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Research on the Measurement and Influencing Factors of Implicit Water Resources in Import and Export Trade from the Perspective of Global Value Chains

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Abstract: In this study, China's virtual water trade was measured on the basis of multi-region input/output tables, and its influencing factors of change were decomposed. The results revealed that virtual water export and import increased from 161.5 billion tons and 114.07 billion tons in 2007 to 193.31 billion tons and 157.1 billion tons in 2014, respectively. Eight economies accounted for more than 50% of China's total virtual water export and import, whereby the total of the United States, Japan, and Europe reached 44% (export) and 31.3% (import). The export scale, export of intermediate products, export industry structure, domestic water consumption coefficient, and domestic intermediate input structure were the main factors of the change in virtual water export. The growth of export scale was the primary reason for the growth of virtual water export. A decline in the domestic water consumption coefficient was the primary reason for the restrained growth of virtual water export. The import scale, import of intermediate products, import industry structure, water consumption coefficient of foreign countries, and the correlation among domestic industries were the main factors affecting the change in virtual water import. The growth of import scale was the primary reason for the growth of virtual water import in most sectors. A decline in the water consumption coefficient abroad was the primary reason for the restrained growth of virtual water import.

Keywords: virtual water; global value chain; input/output model; structural decomposition

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1. Introduction

Since Tony Allan put forward the concept of "virtual water" (VW) at a SOAS (School of Oriental and African Studies) seminar in the 1990s, research on virtual water issues, including virtual water calculations, has received increasing attention from scholars and governments, leading to the development of a reasonable virtual water strategy. This strategy can effectively improve the allocation and utilization of water resources, promote the balance of cross-border water use, and alleviate the difficulties in areas facing water shortage [1]. In recent decades, the depth and breadth of China's participation in the international division of labor and international trade has continuously expanded [2]. While trade has continued to grow rapidly, it has also brought about a large amount of resource consumption. Therefore, an accurate calculation and analysis of the water consumption implied by import and export trade, as well as its influencing factors, can provide a strong basis and guidance for the formulation of virtual water strategies [3]. The issue of implied virtual water in foreign trade has received increasing attention by scholars at home and abroad. Below, we elucidate the calculation of trade volume, the calculation of trade hidden content, and the decomposition of influencing factors.

First, in terms of trade volume measurement, with the continuous extension of production chains and the rapid development of trade in intermediate products, trade economists and policymakers have reached the consensus that traditional trade statistics based on gross trade value have serious shortcomings and can no longer reflect the current actual situation of international trade based on global value chains (GVC), under which trade statistics based on "value added" are becoming increasingly important [4]. Wang et al. (2015) combed the previous relevant research, decomposed and analyzed the total trade flow, sectoral trade flow, bilateral trade flow, and bilateral sectoral trade flow, and outlined the relationship between the "traditional trade" statistical system and the "value-added trade" statistical system. Following the research of Koopman et al. [5] and Wang et al. [4], some scholars studied the added value of the trade process under the background of GVC [2,3,5–7]. The research of Koopman et al. and Wang et al. has received extensive attention from scholars. However, outside of the fields of macroeconomics and sectoral economics, research on virtual water is somewhat lacking; this study aims to fill some of these gaps.

Second, in terms of virtual water trade measurement, in 1974, the concept of "implied flow" was put forward by scholars for the first time. "Virtual water" (VW) is the derivative of "embodied flow", i.e., the total amount of water resources consumed to complete the production of products and services in the whole value chain process. At present, scholars mainly use two methods to measure the virtual water volume: (1) "bottom-up" product life-cycle measurement [8–10], and (2) "top-down" input/output analysis (IOA). The bottom-up method is more suitable for the measurement of fine commodities, while the input/output method is more suitable for the overall measurement of a whole country or region [11]. Input/output analysis (IOA) was put forward by American scholar Leontief in 1936. Leontief used this method to study the relationships between various industries in the United States, and he predicted and analyzed the steel demand in 1950. Since then, many scholars have adopted this method to study the macroeconomic field, and its application has been extended to the field of resources and environment [12]. It has undergone several modifications, such as the single-region competitive input/output model, single-region noncompetitive (import) input/output model, bilateral trade input/output model, and multi-region input/output model. Some scholars have applied this method to the study of virtual water trade [13–18]. In recent years, some scholars have tried to measure and analyze the implied emissions and resource consumption in the trade process from the perspective of global value chains [19–23]. At present, no study has measured virtual water trade in combination with the whole process of value chains.

Third, in terms of the decomposition of influencing factors, at present, structural decomposition analysis (SDA) and exponential decomposition analysis (IDA) are the main methods used by scholars to decompose and analyze the influencing factors of implicit flow change. Zhang [24] used this model to measure SO_2 emission and decompose the influencing factors of its change. This method has been continuously adopted by scholars in research [11,25–29]. Compared with IDA, SDA is rich in explanation factors, but it still cannot overcome the problem of the deviation of results and residual terms caused by decomposition; thus, scholars have tried various methods to deal with this problem, e.g., the logarithmic mean Divisia index (LMDI) decomposition method proposed by Ang [30] and the two-level average division method proposed by Dietzenbacher and Los [31], which has been widely adopted in recent years [20,32,33]. However, these adjustments still cannot eliminate the problem of the decomposition results deviating from the true values [34,35].

Dietzenbacher and Los [31] showed that, when R factors jointly determine the change in a variable, different decomposition forms can be obtained by analyzing the influence degree of these factors, all of which should be considered comprehensively (that is, the average value of all these forms should be used as the decomposition result). Zhang [24] adopted this method in his research, while also pointing out that the calculation complexity of this method is too large when there are many influencing factors. Albrecht et al. [35], on the basis of the concept of the Shapley value, proposed and used Shapley decomposition in their research, and they adopted the method of hierarchical decomposition to obtain accurate values and effectively reduce the amount of calculation.

To sum up, this paper expands the field of virtual water on the basis of existing research as follows: (1) using the value-added decomposition analysis method based on global value chains as a reference, this paper constructs the "whole process measurement model" of virtual water trade, and the calculation and decomposition are carried out considering the overall and sub-sectoral aspects, making the results more detailed and reasonable; (2) Shapley decomposition is used to eliminate the large deviation and residual term of decomposition results.

2. Materials and Methods

2.1. Data Sources and Processing

The data in this paper came from the WIOD database funded by the European Union. The data released by the database in 2013 included the data of 41 countries (regions) from 1995 to 2011, and the industries were classified into 35 categories. The data released in 2016 included the data of 44 countries from 2000 to 2014, and the industries were subdivided into 56 categories. Firstly, this paper adjusted the industry integration into 35 categories, of which 33 were actually studied due to a lack of data in department 19 (sales and maintenance of motor vehicles and motorcycles, fuel retail) and department 35 (domestic service industry). Due to space limitations, we selected the years before and after the 2008 global financial crisis and the latest 2014 data results for analysis. This selection allowed for clear reflection on the changing characteristics of world trade, as well as the true trade situation of hidden water resources from the perspective of global value chains.

2.2. MRIO Model

Assuming that the economic system includes M countries (regions) and each country has N industries, the MRIO model of the economic system can be expressed as follows:

$$X^M = A^M X^M + Y^M \quad (1)$$

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mm} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_m \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1} & A_{m2} & \cdots & A_{mm} \end{bmatrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{bmatrix} + \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1m} \\ y_{21} & y_{22} & \cdots & y_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mm} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{bmatrix} = \begin{bmatrix} I-A_{11} & -A_{12} & \cdots & -A_{1m} \\ -A_{21} & I-A_{22} & \cdots & -A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{m1} & -A_{m2} & \cdots & I-A_{mm} \end{bmatrix}^{-1} \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1m} \\ y_{21} & y_{22} & \cdots & y_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mm} \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} I-A_{11} & -A_{12} & \cdots & -A_{1m} \\ -A_{21} & I-A_{22} & \cdots & -A_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{m1} & -A_{m2} & \cdots & I-A_{mm} \end{bmatrix}^{-1} = \left(I - A^M\right)^{-1} = B^M \quad (5)$$

Here,A^M is the direct consumption matrix of order $MN \times MN$, and A_{ij} represents the direct consumption of the total output of each industry unit in economy j to the output of each industry in economy i.

B^M is the order complete demand matrix $MN \times MN$, and B_{ij} represents the complete demand of one unit of final products produced by each industry in economy j for the output of each industry in economy i.

X^M is the total output matrix of $MN \times M$ order, and X_i is the matrix of $N \times 1$ order, which represents the total output of various industries in economy i; X_{ij} is a matrix of order $N \times 1$, which represents the part of the total output of economy i used to provide the final product demand of economy j.

Y^M is the final demand matrix of $MN \times M$ order, and Y_i is the matrix of $N \times 1$ order, which represents the final global demand for various industries in economy i; Y_{ij} is a matrix of order $N \times 1$, which represents the final demand of various industries in economy j for economy i.

2.3. Calculation of Implied Virtual Water Volume in Value-Added Trade

$E_g B_{gg} \sum_{i \neq g}^{M} y_{gi}$ represents the implied virtual water of final product export, $E_g B_{gg} \sum_{i=k}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki}$ represents the implied virtual water of direct export of intermediate products, $E_g B_{gg} \sum_{i \neq k}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki}$ represents the implied virtual water of indirect export of intermediate products, $E_g B_{gg} \sum_{k \neq g}^{M} A_{gk} x_{kg}$ represents the implied virtual water of imported products after processing, and $\sum_{i \neq g}^{M} \sum_{k \neq i}^{M} E_i B_{ii} B_{kg} A_{ik} x_{kg}$ represents the hidden virtual water of foreign value-added products. ${VW_g}^{PDC}$ represents the repeated calculation of virtual water factors. Among them, items $E_g B_{gg} \sum_{i \neq g}^{M} y_{gi}$, $E_g B_{gg} \sum_{i=k}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki}$, and $E_g B_{gg} \sum_{i \neq k}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki}$ represent the implied virtual water volume of export with added value.

$$\begin{aligned} {VW_g}^{EX} = {} & E_g B_{gg} \sum_{i \neq g}^{M} y_{gi} + E_g B_{gg} \sum_{i=k,}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki} + E_g B_{gg} \sum_{i \neq k,}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki} \\ & + E_g B_{gg} \sum_{k \neq g}^{M} A_{gk} x_{kg} + \sum_{i \neq g}^{M} \sum_{k \neq i}^{M} E_i B_{ii} B_{kg} A_{ik} x_{kg} + {VW_g}^{PDC} \end{aligned} \quad (6)$$

where ${VW_g}^{EX}$ represents the implied virtual water in the total export of country g, and E_g represents the $1 \times N$ line vector of the virtual water consumption coefficient of various departments in country g.

2.4. SDA Decomposition Analysis

A^M can be decomposed into five parts: A^*_{gd} (domestic intermediate input/output structure effects), A^*_{gi} (intermediate product export effects), A^*_{ig} (intermediate product import effects), A^*_{-gd} (other domestic intermediate input/output structure effects), and A^*_{ij} (other country industry correlation effects).

ΔVW_g^{EX} represents the change in the implied virtual water export of country g in period t compared to period 0 (base period). According to the structural decomposition analysis method, the change in ΔVW_g^{EX} can be decomposed into the effect of the water consumption coefficient ΔE^* (representing the change in E^M when other factors remain unchanged; the same applies to the other effects), the input/output structure effect ΔB^*, and the final demand effect ΔY^*. Among them, the water consumption coefficient effect ΔE^* can be decomposed into the following two items: $\Delta E_g{}^*$ (domestic water consumption intensity effect) and $\Delta E_{-g}{}^*$(foreign water consumption intensity effect). The input/output structural effect ΔB^* can be decomposed into the following five items:ΔA^*_{gd}, ΔA^*_{gi},ΔA^*_{ig}, ΔA^*_{-gd}, and ΔA^*_{ij}. The final demand effect ΔY^* can be decomposed into the following three scale effects:ΔY^*_{gs} (domestic scale, foreign scale, and export scale), industry structure effect ΔY^*_{gi} (domestic structure, foreign structure, and export industry structure), and export regional structure effect ΔY^*_{gf}.

$$VW_{\mathrm{gvax}}{}^{EX} = E_g B_{gg} \sum_{i \neq g}^{M} y_{gi} + E_g B_{gg} \sum_{i=k,}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki} + E_g B_{gg} \sum_{i \neq k,}^{M} \sum_{k \neq g, i \neq g}^{M} A_{gk} x_{ki} \quad (7)$$

where $VW_{\mathrm{gvax}}{}^{EX}$ is the implied virtual water in the value-added export of country g. According to the relationship of A^M and B^M with X^M and Y^M in the aforementioned MRIO model, $VW_{\mathrm{gvax}}{}^{EX}$ can be expressed as follows:

$$VW_{\mathrm{gvax}}{}^{EX} = f(E^M, B^M, Y^M) \quad (8)$$

$$\begin{aligned} \Delta VW_{\mathrm{gvax}}{}^{EX} &= \Delta VW_{\mathrm{gvax}}{}^{EX}{}_t - \Delta VW_{\mathrm{gvax}}{}^{EX}{}_0 \\ &= f(E^M{}_t, B^M{}_t, Y^M{}_t) - f(E^M{}_0, B^M{}_0, Y^M{}_0) \end{aligned} \quad (9)$$

$$\Delta B^* = B^M{}_t - B^M{}_0 = B^M{}_t \Delta A^M B^M{}_0 \quad (10)$$

2.5. Application of Shapley Decomposition Method

In this paper, the Shapley method was used to deal with the decomposition process, and the above hierarchical decomposition method was used to reduce the amount of calculation, as expressed below.

$$x_i = \sum_{S \subseteq N} w(|s|)[v(s) - v(s/i),\ i = 1, 2,\ \ldots\ n] \quad (11)$$

$$w(|s|) = \frac{(n - |s|)!(|s| - 1)!}{n!} \quad (12)$$

where A is the Shapley value of the ith influencing factor, N is the set of all influencing factors, $n = |N|$ is the number of influencing factors, s is the set including the ith influencing factor, $S = |s|$ indicates the number of influencing factors in set s, $v(s)$ is the total value of set s, and $v(s \backslash i)$ is the total value of set s not considering the ith influencing factor.

3. Results

3.1. Consumption of Virtual Water Resources in Value-Added Trade and Its Regional Structure

As shown in Figure 1, in 2007, 2010, and 2014, the export VWEX (and its proportion of the total virtual water consumption in the country) was 161.15 billion tons (27.4%), 182.41 billion tons (30.1%), and 193.31 billion tons (26.9%), respectively. Virtual water import VWIM (and the proportion of total virtual water consumption in the country) was 114.07 billion tons (19.4%), 148.96 billion tons (24.6%), and 157.1 billion tons (21.9%), respectively. The net export of VWN (and the proportion of total consumption in the country) was 47.08 billion tons (8%), 33.46 billion tons (5.5%), and 36.22 billion tons (5%), respectively. During the study period, the total export volume and total import volume both showed an increase, but their ratio to the country's total water consumption showed a trend of first increasing and then decreasing. The 3-year export water consumption intensity PEX was 40.6 tons/10,000 USD, 36.3 tons/10,000 USD, and 28.8 tons/10,000 USD, respectively, while the 3-year import water consumption intensity PIM was 35.1 tons/10,000 USD, 31.1 tons/10,000 USD, and 26.6 tons/10,000 USD, respectively. During the study period, the import and export water consumption intensity showed a downward trend, but the export water consumption intensity always remained greater than the import water consumption intensity.

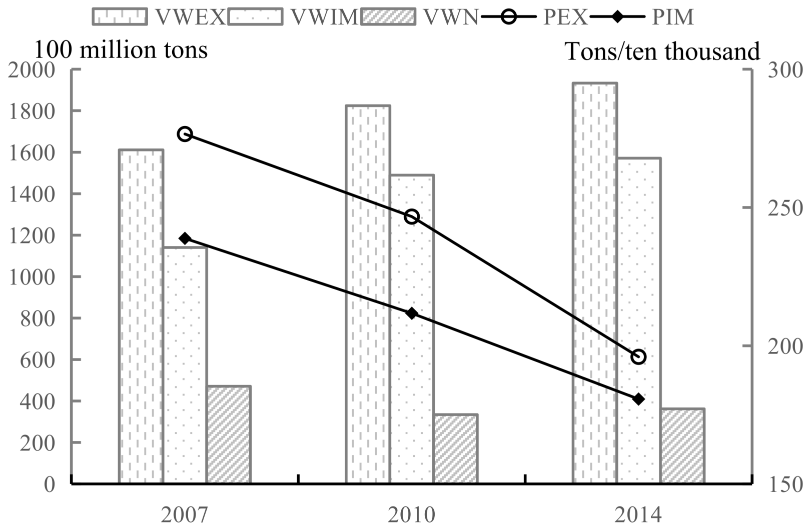

Figure 1. Virtual water content and water consumption coefficient of value-added trade.

As shown in Table 1, during the study period, eight economies, namely, the United States, the European Union, Japan, Russia, South Korea, Taiwan (China), Canada, and Australia, accounted for more than 50% of China's total export and import of virtual water, and these economies were all important trading partners of China, with the combined proportions of the United States, Japan, and Europe reaching 44% (export) and 31.3% (import).

Table 1. Virtual water trade volume and its regional structure (unit: 100 million tons).

Area	2007		2010		2014	
	Export	**Import**	**Import**	**Import**	**Import**	**Import**
Total	1611.5 (27.4%)	1140.7 (19.4%)	1824.1 (30.1%)	1489.6 (24.6%)	1933.1 (26.9%)	1571 (21.9%)
USA	307.3 (19.1%)	82.8 (7.0%)	327.5 (18.0%)	108.9 (7.3%)	326.9 (16.9%)	127.5 (8.1%)
EU	324.9 (20.2%)	132.4 (11.6%)	359.8 (19.7%)	179.7 (12.1%)	350.2 (15.8%)	195.7 (12.5%)
Japan	134.7 (8.4%)	159.8 (14.0%)	139.9 (7.7%)	188.5 (12.7%)	123.3 (6.4%)	130.6 (8.3%)
Russia	37.6 (2.3%)	23.5 (2.1%)	34.2 (1.9%)	27.7 (1.9%)	44.3 (2.3%)	33.4 (2.1%)
Korea	74.1 (4.6%)	123.8 (10.9%)	79.5 (4.4%)	147.6 (9.9%)	82.8 (4.3%)	152.4 (9.7%)
Chinese Taiwan	31.0 (1.9%)	120.5 (10.6%)	34.3 (1.9%)	123.5 (8.3%)	38.2 (2.0%)	121.9 (7.8%)
Canada	25.6 (1.6%)	13.1 (1.1%)	25.7 (1.4%)	15.9 (1.1%)	24.8 (1.3%)	20.2 (1.3%)
Australia	23.8 (1.5%)	30.8 (2.7%)	31.5 (1.7%)	65.2 (4.4%)	32.3 (1.7%)	78.3 (5.0%)
Other	652.5 (40.49%)	454.0 (39.8%)	791.6 (43.4%)	632.6 (42.47%)	955.4 (49.42%)	710.9 (45.25%)

In terms of virtual water export, the total proportion of the eight economies showed a downward trend, from 59.51% in 2007 to 50.58% in 2014. The United States, the European Union, and Japan all displayed significant declines, suggesting that, from the perspective of water consumption, China's export services dependent on these countries declined, with their export target countries showing more diversification. The proportions of South Korea and Canada also showed a slight downward trend, whereas those of Russia, Taiwan (China), and Australia remained basically stable. In terms of virtual water import, the proportions of the United States, the European Union, Australia, and Canada increased, while the proportions of Japan, South Korea, and Taiwan (China) declined. Russia remained basically stable during this period.

3.2. Decomposition of Influencing Factors of Virtual Water Trade Volume Changes

3.2.1. Decomposition of Influencing Factors of Virtual Water Export Changes

Table 2 provides the overall influencing factors of the changes in virtual water export during the study period. The results show that the total virtual water export volume during this period showed an increasing trend. It increased by 21.26 billion tons in 2010 compared to 2007 and by 10.90 billion tons in 2014 compared to 2010. The total growth at the two stages was 32.17 billion tons. Five effects, such as the export of intermediate products, were positive at both stages, increasing the amount of virtual water export. Seven effects, such as the domestic water consumption coefficient, were negative at both stages, inhibiting the increase in virtual water export. Industrial linkages among the other countries, as well as the geographical structure of the outlets, were positive at the first stage, thereby increasing the number of virtual water outlets; however, they were negative at the second stage, thereby restraining the increase in the number of virtual water outlets.

Table 2. Decomposition of factors affecting virtual water export changes from 2007 to 2014 (unit: 100 million tons).

Influencing Factors			2010–2007	2014–2010	2014–2007
Water consumption coefficient effect		Domestic effect	−249.2	−187.8	−437
		Foreign effect	−2.5	−3.5	−6
Input/output structure effect		Structural effects of domestic intermediate inputs	−35.2	−12.1	−47.3
		Intermediate product export effect	92.7	56.2	148.9
		Intermediate goods import effect	1.2	2.3	3.5
		Related effects of other domestic industries	−1.4	−2.4	−3.8
		Industry linkage effects in other countries	3.1	−2.3	0.8
Final demand effect	Scale effect	Export	365.2	247.8	613
		Domestic	−6.2	−5.1	−11.3
		Foreign	8.2	8.1	16.3
	Industry structure effect	Export	20.2	18.1	38.3
		Domestic	−1.1	−2.1	−3.2
		Foreign	−2.1	−3.3	−5.4
	Export geographic structure effect		11.2	−11.9	−0.7
Total changes in virtual water export			212.6	109.0	321.7

Growth of the export scale was the primary reason for the increase in virtual water export, and its influence effect was 61.3 billion tons, corresponding to the continuous growth of China's foreign trade export during the study period. The second major factor leading to the growth of virtual water export was the export effect of intermediate products (forward correlation effect with other countries), which brought about a virtual water export growth of 14.89 billion tons, which also corresponds to the change in the proportion of intermediate products in China's export trade. In addition, the export industry structure also increased the export volume of virtual water to a certain extent, with an impact value of 3.83 billion tons. The decline in the domestic water consumption coefficient was the primary reason for the restrained increase in virtual water export, and its impact was −43.7 billion tons, which shows that China made great achievements in water resource utilization efficiency from a staged perspective. The intensity of this impact declined, indicating the difficulty in continuously improving water use efficiency. The second major factor inhibiting the growth of virtual water export was the structural effect of domestic intermediate input, with an impact value of −4.73 billion tons, indicating that its structure during this period showed a "water-saving" trend, which also corresponds to the level of agricultural products. The proportion of water-consuming products in the intermediate input declined.

To sum up, export scale, intermediate product export, the export industry structure, the domestic water consumption coefficient, and the domestic intermediate input structure were the main influencing factors of virtual water export change, with a total impact value of 31.59 billion tons (within 5% of the total change). Figures 2 and 3 show the decomposition of influencing factors with respect to the change in virtual water export across different departments in 2007–2010 and 2010–2014, respectively. The above five factors were extracted in this paper. At the first stage (2007–2010), only the virtual water export of departments 3 and 12 decreased, whereas, at the second stage (2010–2014), only the virtual water export of departments 1, 3, 9, and 22 decreased, while the virtual water export of other departments increased. The export scale growth was the primary reason for the virtual water export growth of most departments. At the first stage, the export effect of intermediate products of all departments was positive. At the second stage, the export effect of intermediate products in four departments was negative. The total effects of the export industry structure at the two stages were positive (2.02 billion tons and 1.81 billion tons, respectively), but there were large differences across departments. The domestic water consumption coefficient was the primary reason for the restrained growth of virtual water export, and the impact benefits of all departments at the two stages were negative (−24.92 billion tons and −18.78 billion tons, respectively), indicating that the measures to improve the utilization efficiency of water resources have achieved tangible results during this period. The total impact value of domestic intermediate input structure at the two stages was also negative (−3.52 billion tons and −1.21 billion tons, respectively), indicating that the domestic intermediate input structure had a "water-saving" trend during this period.

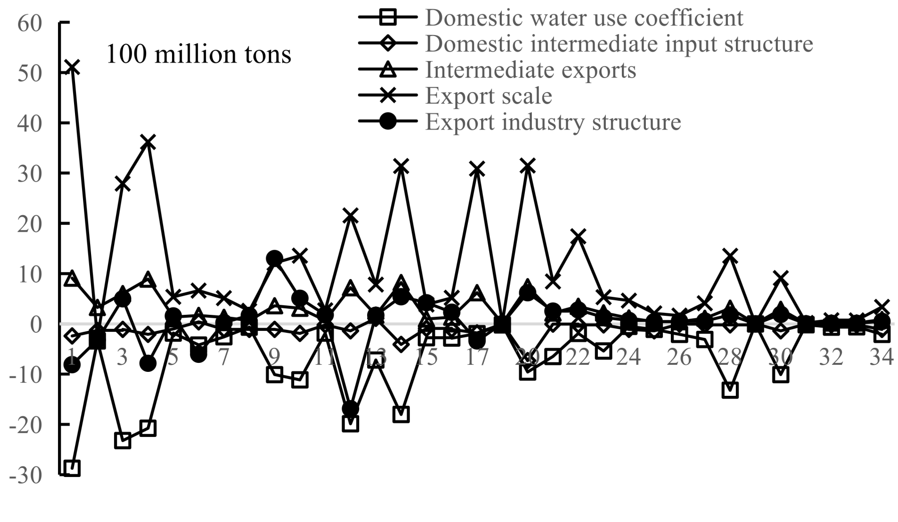

Figure 2. Decomposition of factors affecting virtual water export by sector in 2010 compared with 2007.

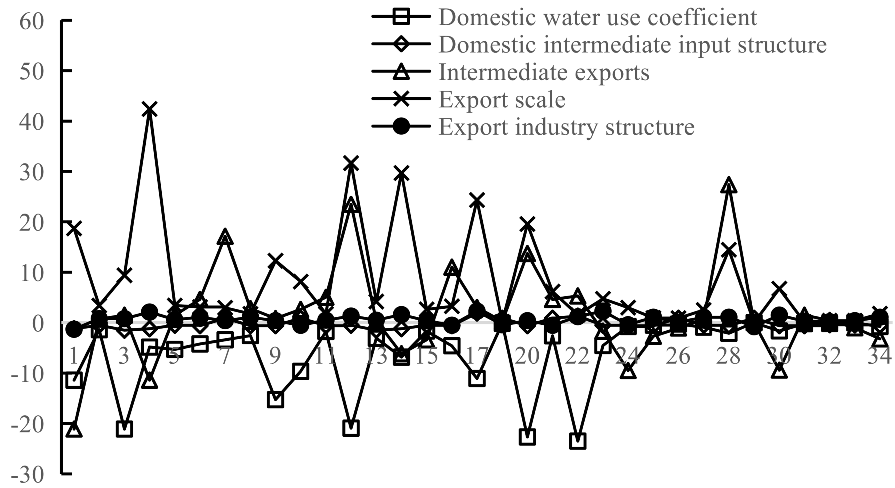

Figure 3. Decomposition of factors affecting virtual water export by sector in 2014 compared with 2010.

3.2.2. Decomposition of Influencing Factors of Virtual Water Import Change

Table 3 provides the overall influencing factors of the changes in virtual water import during the study period. The results show that, during this period, the virtual water import showed an increasing trend. In 2010, it increased by 34.89 billion tons compared to 2007, and, in 2014, it increased by 8.14 billion tons compared to 2010. The total growth of the two phases was 43.03 billion tons. The four effects of intermediate product export were positive at both stages, increasing the amount of virtual water import. Five effects, such as the domestic water consumption coefficient, were negative at both stages, inhibiting the increase in virtual water import. Other domestic industries showed reversed impact values of the five effects at the two stages, whereby they were positive at one stage, thereby increasing the amount of virtual water import, while they were negative at the other stage, thereby inhibiting the increase in virtual water import.

Table 3. Decomposition of influencing factors of changes in virtual water import from 2007 to 2014 (unit: 100 million tons).

Influencing Factors			2010–2007	2014–2010	2014–2007
Water consumption coefficient effect		Domestic effect	−1.2	−1.1	−2.3
		Foreign effect	−268.6	−204.3	−472.9
Input/output structure effect		Structural effects of domestic intermediate inputs	2.3	−3.8	−1.5
		Intermediate product export effect	4.5	15.6	20.1
		Intermediate goods import effect	113.2	66.2	179.4
		Related effects of other domestic industries	−25.2	−32.3	−57.5
		Industry linkage effects in other countries	1.2	−6.5	−5.3
Final demand effect	Scale effect	Import	499.1	317.2	816.3
		Domestic	4.1	−3.2	0.9
		Foreign	−2.4	−2.9	−5.3
	Industry structure effect	Import	25.2	16.1	41.3
		Domestic	1.2	−1.9	−0.7
		Foreign	−1.2	−5.3	−6.5
	Import geographic structure effect		0.3	−4.6	−4.3
Total changes in virtual water import			348.9	81.4	430.3

The increase in the scale of import was the primary reason for the increase in virtual water import, and its impact was 81.03 billion tons, which corresponds to the continuous growth of China's foreign trade import during the study period. The second major factor leading to the growth of virtual water import was the import effect of intermediate products. The structure of the import industry had also increased the volume of virtual water import to a certain extent, with an impact value of 4.13 billion tons. The decline in the foreign water consumption coefficient was the primary reason for the restrained increase in virtual water import, while the second largest factor restraining the growth of virtual water export was the structural effect of other domestic intermediate inputs.

To sum up, import scale and other factors were the main influencing factors of virtual water import changes. The total impact value was 43.03 billion tons (within 5% of the total change). Figures 4 and 5 show the decomposition of influencing factors on the change in virtual water import across different departments in 2007–2010 and 2010–2014, respectively. The above five factors were extracted in this paper.

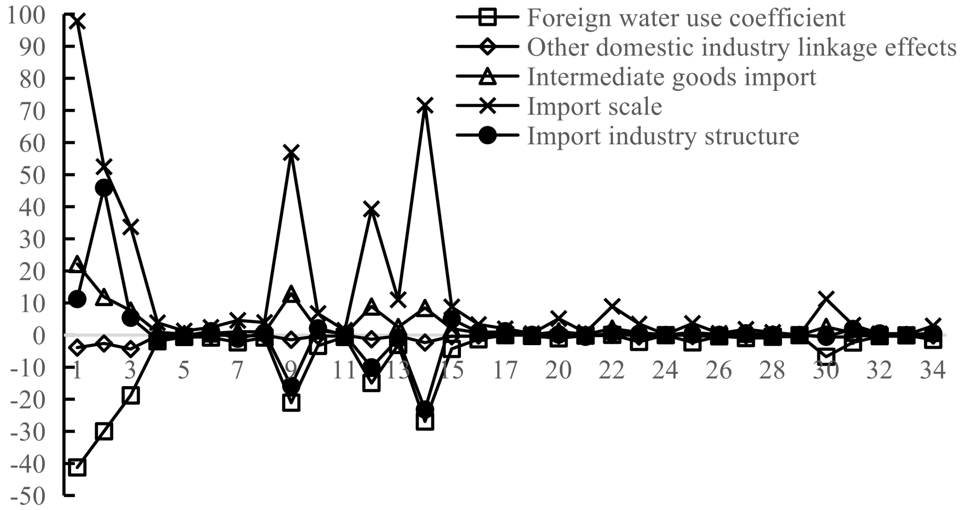

Figure 4. Decomposition of factors affecting virtual water import by sector in 2010 compared to 2007.

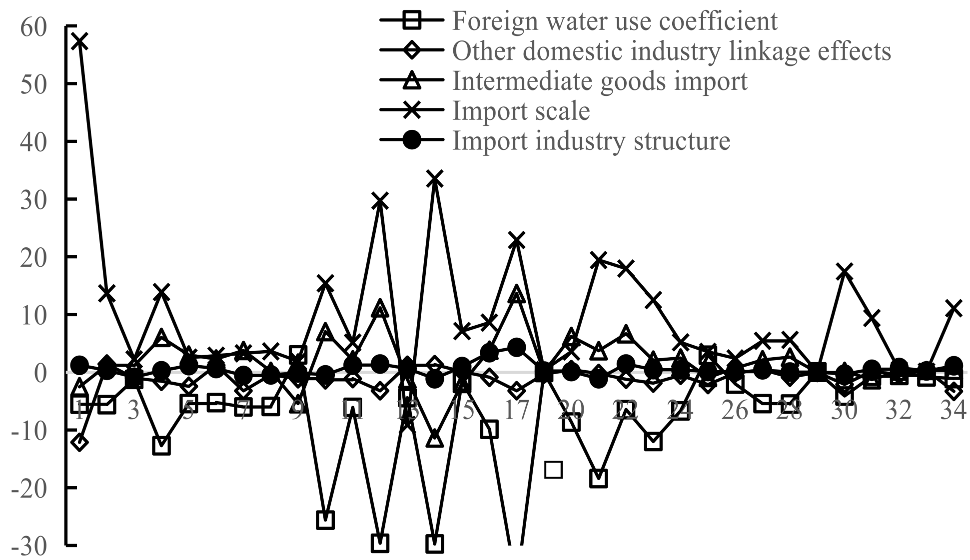

Figure 5. Decomposition of factors affecting virtual water import by sector in 2014 compared to 2010.

At the first stage (2007–2010), the virtual water import of all departments decreased, while, at the second stage (2014–2007), the virtual water import of the five departments decreased, while the virtual water export of other departments increased. The increase in import scale was the primary reason for the increase in virtual water import in most departments. At the first stage, the import effect of intermediate products in all departments was positive. At the second stage, the import effect of intermediate products in six departments was negative, which indicates that the growth rate of the proportion of imported intermediate products at the second stage was lower than that at the first stage. The total effects of the import industry structure at the two stages were positive (2.52 billion tons and 1.61 billion tons, respectively). However, there were large differences across departments. The foreign water consumption coefficient was the primary reason for the restrained growth of virtual water import. At the first stage, only department 22 showed a negative effect, whereas, at the second stage, department 25 (air transportation) and department 9 (chemical and chemical product manufacturing) showed positive effects. This shows that, during this period, the international measures to improve the utilization efficiency of water resources achieved tangible results. The total impact value of the domestic industrial correlation effect at both stages was negative (−2.52 billion tons and −3.23 billion tons, respectively), indicating that the domestic intermediate input structure of each economy as a whole exhibited a "water-saving" trend during this period. At the first stage, the impact effect of the domestic intermediate input structure of three departments was negative, whereas, at the second stage, the impact effect of seven departments was negative, and the impact at both stages was negative.

4. Discussion

During the research period, the import and export of virtual water increased significantly, with the export of virtual water increasing from 161.15 billion tons in 2007 to 193.31 billion tons in 2014, and the import of virtual water increasing from 114.07 billion tons in 2007 to 157.1 billion tons in 2014. The measurement of virtual water trade is helpful to clarify the actual "production-side consumption" and "consumption-side consumption" of an economy, and it provides important data support for planning and formulating virtual water strategies and participating in relevant international negotiations. The export water consumption intensity PEX in the 3 years was 40.6 tons/10,000 USD, 36.3 tons/10,000 USD, and 28.8 tons/10,000 USD, while the import water consumption intensity PIM in the 3 years was 35.1 tons/10,000 USD, 31.1 tons/10,000 USD, and 26.6 tons/10,000 USD. The import and export water consumption intensity exhibited a downward trend, which indicates that the water resource utilization efficiency improved in these years.

The eight economies of the United States, the European Union, Japan, Russia, South Korea, Taiwan, Canada, and Australia accounted for more than 50% of China's total virtual water export and import. The combined proportions of the United States, Japan, and Europe amounted to 44% (export) and 31.3% (import), which shows that the concentration of China's trade was still high. The good news is that, in terms of virtual water export, the total proportion of the eight economies showed a downward trend, from 59.51% in 2007 to 50.58% in 2014. The United States, the European Union, and Japan all exhibited significant declines. From the perspective of consumption, the proportion of China's export services dependent on the United States, Japan, and Europe declined, while the export destination countries showed a trend of more diversification.

The decomposition results show that the export scale, intermediate product export, export industry structure, domestic water consumption coefficient, and domestic intermediate input structure were the main influencing factors of virtual water export change, with a total impact value of 31.59 billion tons (within 5% of the total change). The growth of export scale was the primary reason for the growth of virtual water export, followed by the export effect of intermediate products and the structural effect of the export industry. The decline in the domestic water consumption coefficient was the primary reason for the restrained growth of virtual water export, followed by the change in the domestic intermediate input structure. The import scale, import of intermediate products, import industry structure, foreign water consumption coefficient, and domestic industry association were the main influencing factors of virtual water import change, with a total impact value of 43.03 billion tons (within 5% of the total change). The growth of import scale was the primary reason for the growth of virtual water import in most sectors, followed by the import effect of intermediate products and the import industry structure. The decline in water consumption coefficient in foreign countries was the primary reason for the restrained growth of virtual water import, followed by the industrial correlation effect in other countries.

5. Conclusions

In this study, the value-added decomposition analysis method was applied to the study of virtual water trade. The export scale was the primary factor affecting the virtual water trade volume, whereby the consumption of resources can be reduced by optimizing the export structure, although its scale is difficult to control. The SDA decomposition results of this paper also show that the import and export industry structure had an important impact on the virtual water trade volume. As an important factor for the restrained growth of virtual water, the reduction in the water consumption coefficient achieved remarkable results in recent years, and it will remain a feasible and important scheme in the future. The trade proportion of intermediate products and the forward and backward correlation with other countries all had an important impact on the virtual water trade volume. Therefore, actively participating in the division of labor in the global value chains, enhancing the level of R&D technology and promoting its position in the global value chains, are not only of great significance in terms of economic effects, but also very urgent in terms of resource conservation and utilization. In addition, the domestic intermediate input/output structure is also a factor that needs attention; thus, it is very important to improve the efficiency of intermediate input and optimize the structure of intermediate input products. It is foreseeable that, with the growth of the economic and trade scale, virtual water consumption will continue to increase; however, advances in technology and structure will ease this growth to a greater extent. In the new era, the breadth and depth of participation in the international division of labor and international trade is bound to expand constantly; thus, it is becoming increasingly important to develop an open economy with high quality. The data and related policy suggestions obtained in this paper deserve attention.

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