 2011, and pointed out that five countries Germany, France, Italy, the Netherlands and Belgium took possession of 60% of the virtual water importation amount. The Netherlands, France, Germany, Belgium and Spain took possession of 65% of virtual water exportation amount. Zhang et al. [6] calculated the trade volume of virtual water in agricultural products between China and the "Belt and Road initiative" countries from 2001 to 2015, and pointed out that China had a trade surplus. Liu et al. [7] studied the water footprint and virtual water trade in the northwest of China from 2000 to 2016, and pointed out that strengthening international agricultural trade relationship could help to reduce the pressure on water supply.

The method used by Hoekstra and Hung [2], Chapagain and Hoekstra [3] to calculate the virtual water trade volume according to production steps is effective in agricultural products field. However, due to the cumbersome calculations, it is not ideal to be applied in the industrial and service products fields. For this reason, some researchers proposed to use the input-output method to calculate the virtual water trade volume in various industries. This method has two models according to the number of researched regions: the single-region model and the multi-region model, and the calculating steps of these two models are basically the same: the first step is to divide the total output with the water resource usage data of each industry in order to obtain the direct water use coefficient, and the second is to multiply the direct water use coefficient by the Leontief inverse matrix and the final used part of the input-output table to obtain the virtual water trade volume of each industry. There are several researches carried out with the input-output method, for example: Deng et al. [8] calculated the virtual water trade in various industries in China in 2007 with the single-region model, studied the impact of changes in water-use efficiency on the virtual water trade structure and pointed out that there are virtual water net importation in agriculture field and virtual water net exportation in the entire industry. Jiang et al. [9] calculated the virtual water trade among 30 provinces of China in 2007 with the multi-regional model and pointed out that even the water-deficient regions may had virtual water net exportation region. Zhao et al. [10] calculated the virtual water trade among 30 provinces in China in 2007 through the use of the multi-regional model, simulated and analyzed the virtual water trade among Chinese provinces in 2030, and pointed out that the virtual water trade in each province in 2007 accounted for 11%-65% of the total water supply. Deng et al. [11], also by using the multi-regional model, calculated the water footprint and virtual water trade of China's eight major regions in 2002 and 2007, and studied the reason for the increase in water footprint and virtual water trade of each region using a structural decomposition analysis method. Serrano et al. [12] calculated the virtual water trade of 27 countries in EU in 2009 used the multi-regional model and pointed out that Germany, unlike those Southeast European countries that were virtual water net exportation countries, had virtual water net importation. Chen et al. [13] studied China's virtual water trade from 2000 to 2012 using the single-region model and pointed out that the virtual water exportation volume in China increased from 65.2 billion tons in 2000 to 114.1 billion tons in 2012. Deng et al. [14] used the single-region model to calculate the virtual water trade volume in various industries in China in 2012, and used the hypothetical extraction method to study the associated effects of virtual water trade in various industries; it pointed out that although the virtual water net exportation volume in 2012 was relatively large, the agricultural virtual water net importation volume was relatively large as well. Sun et al. [15] studied the virtual water trade in Tibet in 2012, and pointed out that Tibet was an area that exported virtual water to other provinces. Deng et al. [16] calculated the virtual water trade among G20 countries from 2006 to 2015, analyzed its characteristics and pointed out that within the research period the virtual water trade volume among these countries had increased in varying degrees. In addition, some studies combined the single-region and the multi-region model, and used the multi-scale input-output model to calculate the virtual water trade [17].

Although there are many studies on virtual water trade in China or other countries (regions) of the world, they are all carried out from a traditional trade perspective. This paper intends to combine the two input-output models to study, from the perspective of value-added trade, the virtual water trade among Chinese provinces (regions). At present, the production and trade relationship between different countries (regions) is getting closer and closer, and it is frequent to product a good through cooperation of variuos companies in different countries (regions). As different production lines and their added value are realized in different countries (regions), the trade for the value-added part is called value-added trade [18]. The traditional calculating method of import and export trade based on cross-border and final products can no longer accurately reflect the value-added situation of different production processes and producing phases in different countries (regions) under the global value chain. For this reason, there are some literature that calculate the carbon emissions involved in the value-added trade of products [19-21]; however, there is still a lack of literature on virtual water trade calculation from the perspective of value-added trade.

China is a vast country where the distribution of water resources and the level of economic development vary greatly among different provinces (regions). Therefore, from the perspective of value-added trade, this paper calculates the domestic trade of virtual water in various provinces (regions) in China, which will be helpful to better implement the virtual water trade strategy and resolve the supply-demand imbalance in this country.

The following key points could be found in this paper: (1) from the perspective of value-added trade, the virtual water consumption and the virtual water trade among different provinces in China are divided into five major paths by using the input-output model. (2) In accordance with the traditional value chain, simple value chain and complex value chain, this paper systematically calculates the virtual water trade among eight major regions in China.

Material and Methods

Methods

According to the structure of China's inter-regional input-output table, it can be obtained that:

$$\begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^m \end{bmatrix} = \begin{bmatrix} A^{11} & A^{12} & \cdots & A^{1m} \\ A^{21} & A^{22} & \cdots & A^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A^{m1} & A^{m2} & \cdots & A^{mm} \end{bmatrix} \begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^m \end{bmatrix} + \begin{bmatrix} Y^1 \\ Y^2 \\ \vdots \\ Y^m \end{bmatrix} \tag{1}$$

where m is the total number. X^r is the column vector of total output corresponding to area. A^{rs} is the intermediate product demand coefficient matrix of area r to area s. A^{rr} is the direct consumption coefficient matrix of area r. $Y^r = \sum_{s=1}^{m} Y^{rs}$ is the final used column vector of area r.

Matrix B is defined as the following Leontief inverse matrix:

$$B = \begin{bmatrix} B^{11} & B^{12} & \cdots & B^{1m} \\ B^{21} & B^{22} & \cdots & B^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ B^{m1} & B^{m2} & \cdots & B^{mm} \end{bmatrix} = \begin{bmatrix} I - A^{11} & -A^{12} & \cdots & -A^{1m} \\ -A^{21} & I - A^{22} & \cdots & -A^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ -A^{m1} & -A^{m2} & \cdots & I - A^{mm} \end{bmatrix}^{-1} \tag{2}$$

where B^{rs} is the block matrix in the Leontief inverse matrix, which represents the total output of area r caused by the output of the final product of 1 unit area s.

Combining formula (1) and formula (2), it can be obtained that:

$$\begin{bmatrix} X^1 \\ X^2 \\ \vdots \\ X^m \end{bmatrix} = \begin{bmatrix} B^{11} & B^{12} & \cdots & B^{1m} \\ B^{21} & B^{22} & \cdots & B^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ B^{m1} & B^{m2} & \cdots & B^{mm} \end{bmatrix} \begin{bmatrix} Y^1 \\ Y^2 \\ \vdots \\ Y^m \end{bmatrix} \tag{3}$$

Rewriting the final used column vector in formula (3) into the final used matrix form, formula (3) can be transformed into:

$$\begin{bmatrix} X^{11} & X^{12} & \cdots & X^{1m} \\ X^{21} & X^{22} & \cdots & X^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ X^{m1} & X^{m2} & \cdots & X^{mm} \end{bmatrix} = \begin{bmatrix} B^{11} & B^{12} & \cdots & B^{1m} \\ B^{21} & B^{22} & \cdots & B^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ B^{m1} & B^{m2} & \cdots & B^{mm} \end{bmatrix} \begin{bmatrix} Y^{11} & Y^{12} & \cdots & Y^{1m} \\ Y^{21} & Y^{22} & \cdots & Y^{2m} \\ \vdots & \vdots & \ddots & \vdots \\ Y^{m1} & Y^{m2} & \cdots & Y^{mm} \end{bmatrix} \tag{4}$$

where X^{rs} represents the total output of area r caused by the final demand of area s, and this part of the total output is consumed by area s.

From formula (4), it can be obtained that:

$$X^{rs} = \sum_{t=1}^{m} B^{rt} Y^{ts} \tag{5}$$

Multiplying both sides of formula (4) by B^{-1}, and arranging them to get:

$$X^{rs} = L^{rr} \sum_{t \neq s}^{m} A^{rt} X^{ts} + L^{rr} Y^{rs} \tag{6}$$

where $L^{rr} = (I - A^{rr})^{-1}$ is the Leontief inverse matrix of area r, which represents the total output of area r caused by the final product output of 1 unit area r. It should be noted that $L^{rr} \neq B^{rr} =$.

When $r = s$, according to formula (6), we can get:

$$X^{rr} = L^{rr} \sum_{t \neq s}^{m} A^{rt} X^{tr} + L^{rr} Y^{rr} \tag{7}$$

On the other hand, the total output can be written as:

$$X^r = \sum_{s=1}^{m} X^{rs} = X^{rr} + \sum_{s \neq r}^{m} X^{rs} \tag{8}$$

Substituting formula (6)-(7) into formula (8) and combining formula (5), we can get:

$$\begin{aligned} X^r &= L^{rr} Y^{rr} + L^{rr} \sum_{s \neq r}^{m} Y^{rs} + L^{rr} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{ur} + L^{rr} \sum_{s \neq r}^{m} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{us} \\ &= L^{rr} Y^{rr} + L^{rr} \sum_{s \neq r}^{m} Y^{rs} + L^{rr} \sum_{s \neq r}^{m} A^{rs} L^{ss} Y^{ss} + L^{rr} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{ur} \\ &\quad + L^{rr} \left(\sum_{s \neq r}^{m} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{us} - \sum_{s \neq r}^{m} A^{rs} L^{ss} Y^{ss} \right) \end{aligned} \tag{9}$$

Further, defining the row vector of the direct water-use coefficient of area r:

$$(w_1^r, w_2^r, \cdots, w_n^r) = (W_1^r, W_2^r, \cdots, W_n^r)\begin{bmatrix} \frac{1}{X_1^r} & 0 & \cdots & 0 \\ 0 & \frac{1}{X_2^r} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \frac{1}{X_n^r} \end{bmatrix} = W^r(\hat{X}^r)^{-1} \quad (10)$$

where the subscript 1, 2, ..., n represents each department in the area r, W_i^r represents the water consumption of the i-th department in the area r, and $\hat{X}$ represents the diagonalization of the total output vector into a matrix form. Combining formula (9) and formula (10), we can get:

$$(W^r)^T = \hat{w}^r X^r = \hat{w}^r L^{rr} Y^{rr} + \hat{w}^r L^{rr} \sum_{s \neq r}^{m} Y^{rs} + \hat{w}^r L^{rr} \sum_{s \neq r}^{m} A^{rs} L^{ss} Y^{ss}$$
$$+ \hat{w}^r L^{rr} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{ur} + \hat{w}^r L^{rr} (\sum_{s \neq r}^{m} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{us} - \sum_{s \neq r}^{m} A^{rs} L^{ss} Y^{ss}) \quad (11)$$

where the superscript T indicates that the row vector is transposed into a column vector and $\hat{w}$ indicates that the direct water use coefficient vector is diagonalized into a matrix form. Since China's inter-regional input-output table contains export items and error items (export items and error items are included in the total output),considering the impact of virtual water exports and error items, this paper revises formula (11) as:

$$(W^r)^T = \hat{w}^r X^r = \hat{w}^r L^{rr} Y^{rr} + \hat{w}^r L^{rr} \sum_{s \neq r}^{m} Y^{rs} + \hat{w}^r L^{rr} \sum_{s \neq r}^{m} A^{rs} L^{ss} Y^{ss}$$
$$+ \hat{w}^r L^{rr} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{ur} + \hat{w}^r L^{rr} (\sum_{s \neq r}^{m} \sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{us} - \sum_{s \neq r}^{m} A^{rs} L^{ss} Y^{ss}) + \varepsilon^r \quad (12)$$

Where ε^r represents the error item of area r. Formula (12) divides the regional water consumption into six items according to the final destination. The specific meaning of each decomposition item is as follows: The first item indicates that water resources are implicitly used in the final product to meet local final product demand, and the second item indicates that water resources are implicitly transferred to other regions in the final product to meet the demand for final products in other regions. The third item indicates that water resources are implicitly transferred to other regions in the intermediate product and put into production as an intermediate product to meet the consumption in other regions. The fourth item indicates that water resources are implicitly transferred to other regions in the intermediate product and finally returned to the originative region to meet the final product consumption in this region. The fifth item indicates that water resources are implicitly transferred in the intermediate product, and then are transferred to other regions and further transferred to the third region. The sixth item represents the error term. (This paper focuses on the analysis of China's domestic virtual water trade, so the impact of the error item is ignored.) Among them, the first and the fourth items can be regarded as the virtual water that meets the consumption in this area, and the second, the third and the fifth items can be regarded as the virtual water outflow to other areas.

Similar to the calculation method of embodied carbon trade from the perspective of value-added trade [19], this paper combines the second, the third and the fifth terms in formula (12) to define the amount of virtual water outflow from area r to area s (that is, the amount of virtual water transferred from area s to area r):

$$(W^{rs})^T = \hat{w}^r L^{rr} Y^{rs} + \hat{w}^r L^{rr} A^{rs} L^{ss} Y^{ss} + \hat{w}^r L^{rr} (\sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{us} - A^{rs} L^{ss} Y^{ss}) \quad (13)$$

The first to the third items of formula (13) are called the virtual water trade volume on the traditional domestic trade value chain, the simple domestic trade value chain and the complex domestic value chain.To be sure, the formula 11 contains five items, but three of five items, the second, the third and the fifth item are related with the virtual water outflowing from area r into area s. because the first and the fourth items in fact refer to the local virtual water consumption of area r.

It should be pointed out that the calculation method of the virtual water trade is similar to that of the value-added trade in formula (13). The direct water-use coefficient diagonal matrix in formula (13) is replaced with the value-added coefficient diagonal matrix, and the amount of the added value outflow from area r to area s (that is, the amount of the added value inflow from area s to area r) can be obtained:

$$(V^{rs})^T = \hat{v}^r L^{rr} Y^{rs} + \hat{v}^r L^{rr} A^{rs} L^{ss} Y^{ss} + \hat{v}^r L^{rr} (\sum_{t \neq r}^{m} A^{rt} \sum_{u=1}^{m} B^{tu} Y^{us} - A^{rs} L^{ss} Y^{ss}) \quad (14)$$

where $\hat{v}$ represents the diagonal matrix of the value-added coefficient (the value-added coefficient is equal to the ratio of the value-added to the total investment).

Material

In this paper, the inter-regional input-output tables of 42 departments in 31 provinces of China in 2012 are cited from Liu et al. [22], and the inter-regional input-output tables in 2015 are extracted from the CEADs database. The water consumption data in agriculture, the secondary industry and the service industry among different provinces of China come from the "China Statistical Yearbook" over the years, in which water consumption in the service industry is approximately replaced by domestic water consumption. In addition, due to the lack of water consumption data for specific sectors of the second industries (sectors 2-28) and the service industry (sectors 29-42), this paper refers to Chen and Guo [23] and uses the following formula to estimate:

$$W_j^r = \frac{W^r \times Z_{27\to j}^r}{\sum_j Z_{27\to j}^r} \qquad (15)$$

where W is the total water consumption in the secondary industry (or the service industry) in region r, and $Z^r_{27\to j}$ is the intermediate input of water production and supply industry in region r (corresponding to the 27th sector in the input-output table) in sector j.

It should be pointed out that because the water consumption data of each province in the "China Statistical Yearbook" is limited to the use of blue water, this paper only studies the virtual water trade of blue water, and does not study the virtual water trade of green water and gray water. In reference to Hoekstra et al. [24], green water refers to the rainwater stored in plants roots, blue water refers to the water in rivers, lakes and underground aquifers, and gray water refers to the water required to purify pollutants in water bodies.

Results and Discussions

Virtual Water in Different Paths in Different Provinces

This paper first uses formula (11) to calculate the virtual water in different paths in various provinces in China. The Figs 1 and 2 show the virtual water proportions in the five major paths in each province in 2012 and 2015:

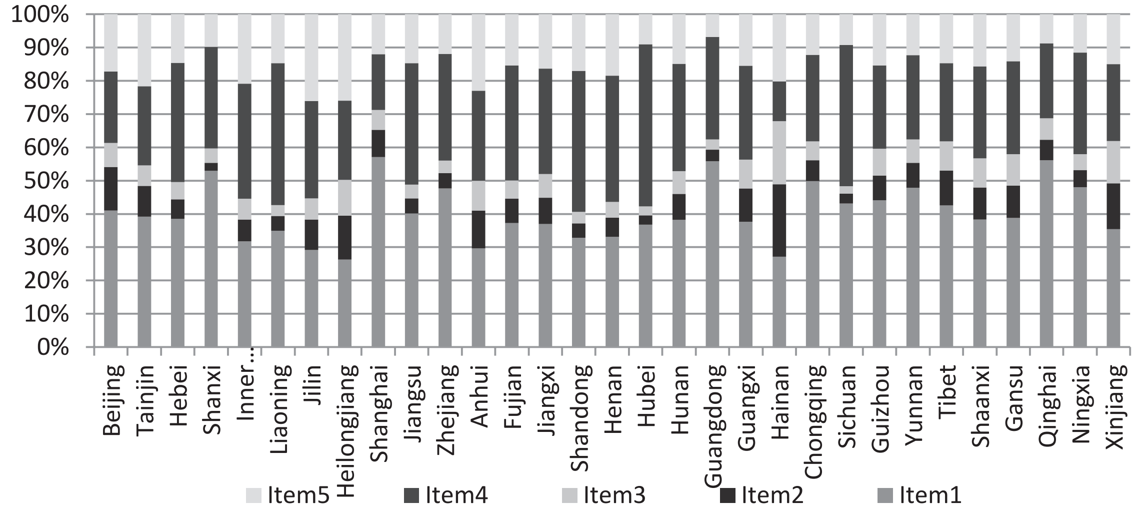

Fig. 1. The proportion of virtual water on the five major paths in China's provinces in 2012.

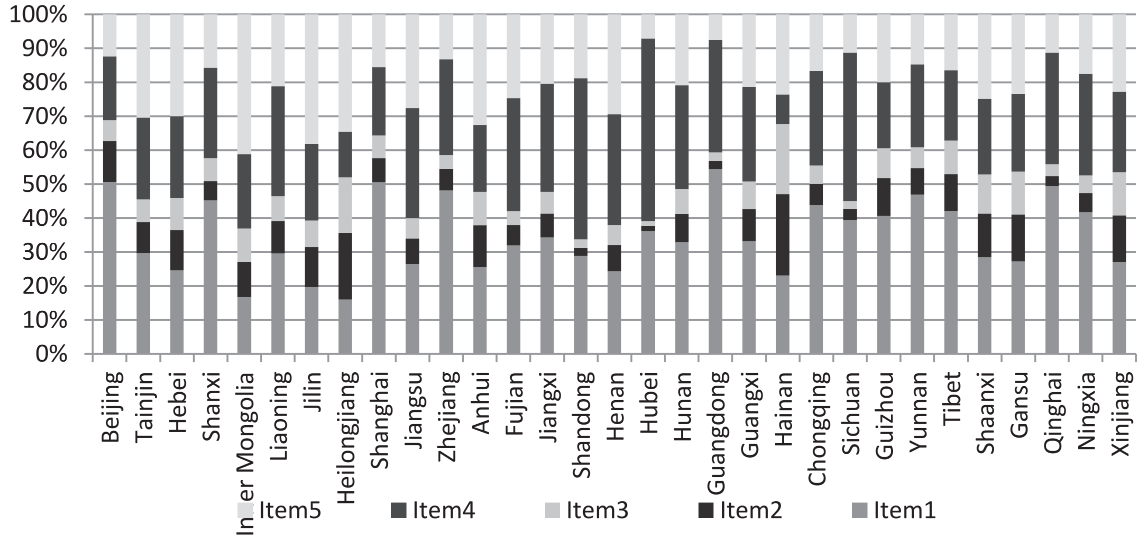

Fig. 2. The proportion of virtual water on the five major paths in China's provinces in 2015.

In most provinces, the first item accounted for more than 20% in 2012 and 2015, a relatively high proportion, which means that the water resources in these provinces were implicitly used in the final products to meet the local demand. This is because in China the production is required to priorly meet the local needs, and only the surplus, if there is, is permitted to be transferred to other places. Among these provinces, Shanghai had the highest proportion in 2012, reaching 57.12%, because in this metropolis the locally produced agricultural products was mainly destined for local consumption and only a small proportion was transferred to other provinces. In 2015, however, Guangdong took the first place, reaching 54.43%, because it was the most populated province in China where the second industries in the cities of the Pearl River Delta were well developed, so the local consumption was relatively high and there was a relatively low proportion of agricultural products output. This resulted in that Guangdong had the highest proportion of the first item among all the provinces in 2015. In 2012 and 2015, the province with the lowest proportion of the first item was Heilongjiang. This is because it is the major food production area in China and each year large number of agricultural products was transferred to other provinces. The water consumption per unit of output of the agricultural products is dozens or even hundreds of times of that of the second industry and the service industry, so the first item of Heilongjiang is the lowest. In addition, it can be found that the proportion of the first item in most provinces in 2015 was lower than that in 2012. This is because the transportation facilities in 2015 were more developed and the domestic trade volume of various products was bigger than in 2012.

In 2012 and 2015, in most provinces, the proportions of the second item and the third item accounted for less than 10%, which shows that the water resources implicitly transferred to other regions to meet their demand or consumption take a relatively low proportion, not only in the final products to be consumed directly, but also in the intermediate products to be put into productions. The second item actually represents the virtual water trade in the traditional domestic trade value chain, and the third item represents the virtual water trade in the simple domestic trade value chain. The reason for the relatively low proportions of the second and the third items is that the products produced in each province are mainly destined to meet local consumers' demand, and only the surplus part is used for domestic and international trade, thereby the virtual water outflow volume to other areas is lower than the local virtual water consumption. It should be pointed out that Hainan has the highest proportion in the second and third items among all the provinces in 2012 and 2015 because,as the second largest island in China, it has more ports than other provinces, which is an great advantage for its trade with other provinces,, especially with Guangdong.

The fourth item of most provinces accounts for more than 20% in 2012 and 2015, which shows that a relatively high proportion of water resources was implicitly transferred to other regions in intermediate products and later returned to the originative region as final products. Since the fourth item actually still represents the local consumption of products processed in various provinces, it just flows back to the region after passing through other regions. Therefore, similar to the explanation of the first result, the products produced in varies provinces give priority to meet their local demands. After this, if there was surplus, it will be transferred to other areas, so it is relatively high proportion of water resources implicitly transferred to other regions in intermediate products and finally returned to the originative region in final products for local consumption.

In most provinces, the fifth item accounted for 10%-20% in 2012. In 2015, the proportion increased. In more than half of the provinces, this item accounted for more than 20%. This shows that the proportion of water resources transferred to other regions in intermediate products and further transferred to a third region increased in 2015. By contrast, the fifth item has a higher proportion than the second and third item, which shows that the virtual water trade volume in the complex domestic value chain was larger than that in the traditional domestic trade value chain and the simple domestic trade value chain. Furthermore, this shows that the industrial division in China tended to be more and more refined, and the different processes of production of a product could be carried out in different provinces. As a result, the virtual water trade volume in the complex domestic value chain was growing.

Virtual Water Trade Volume in Different Value Chains in Different Regions

In order to facilitate the analysis of China's domestic trade in virtual water, this paper refers to Deng et al. (2016) and further divides the 31 provinces into eight regions. The division of specific regions is shown in Fig. 3.

It should be noted that the virtual water trade between provinces in the same region has been internalized into the virtual water consumption in each region. The research on the inter-regional virtual water trade will not analyze the trade between different provinces of the same region, such as Beijing and Tianjin in the Beijing-Tianjin region.

This paper first analyzes the volume of virtual water outflow and inflow in the three major value chains in China's eight major regions in 2012 and 2015. The detailed results are shown in Table 1 and Table 2:

For most regions, the virtual water trade volume on the complex value chain is bigger than in the other two value chains, the virtual water trade volume on the traditional value chain takes the second place and the virtual water trade volume on the simple value

Fig.3.Theeight regions of China

Fig. 3. The eight regions of China.

chain is the smallest. Compared with 2012, the value in 2015 is greater. With the further refinement of China's industrial division of labor, different processes of production of a product will be carried out between different regions, and there will be a large number of inter-regional intermediate and final product trades, so that the trade volume of products in the complex value chain is the largest. The virtual water trade volume in the traditional value chain is larger than that in the simple value chain. The main reason is that the trade volume of products used for the final use part of each region is larger than that used for the intermediate use part. With the economic development in China, transportation facilities have been more convenient and the trade sum of regional products has increased. Therefore, compared with 2012, the virtual water trade volume in most regions in 2015 is larger.

Since China's domestic trade is a closed loop, the virtual water transferred-out from area r to area S is equal to the virtual water inflow volume from area r to area r, so the total value of the virtual water transferred-out in each area is equal to the virtual water inflow in each area, which means that the sum of virtual water net transferred-out volume of each area is equal to 0.

Table 1. The volume of virtual water outflow and inflow in the three value chains of China's eight major regions in 2012 (unit: billion cubic meters).

Regions	The traditional value chain		The simple value chain		The complex value chain		Total		
	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Net Outflows
Beijing-Tianjin	0.70	4.20	0.42	2.40	1.10	7.16	2.22	13.76	-11.54
Northeast	6.07	2.14	4.81	2.86	15.05	6.22	25.93	11.22	14.71
Northern coastal	1.99	4.05	1.79	7.46	7.06	7.68	10.84	19.18	-8.34
Eastern coastal	3.54	9.73	3.21	6.45	10.29	18.51	17.04	34.69	-17.65
Central	9.12	5.14	7.96	5.82	22.04	13.74	39.12	24.69	14.43
Southern coastal	3.43	7.70	3.19	5.55	5.93	15.76	12.55	29.01	-16.46
Southwest	5.10	4.73	4.74	3.26	10.14	11.65	19.98	19.64	0.35
Northwest	10.65	2.90	10.14	2.48	17.66	8.56	38.45	13.94	24.51
Total	40.59	40.59	36.27	36.27	89.27	89.27	166.13	166.13	0.00

Table 2. The volume of virtual water outflow and inflowin the three value chains of China's eight major regions in 2015 (unit: billion cubic meters).

Regions	The traditional value chain		The simple value chain		The complex value chain		Total		
	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Net Outflows
Beijing-Tianjin	0.48	4.29	0.31	3.32	0.87	12.28	1.66	19.89	-18.23
Northeast	9.45	2.06	7.88	1.96	20.96	8.21	38.30	12.22	26.07
Northern coastal	2.59	3.73	2.27	7.96	11.62	7.90	16.48	19.59	-3.11
Eastern coastal	4.51	11.06	3.95	5.82	13.29	23.59	21.75	40.47	-18.72
Central	9.86	7.45	7.85	10.56	29.90	23.18	47.61	41.19	6.43
Southern coastal	2.55	11.09	2.60	6.98	7.14	22.25	12.30	40.32	-28.02
Southwest	5.89	6.22	5.11	4.29	13.81	19.18	24.80	29.70	-4.90
Northwest	13.66	3.11	13.21	2.28	29.33	10.32	56.20	15.71	40.49
Total	48.99	48.99	43.18	43.18	126.92	126.92	219.10	219.10	0.00

For example, in 2015, the sum of virtual water transferred-out and virtual water inflow in the three value chains in China's eight major regions were both 219.10 billion m^3.

From the perspective of the virtual water net transferred-out volume in the three value chains in the eight major regions, both in 2012 and 2015, the volume to the virtual water net transferred-out in Beijing-Tianjin region, the northern coastal region, the eastern coastal region and the southern coastal region is negative that is, there is positive virtual water inflow volume; there is virtual water net transferred-out in the northeast region,the central region and the northwest region. It should be noted that China's virtual water trade situation is inconsistent with China's water resources distribution. For example, there is a shortage of water resources in the northwest region, but there remains virtual water net outflow; the eastern and southern coastal regions have abundant water resources, but there remains virtual water net inflow. The reason for this phenomenon is explained in details in the discussion part of this paper.

From the total value of the three value chains, the central region had more virtual water inflow than other regions in 2012 (39.12 billion m^3), while in 2015 the northwest region had the largest amount of virtual water outflow (56.20 billion m^3); both in 2012 and 2015, the eastern coastal region had the largest amount of virtual water inflow (34.69 billion m^3 and 41.19 billion m^3 respectively). The large amount of virtual water outflow to northwest China is mainly due to the fact that in this vast region there are more provinces than in other regions, there are more sorts of products produced there, and the region has a relatively small population and low consumption, so the virtual water outflow to other regions is relatively big. The central region also has relatively more provinces, produces more types of products and more agricultural products, such as rice, are transferred to other regions in the country, so the amount of virtual water transferred-out is also large. The eastern coastal region has a dense population, especially in Shanghai, where agricultural products such as grain cannot be self-sufficient, food and other agricultural products that consume more water during the production need to be acquired from other regions, so the amount of virtual water inflow is relatively large.

Furthermore, this paper takes the Beijing-Tianjin region as an example to analyze the virtual water outflow volume from this region to the other seven regions and the virtual water inflow volume from the other seven regions. The detailed results are shown in Table 3 and Table 4:

In Table 3 and Table 4, it can be found that: (1) in 2012 and 2015, the Beijing-Tianjin region had virtual water inflow from other regions, and compared with 2012, the virtual water inflow volume increased in 2015. (2) From the perspective of the sum of the three value chains, the Beijing-Tianjin region had more virtual water outflow to the central region than to other regions in 2012 and 2015 (0.45 billion m^3 and 0.39 billion m^3 respectively). In 2012, a big part of the virtual water inflow of Beijing-Tianjin region was from the northwest region (3.33 billion m^3). In 2015, most of the virtual water inflow was from the central region (4.86 billion m^3). (6) From the perspective of the total value of inflow volume and outflow volume, compared with 2012, the virtual water outflow to other regions in the three value chains in the Beijing-Tianjin region decreased in 2015, but the virtual water inflow from other regions increased in volume. The explanation of the above phenomenon is similar to the explanation of the results in Table 1 and Table 2, so it will not be repeated here.

Finally, this paper further takes the total value of the three items in formula (13) (that is, the sum of the

Table 3. The virtual water trade volume between the Beijing-Tianjin region and the other seven regions in 2012 (unit: billion m³).

Regions	The traditional value chain		The simple value chain		The complex value chain		Total		
	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Net Outflows
Northeast	0.05	0.57	0.04	0.28	0.09	1.11	0.17	1.97	-1.79
Northern coastal	0.11	0.32	0.10	0.20	0.14	0.77	0.35	1.28	-0.93
Eastern coastal	0.14	0.32	0.07	0.26	0.22	0.83	0.43	1.41	-0.98
Central	0.13	0.89	0.09	0.53	0.23	1.74	0.45	3.17	-2.71
Southern coastal	0.10	0.36	0.05	0.22	0.15	0.46	0.30	1.04	-0.74
Southwest	0.09	0.52	0.04	0.28	0.14	0.77	0.26	1.57	-1.31
Northwest	0.08	1.22	0.04	0.63	0.13	1.48	0.25	3.33	-3.08
Total	0.70	4.20	0.42	2.40	1.10	7.16	2.22	13.76	-11.54

Table 4. The virtual water trade volume between the Beijing-Tianjin region and the other seven regions in 2015 (unit: billion m³).

Regions	The traditional value chain		The simple value chain		The complex value chain		Total		
	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Net Outflows
Northeast	0.02	0.77	0.02	0.51	0.06	1.79	0.10	3.08	-2.98
Northern coastal	0.04	0.22	0.04	0.20	0.05	1.15	0.13	1.57	-1.44
Eastern coastal	0.09	0.47	0.05	0.38	0.17	1.55	0.31	2.40	-2.08
Central	0.09	0.97	0.09	0.69	0.21	3.20	0.39	4.86	-4.46
Southern coastal	0.11	0.28	0.05	0.30	0.16	0.77	0.32	1.35	-1.03
Southwest	0.07	0.50	0.04	0.34	0.13	1.24	0.25	2.09	-1.84
Northwest	0.05	1.07	0.02	0.91	0.08	2.58	0.15	4.55	-4.41
Total	0.48	4.29	0.31	3.32	0.87	12.28	1.66	19.89	-18.23

virtual water trade on the traditional domestic trade value chain, the simple domestic trade value chain, and the complex domestic value chain) as an example to analyze the virtual water trade in the eight regions. The results are demonstrated in Table 5 and Table 6:

Since each region produces more than one product, and even if it is the same product, different processes may be carried out in different regions, so the product outflow volume and inflow volume between the two regions may be relatively large, which will lead to

Table 5. Virtual water trade volume among the eight major regions in 2012 (unit: billion m³).

Regions	Beijing-Tianjin	Northeast	Northern coastal	Eastern coastal	Central	Southern coastal	Southwest	Northwest
Beijing-Tianjin	0.00	0.17	0.35	0.43	0.45	0.30	0.26	0.25
Northeast	1.97	0.00	2.40	6.19	4.49	5.28	3.30	2.30
Northern coastal	1.28	1.03	0.00	1.03	2.45	2.02	1.62	1.42
Eastern coastal	1.41	1.70	1.69	0.00	4.20	2.84	2.84	2.36
Central	3.17	2.91	4.79	11.14	0.00	7.62	5.36	4.13
Southern coastal	1.04	1.20	1.69	2.59	2.52	0.00	1.98	1.52
Southwest	1.57	1.48	2.50	4.64	3.76	4.08	0.00	1.96
Northwest	3.33	2.72	5.75	8.67	6.82	6.87	4.28	0.00

Table 6. Virtual water trade volume among the eight major regions in 2015 (unit: billion m^3).

Regions	Beijing-Tianjin	Northeast	Northern coastal	Eastern coastal	Central	Southern coastal	Southwest	Northwest
Beijing-Tianjin	0.00	0.10	0.13	0.31	0.39	0.32	0.25	0.15
Northeast	3.08	0.00	3.86	7.57	8.67	7.32	4.80	3.00
Northern coastal	1.57	1.37	0.00	2.82	3.81	2.51	2.72	1.68
Eastern coastal	2.40	1.81	1.63	0.00	6.10	3.70	3.70	2.41
Central	4.86	3.77	3.77	11.23	0.00	10.11	8.71	5.16
Southern coastal	1.35	0.96	1.16	2.11	2.83	0.00	2.60	1.30
Southwest	2.09	1.46	2.37	5.26	6.20	5.39	0.00	2.03
Northwest	4.55	2.76	6.65	11.17	13.19	10.96	6.92	0.00

a large amount of virtual water inflow and outflow between the two regions, such as the southern coastal region and the eastern coastal region. In addition, the diagonal elements in Table 5 and Table 6 are all 0, which is because it has been decided that there will be no virtual water trade within a single region.

Further Discussion

Different from the existing literature on virtual water trade calculation [11], this paper calculates the virtual water trade in 31 provinces and eight regions in China based on the perspective of value-added trade, starting from three different value chains: the traditional value chain, the simple value chain and the complex value chain. Most of the traditional virtual water trade calculation actually only calculates the virtual water trade in the traditional value chain (there are certain differences in the calculation methods of different literature), and ignores the virtual water trade in the simple value chain and the complex value chain. Therefore, there is a big difference from the calculating results of the virtual water trade in the three value chains from the perspective of value-added trade.

The path decomposition of virtual water consumption and virtual water trade in this paper is different from the structural decomposition analysis in the existing literature [11]. In this paper, the virtual water trade between two regions in the same year is classified into traditional value chain, simple value chain and complex value chain according to the value chain form. Deng et al. [11] did a structural decomposition analysis of the changes in virtual water trade between regions in different years.

Similar to the results of the existing literature [25-26], the research in this paper also finds that there is not necessarily virtual water net outflow in water-deficient areas (for example, the northwest region in Table 1 and Table 2), there is not necessarily virtual water inflow in areas with abundant water resources for example, the eastern coastal area in Table 1 and Table 2. The main reason for this phenomenon is that some products, such as agricultural products, consume not only water resources but also require input of various elements such as capital, labor, and land. Besides the production aspect, the consumption aspect also needs to be considered. If the local population is large and the consumption demand is big, even if the output of locally produced products is large, it still could not meet the local demand. Therefore, it is necessary to acquire products from other regions, along with the virtual water inflow, of course.

It should be noted that due to the lack of statistical data on the water consumption of various industries, this paper estimates the data on water consumption in the various industries in each province of China. According to formula (11), it is possible to calculate the virtual water of various industries in Chinese provinces and industries in different paths; according to formula (13), it is possible to calculate the virtual water trade volume of various industries between various regions in China. Since the water consumption data of each industry in each province is estimated data, this paper does not further analyze the virtual water trade from the industry level. In addition, due to the lack of statistical data on green water and gray water in various provinces and industries in China, this paper only studies the virtual water of blue water in different paths in various provinces in China, and the virtual water trade volume of blue water between various regions in China.

Conclusions and Implications

From the perspective of value-added trade, this paper uses an input-output model to decompose the use of water resources in Chinese provinces in five major paths, and calculates the virtual water trade among the eight major regions. The research finds that: (1) In 2012 and 2015, most provinces' water resources were implicitly used in final products to meet local demand for final products; the water resources implicitly transferred to other regions, both in the final product to meet the final product demand in other regions and in the intermediate products to be out into production to meet the consumption needs of other regions, has a relatively low proportion. What is more, there is a relatively high proportion of water resources implicitly transferred to other regions in intermediate products and later returned to the originative region in final products to meet the consumption needs in this region. And the volume of virtual water trade in the complex domestic value chain is larger than that in the traditional domestic trade value chain and the simple domestic trade value chain. (2) Both in 2012 and 2015, there were virtual water net inflows to Beijing-Tianjin region, the northern coastal region, the eastern coastal region and the southern coastal region. While there were virtual water net outflows from the northeast region, the central region and the northwest region. In 2012, there were virtual water net outflows in the southwest region, but net inflows in 2015.

Based on the analysis mentioned above, the following inspirations on policy could be obtained: (1) In order to alleviate the problem of water supply-demand imbalance, the government of China needs to further promote virtual water trade. At the present stage, the situation on virtual water trade is inconsistent with the situation on the distribution of water resources in China. In particular, although there is serious water shortage in the northwest region, there is still a large amount of virtual water net outflow in this area. Therefore, the northwest region under the principle of making-ends-meet should try to reduce the production of products that consume a large amount of water, and appropriately control the amount of virtual water outflow to other regions in the country. (2) Since water consumption in agriculture is much bigger than that in the second and the third industries, it's necessary to increase investment in new technologies and new products to produce high value-added products, develop modern service industries, and promote the industrial structure up gradation. (3) When the water supply amount is certain, improving the efficiency of water use is also an important measure to alleviate the water supply-demand imbalance. Therefore, it's necessary to increase investment in water-saving irrigation technology such as sprinkler irrigation and drip irrigation in according with local conditions of each province. (4) The Chinese government needs to further formulate and improve water conservation policies and regulations, strengthen the publicity of the water-saving policy, cultivate the citizens' awareness of water saving and build a water resources safety guarantee system with Chinese characteristics. (5) Due to the enormous differences in the volume of virtual water trade in different value chains, Chinese provinces should not only focus on virtual water trade in traditional value chains, but also need to pay attention to virtual water trade in simple value chain and complex value chain. This will help the government correctly recognize the role of each province (region) in the use and management of water resources, and clarify their rights and obligations.

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Conflict of Interest

The authors declare no conflict of interest.

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