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The impact of virtual water strategy on domestic inter-regional agriculture products trade of China

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Abstract. Faced with increasingly severe pressure on water resources, virtual water and virtual water trade theory provide a feasible solution to improve global water use efficiency for agricultural product and to alleviate the pressure on water resources in water-scarce countries or regions. However, virtual water strategy has not been considered in domestic inter-regional agriculture products trade of China. In this research, we will create scenarios, from two aspects of economy and the allocation and utilization of water resources, to study the impact of virtual water strategy on domestic inter-regional agriculture products trade of China. Two kinds of scenarios will be created. One kind of scenarios does not consider the virtual water strategy, which only consider the economic revenue - net social revenue maximization scenario. The other kind of scenarios considers the virtual water strategy - water resource balance scenario. And we will research the impact of virtual water strategy will be made on domestic inter-regional agriculture productions trade of China. The result shows that virtual water strategy could make advantage impact on the allocation and utilization of water resources by domestic inter-regional agriculture products trade of China. But domestic inter-regional agricultural products virtual water trade of China considered the virtual water strategy would cause great negative impact on net social revenue.

1. Introduction

Accessible fresh water is scarce, only 1% of the global water volume is accessible freshwater [1], and it is likely that this quantity will decrease in many regions under future climate change, e.g. through more frequent and more pronounced droughts and through reduced inflow from glaciers [2]. Virtual water and virtual water trade theory provide a feasible solution to improve global water use efficiency for agricultural production and to alleviate the pressure on water resources in water-scarce countries or regions [3]. China is a serious water shortage country. The security situation of water resources is very grim. Per capita use of water resources of China is only 2300m³, which less than the 1/4 of the world per capita consumption, ranked 110 in the world. China is one of the world's 13 most water-poor countries. Agriculture is also the largest water user in China, accounting for nearly 70% of total water withdrawals [4].

Based on the traditional point of view of virtual water strategy, water-scarce countries or regions imported agricultural products through the trade of agricultural from water-rich countries or regions, not only alleviate the water shortage situation, and guarantee the safety of the food. However, the result of the domestic agricultural products virtual water trade research is contrary. Although the domestic agricultural products virtual water trade research of China is very scarce. Guan et al.



developed an extended regional input-output model for eight hydro-economic regions in China to account for virtual water flows between North and South China [5]. The findings showed that the current trade structure in China is not very favourable with regards to water resource allocation and efficiency. North China as a water-scarce region virtually exports about 5% of its total available freshwater resources. South China as a region with abundant water resources was importing virtual water from other regions. Ma et al. utilized the similar method to estimate that southern China got 18.3 billion m³ of virtual water through the exchange of agricultural products from the north areas in 1999 [6]. Sun et al. estimated that total of southern region received 30.08 billion m³ of virtual water through the exchange of agricultural products from the total of northern region; meanwhile the virtual water trade for wheat, maize and rice between regions had saved 3.63 billion m³ water in 2009 of China [7].

Virtual water strategy is not considered in domestic inter-regional agriculture products trade of China. What impact of virtual water strategy will be made? We will create scenarios from two aspects of economy and the allocation and utilization of water resources, to study the impact of virtual water strategy by domestic inter-regional agriculture products trade of China. Two scenarios will be created - net social revenue maximization scenario and water resource balance scenario. We will use the specific Spatial Equilibrium model to estimate the agricultural products virtual water trade between regions under the two scenarios. In this study we will optimize the agricultural products virtual water trade of domestic inter-regional trade of 30 Chinese provinces, autonomous regions and municipalities (Chongqing is attributed into Sichuan Province) in 2009 under two scenarios. Investigating the status of water resources, all regions will be defined as different water resources area sets. This can be more intuitive description of mitigation effect of the pressure on water resources in China. We hope our results can help to inform water policy in China.

2. Methodology and data

2.1. Optimization of agricultural products trade volume

Spatial Equilibrium models are used to optimize the inter-regional agricultural products trade. The agricultural product lack volume of N regions in 30 regions is seen as the demand for the other (30- N) regions. Then the agricultural product surplus volume of (30- N) regions is seen as the supply for the N regions. The specific Spatial Equilibrium models are shown:

Net social revenue maximization objective function

$$MAX NSR = \sum_{i=1}^N \sum_{j=1}^{30-N} X_{ij} \times P_i - \sum_{i=1}^N \sum_{j=1}^{30-N} X_{ij} \times P_j - \sum_{i=1}^N \sum_{j=1}^{30-N} X_{ij} \times F \times d_{ij} \quad (1)$$

Where NSR is the Net Social Revenue; i is the agricultural products lack regions; j is the agricultural products surplus regions; X_{ij} is the trade volume of agricultural products from region j to region i ; P_i is the retail agricultural products prices in region i ; P_j is the retail agricultural products prices in region j ; F is the transportation costs of per unit of agricultural products; d_{ij} is the distance between region i and region j .

Water resource balance objective function

$$MIN WRG = - \prod_{i=1}^N \left(WRPC_i + \sum_{j=1}^{30-N} X_{ij} \times \frac{VWC_j}{P_i} \right) \times \prod_{j=1}^{30-N} \left(WRPC_j - \sum_{n=1}^N X_{nj} \times \frac{VWC_j}{P_i} \right) \quad (2)$$

Where WRG is water resource gap; $WRPC_i$ is the water resources of per capita of region i ; $WRPC_j$ is the water resources of per capita of region j ; p_i is the population of region i ; p_j is the population of region j .

Constraints

- (1) $\sum_{j=1}^{M-N_k} X_{ijk} \leq \sum_{i=1}^{N_k} CL_{ik}$
- (2) $\sum_{j=1}^{M-N_k} X_{ijk} \leq \sum_{j=1}^{M-N_k} CS_{jk}$
- (3) $\sum_{i=1}^{N_k} CL_{ik} \leq \sum_{i=1}^{M-N_k} CS_{jk}$
- (4) $\sum_{i=1}^{N_k} X_{ijk} = \sum_{i=1}^{N_k} CL_{ik}$
- (4) $\sum_{i=1}^{N_k} CL_{ik} > \sum_{j=1}^{M-N_k} CS_{jk}$

$$\sum_{i=1}^{N_k} X_{ijk} = \sum_{j=1}^{M-N_k} CS_{jk}$$

Calculate X_{ij}

Where CL_{ik} is the agricultural products lack volume of agricultural product k in region i (ton); CS_{jk} is the agricultural product surplus volume of agricultural product k in region j (ton); N_k is the number of the agricultural product k lock regions; M is the number of the total regions ($M=30$ in this study case); $M-N_k$ is the number of the agricultural product k surplus regions.

2.2. Agricultural products virtual water trade volume

We use the virtual water volume of import agricultural products in origin area minus virtual water volume of export agricultural products in local area to calculate the virtual water trade volume (VWT) between two regions.

$$VWT_{ab} = \sum_{k=1}^n (X_{abk} \times VWC_{bk} - X_{bak} \times VWC_{ak}) \quad (3)$$

Where VWT_{ab} is the virtual water trade volume from region b to region a (m^3); X_{abk} is the import volume of agricultural product k from region b to region a (ton); VWC_{bk} is the virtual water content per unit weight of agricultural product k in the region b (m^3/ton); X_{bak} is the export volume of agricultural product k from region a to region b (ton); VWC_{bk} is the virtual water content per unit weight of agricultural product k in region a (m^3/ton).

We also use the agricultural products import volume minus the export volume, then multiplied by the corresponding agricultural products virtual water content in local area to calculate the water saving volume.

$$WS_a = \sum_{k=1}^n \left(\sum_{j=1}^{M-N_k} X_{ajk} - \sum_{i=1}^{N_k} X_{iak} \right) \times VWC_{ak} \quad (4)$$

Where WS_a is the water saving of region a (ton); X_{ajk} is the import volume of agricultural product k from region j to region a (ton); X_{iak} is the export volume of agricultural product k from region a to region i (ton).

2.3. The regions sets based on the quantity of water resources

China is known for her massive land. The difference of distribution of water resources in the adjacent region is extremely huge. So, the partition of South China and North China cannot very well on the study of the effect on water resource allocation China by domestic agricultural virtual water trade. So, in this paper, we investigated the status of water resources of the Chinese provinces, autonomous regions and municipalities according to the water resources bulletin (Table 1). All regions are defined as the severe drought regions (quantity of water resources per capita between 0-1000 m^3) (SDR), the moderate drought regions (between 1000-2000 m^3) (MDR^a), the mild drought regions (between 2000-3000 m^3) (MDR^b) and the water rich regions (above 3000 m^3) (WRR).

Table 1. The regions sets based on the quantity of water resources

Severe drought regions	Moderate drought regions	Mild drought regions	Water rich regions
Beijing, Tianjin, Hebei, Henan, Liaoning, Shanxi, Shandong, Jiangsu, Shanghai, Ningxia	Hubei, Shaanxi, Gansu, Jilin, Anhui, Zhejiang	Heilongjiang, Hunan, Sichuan, Guizhou, Guangdong, Inner Mongolia	Fujian, Qinghai, Xinjiang, Jiangxi, Yunnan, Guangxi, Xizang, Hainan

2.4. Data

Rice, Wheat, and maize are three major grain crops in China, accounting for more than 86% of the total national crop output [8]. Therefore, this paper takes the three kinds of crop as the research objects. Domestic balance data of supply and demand of grain is provided by the China National Grain and Oil Information Center [9]. The price data is from the China Price Information Center and China Price Yearbook [10]. The virtual water content of all kinds of agricultural products calculated results is

shown by Sun [7]. Transportation costs are the railway grain transportation costs calculated according to the average tariff 0.051yuan / km / t. The distance between regions is used the railway transport distance between provincial capitals. The population data and the water resources of per capita data are provided by China Statistical Yearbook [11] and China Water Resources Bulletin [12].

3. Result and discussion

3.1. Net social revenue maximization scenario

The net social revenue is maximized by maximizing the net income from exports and imports. This scenario reflects a strong national self-interest strategy in improving the economic return for the country.

Using the Spatial Equilibrium model by LP model under the net social revenue maximization objective function, we calculated the virtual water flows of China's agricultural products trade in 2009. Under the net social revenue maximization scenario, the total amount of domestic inter-regional agricultural products virtual water trade of China was 56.5 billion m³, accounted for 15.2% of agricultural water of China in 2009. Through the calculation, we found that China's virtual water trade flow is not conducive to China water resources balance under net social revenue maximization scenario. The severe drought regions exported 9.6 billion m³ virtual water to the moderate drought regions, the mild drought regions and the water rich regions. This was further exacerbated the pressure on water resources in the severe drought regions. Otherwise, the water rich regions imported the most virtual water - 8.0 billion m³ virtual water - from the severe drought regions by the inter-regional agricultural products trade. This is further exacerbated the pressure of water resources in severe drought regions which are already very serious lack of water resource. Meanwhile, this was also exacerbated the uneven distribution of water resources in China (Table 2). The corn virtual water flows were the most, the wheat virtual water flows were slightly more than the rice virtual water flows of China in 2009 under net social revenue maximization scenario.

Table 2. Matrix of virtual water flows of inter-regional agricultural products trade of China in 2009 under net social revenue maximization scenario (10⁷ m³)

	Region	SDR	Export (Rice, Wheat, Corn)			Total	Net Export
			MDR ^a	MDR ^b	WRR		
Import	SDR	-/538.4/-	9.6/-/310.9	447/-/14.2	-/37.8/-	456.6/576.2/325.1	957.8
	MDR ^a	-/487.5/88.2	-/372.2	330.2/-/	-/158.6/34.8	330.0/646.1/495.2	-156.3
	MDR ^b	-/222.5/529.2	7.3/159.4/-	469.9/-/296.7	-/38.9	477.2/381.9/864.8	-6.5
	WRR	-/96.3/353.6	331.9/29.3/94.4	138.4/-/21.2	-/41.9/48.9	470.3/167.5/518.1	-795
	Total	-/1344.7/971.0	348.8/188.7/777.5	1385.3/-/332.1	-/238.3/122.6	1734.1/1771.7/2203.2	

Through importing virtual water embodied in grain, a nation or region could save the water required to produce those grains in their own country or region. For example, the VWC of rice in Southwest China was 1131 m³ per ton, in the Middle–Lower Reaches of the Yangtze River, the VWC for rice was 1293 m³ per ton. The Middle–Lower Reaches of the Yangtze River region could save 1293 m³ water by importing 1 ton of rice from the Southwest China. Meanwhile, China would lead to 162 m³ of water saving per ton at the national scale [7].

Based on the principle mentioned above, an analysis was conducted to determine whether there were any water saving benefits of virtual water flows related to grain transfer between regions from the national perspective under net social revenue maximization scenario. The results are shown in Table 3. Through rice, wheat and corn transfer between regions, 2.8 billion m³, 7.5 billion m³ and 8.3 billion m³ water was respectively saved at the national scale. In summary, the virtual water trade for rice, wheat and corn between regions saved 18.6 billion m³ water in China.

The severe drought regions lose 6.5 billion m³ water, which was the only water lose water resources area set through domestic inter-regional agricultural products virtual water trade. The water rich regions saved the most water. The water rich regions saved 13.7 billion m³ water, which accounted for 73.5% of the total water saving of China in 2009.

Tab. 3 The water saving by inter-regional agricultural products trade of China in 2009 under net social revenue maximization scenario (10^7 m^3)

Region	Import	Export	Water Saving	Total Water Saving
SDR	498.2/779.9/390.9	-/1344.7/971.0	498.2/-565.7/-581.0	-648.5
MDR ^a	339.1/987.6/736.0	348.8/188.7/777.5	-9.7/798.9/-41.5	747.7
MDR ^b	598.6/472.0/1041.4	1385.3/-/332.1	-786.7/472.0/709.3	394.6
WRR	587.9/280.0/861.7	-/238.3/122.6	587.9/41.7/739.1	1368.7
China	2023.8/2519.5/30030.0	1734.1/1771.7/2203.2	288.6/746.9/826.0	1862.5

Through inter-regional agricultural products trade under net social revenue maximization scenario, the net social revenue is 9.1 billion RMB in 2009. In which, China earned 3.3 billion RMB and 7.7 billion RMB respectively through rice and corn inter-regional trade. However, China lose 1.9 billion RMB through wheat inter-regional trade.

3.2. Water resource balance scenario

As much as possible to achieve the regional water resources balance can help relieve uneven distribution of water resources in China. Under the water resource balance scenario, the total amount of domestic inter-regional agricultural products virtual water trade of China was 62.8 billion m^3 , accounted for 16.9% of agricultural water of China in 2009. Under the social revenue maximization scenario, the severe drought regions were the only virtual water net export regions. The different is that the mild drought regions were the only virtual water net export regions under the water resource balance scenario. Compare with the social revenue maximization scenario, the severe drought regions changed from virtual water net exports regions into virtual water import most regions under the water resource balance scenario. The severe drought regions added 19.1 billion m^3 virtual water. The moderate drought regions added 6.5 billion m^3 virtual water imports. The mild drought regions changed from virtual water net import regions into the only virtual water export regions which reduced 19.4 billion m^3 virtual water. The water rich regions reduced 6.3 billion m^3 virtual water imports. Contrast the social revenue maximization scenario, which is equivalent to exported 25.7 billion m^3 virtual water from the mild drought regions and the water rich regions to the severe drought regions and the moderate drought regions. The severe drought regions and the moderate drought regions imported great amount of water that greatly eased the pressure on water resources of the most water-scarce regions. The corn virtual water flows were the most, the rice virtual water flows were slightly more than the wheat virtual water flows of China in 2009 under water resource balance scenario.

Table 4. Matrix of virtual water flows of inter-regional agricultural products trade of China in 2009 under water resource balance scenario (10^7 m^3)

under water Resource Balance Scenario (10 - m)							
Export (Rice, Wheat, Corn)							
	Region	SDR	MDR ^a	MDR ^b	WRR	Total	Net Export
Import	SDR	-/495.5/-	-/48.8	292.5/-/364.0	241.8/76.7/-	534.3/572.2/412.8	-955.5
	MDR ^a	-/-	-/713.1/-	355.7/-/628.1	-/-	355.7/713.1/628.1	-810.9
	MDR ^b	-/68.3/-	-/124.1/-	533.9/175.4/797.1	-/-	533.9/367.8/797.1	1930.0
	WRR	-/-	-/-	-/482.1	606.8/165.1/113.5	606.8/165.1/595.6	-163.6
	Total	-/563.8/-	-/837.2/48.8	1182.1/175.4/2271.3	848.6/241.8/113.5	2030.7/1818.2/2433.6	

Shown in Table 5, through wheat and corn transfer between regions, 3.0 billion m^3 and 6.0 billion m^3 of water was respectively saved at the national scale. But through the rice transfer between regions, 69.0 million m^3 water was loose at the national scale. In summary, the virtual water trade for rice, wheat and corn between regions saved 12.9 billion m^3 water in China.

The same as the virtual water flows, the severe drought regions were the only virtual water loss regions under the social revenue maximization scenario. However, the mild drought regions were the only virtual water loss regions under the water resource balance scenario, too. Compare with the social revenue maximization scenario, the severe drought regions changed from water loss regions into water saving regions which added 17.5 billion m^3 water saving under the water resource balance scenario.

The moderate drought regions added 19.2 billion m³ water saving. The mild drought regions changed from water saving regions into the only water loss regions which lost 19.1 billion m³ virtual water compare with the social revenue maximization scenario. The water rich regions lost 8.4 billion m³ virtual water. In summary, compared with the social revenue maximization scenario, China lost 5.7 billion m³ virtual water under the water resource balance scenario. The water saving under the water resource balance scenario accounted for 69.3% of water saving under the net social revenue maximization scenario.

Table 5. The water saving by inter-regional agricultural products trade of China in 2009 under water resource balance scenario (10⁷ m³)

Region	Import	Export	Water Saving	Total Water Saving
SDR	498.2/779.9/390.9	-/563.8/-	498.2/216.1/390.9	1105.2
MDR ^a	339.1/987.6/736.0	-/837.2/48.8	339.1/150.4/687.2	1176.7
MDR ^b	598.6/472.0/1041.4	1182.1/175.4/2271.3	-583.5/296.6/-1229.9	-1516.8
WRR	587.9/280.0/861.7	848.6/241.8/113.5	-260.7/38.2/748.2	525.7
China	2023.8/2519.5/3030.0	2030.7/1818.2/2433.6	-6.9/701.3/596.4	1290.8

Through inter-regional agricultural products trade under the water resource balance scenario, the net social revenue is -1.2 billion RMB in 2009. In which, China earned 6.1 billion RMB through the corn inter-regional trade. However, China lose 1.5 billion RMB and 5.8 billion RMB respectively through rice and wheat inter-regional trade. Compare with the net social revenue maximization scenario, China reduced 4.8 billion RMB, 3.9 billion RMB and 1.6 billion RMB respectively through rice, wheat and maize trade under the water resource balance scenario. Totally, China reduced 10.3 billion RMB under the water resource balance scenario rather than under the net social revenue maximization scenario.

4. Conclusions

The dominant challenge for agricultural water resources management is how to secure water to meet food demands of the rapidly expanding world [13]. Study the impact of the domestic inter-regional agricultural products virtual water trade of China by virtual water strategy can give information to help to inform water policy in China.

Virtual water strategy could make advantage impact on the allocation and utilization of water resources by domestic inter-regional agriculture products trade of China. For water resource balance, under the water resource balance scenario, the mild drought regions exported virtual water to the other regions. The severe drought regions and the moderate drought regions imported great amount of water which greatly eased the pressure on water resources of the most water-scarce regions. But it also brings us to another problem. For example, for net social revenue, through inter-regional agricultural products trade under the net social revenue maximization scenario, the net social revenue was 9.1 billion RMB in 2009. But under water resource balance scenario, the net social revenue was 10.3 billion RMB less than under the net social revenue maximization scenario. And under the water resource balance scenario the water saving was less, accounting for only 69.3% of water saving under the net social revenue maximization scenario. Therefore, a comprehensive objective function optimization method should be used multi-objective optimization on food virtual water trade. It can be a better solution to deal with the issue of water resources by grain trade.

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