Input-output analysis of virtual water trade volume of Zhangye

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ABSTRACT

Virtual water trade refers to the transfer of virtual water associated with the transfer of commodities. It has emerged as a new field of water management which may be utilized as a strategy to alleviate water scarcity and to achieve water and food security in water short nations or areas. However, difficulties arise in the calculation or estimation of virtual water content of commodities, particularly for industrial products. By taking Zhangye in Heibe Basin as a case, this paper explores a new way to assess virtual water consumption based on input-output analysis. The analysis results show that the deficit of virtual water trade of Zhangye in 2000 reached 5.68×108 m^3, which might intensifies her water scarcity further if a trade mix substitution mechanism is lacking. There is a need for her to attend to the optimal use of water resources in order to maximize her sustainable welfare of her population. Our study has also shown that the input-output model is an operational tool for virtual water assessment.

1. INTRODUCTION

The concept of virtual water was first introduced by Allan (1996) to quantify the water required in the production process of an agricultural commodity. This water is embedded in the commodity. Allan (1998) extended the principle of virtual water to other commodities and services by quantifying the water required in the production of these commodities or services.

International trade involves international flows of virtual water, in addition to the flows of the physical commodities between nations. In a study of virtual water flows, Hoekstra and Hung (2005) estimated a global volume of crop-related international virtual water flows to be 695 Gm^3 per year in average over the period 1995-1999. Water short areas may therefore accomplish water security by importing water-intensive commodities like food and electric power, from other nations that have more water. On the other hand, water rich nations may export more water-intensive products to relieve the water shortage problems of imported countries. Virtual water trade between nations could therefore become a useful and feasible strategy to improve global water use efficiency and to achieve water security in water-scarce countries or regions.

In order to assess the virtual water flows between nations, the basic approach (Hoekstra and Hung, 2003, Chapagain and Hoekstra, 2003) is to multiply the trade volumes by their associated unit virtual water requirements. However, as far as we are aware, studies of virtual water are confined to the production of crops and livestock and studies of virtual water trade are confined to food trade.

In this paper, we employ an input-output model (Leontief, 1970 and Leontief and Ford, 1972) to estimate the transfer of virtual water between different economic or industrial sectors and apply it to Zhangye area of China. To the best of our knowledge this is a pioneered application of input-output analysis to virtual water study. Our analysis results uncover an important issue of optimal water use and water trade embodied in commodities. Virtual water trade is an important, yet currently neglected element in the economic literature.

The use of input-output analysis for virtual water trade can avoid the tedious work of estimating the water content of individual products. The water content of an industrial product or a final product is considered to consist of two components, namely direct water consumption and indirect water consumption. Direct water consumption is the amount of water required by the establishment in producing the product. The production of such a product will usually involve the input of various raw materials and other products and services at various stages of the production process. The production of these intermediate inputs themselves has also consumed water at their respective places of production but it has not been accounted by the establishment producing this final product. The water content of intermediate inputs may be termed indirect water consumption which together with the direct water consumption constitutes the total water content of this final product. Economic input-output analysis allows the determination of interdependencies of direct and indirect water contents between commodities. The method attributes the virtual water contents of all intermediate inputs to the virtual water content of the final product without the need of reverting to the detailed stages of the production process.

2. INPUT-OUTPUT ANALYSIS OF VIRTUAL WATER

An input-output model of an economy may be represented by the matrix relation

$$X = (I - A)^{-1}(Y_D + Y_E - Y_M)$$

where X is the vector of output quantities, Y_D is the final domestic demand, Y_E is the exports, Y_M is the imports, A is the matrix of technical coefficients representing the inter-industrial interdependence and I is the identity matrix. The change in total output resulted from imports and exports is given by:

$$\begin{aligned} \Delta X &= (I - A)^{-1}(Y_D + Y_E - Y_M) - (I - A)^{-1} Y_D \\ &= (I - A)^{-1} Y_E - (I - A)^{-1} Y_M \\ &= \Delta X_E - \Delta X_M \end{aligned}$$

where $\Delta X_E = (I - A)^{-1} Y_E$ is the increase in total output that is required to cope with the exports Y_E, and $\Delta X_M = (I - A)^{-1} Y_M$ would have been the additional total output required should the imports Y_M be produced domestically.

In order to rationalize the input-output model for virtual water analysis, we define the unit direct water usage coefficient of an economic sector to be the total water consumption for production by the economic sector divided by the total products produced, i.e.

$$f_i = W_i / X_i,$$

where f_i is the direct unit water usage of the ith sector, W_i is the total water consumption in production and X_i is the total quantity of the products produced. Here the water usage is based on the monetary value of product, however, it may be based on the quantity of production.

Given that intermediate inputs are usually required by an economic sector in its production process, we shall introduce a unit total water usage coefficient by

$$f_i^t = f_i + \sum_{k=1}^{n} f_k^t a_{ki}.$$

Here, f_i^t is the unit total water usage of the ith sector, and

$$a_{ki} = u_{ki} / \sum_{k=1}^{n} u_{ki},$$

is the relative share of the kth sector product inputted for ith sector's production, where u_{ki} is the input of kth sector product by the ith sector. The first term on the right hand side represents the direct water consumption and is readily available. The second term which refers to the water content of intermediate input, or the indirect water consumption of the sector i, is usually unknown. By considering water contents as an input, the interdependency between water consumption of various economic sectors may be assessed. We shall obtain the matrix identity

$$F^t = (I - A)^{-1} F$$

where F^t is the vector of total unit water usages, F is the vector of direct unit water usages and $A = (a_{ki})$ is the matrix of relative shares of intermediate inputs. By such an input-output formulation the total unit water usage may be determined from the direct water usage.

When imports and exports multiplied to total water unit consumption we shall obtain the additional water requirement if these imports and exports would have been produced locally:

$$W_v = (Y_E - Y_M)' F^t.$$

The input-output model approach bypasses the need of estimating the water content inputs in the production process. Instead, it only requires the water consumption statistics of various economic or industrial sectors and an input-output model relating the transfers of products between these sectors. Provided reliable water consumption statistics are available and the input-output interrelations can be correctly formulated transfers of virtual water associated with commodities transfers among economic sectors can be estimated reliably.

3. A CASE EXAMPLE

We have applied the input-output model to analyze the virtual water trade of Zhangye area in 2000. According to water consumption statistics published by Bureau of Statistics of Gansu (2000), there are thirty industrial and production sectors in Zhangye. We have consolidated these industrial and production sectors into eight broad ones, namely crop plantation, forestry, livestock farming, fishery, manufacturing, power and fuel, construction and service industry. The productions and water usage of these broad sectors are given in Table 1. Table 2 gives the intermediate input of these industrial sectors (Zhu, 2001). The estimated virtual water transfers are given in Table 3.

Our study reveals that Zhangye has a net export of virtual water in 2000. Being a water short area, Zhangye has had not been demonstrated to make use of the virtual water trade strategy to compensate its already scarce water resources, instead it has even exported 5.68×10^8 m^3 virtual water through various trades. The virtual water exports accounted for 26.9% of the total industrial water usage. For individual economic sectors, the crop plantation alone has a net export of 6.81×10^8 m^3 in 2000. On the other hand, the imports of virtual water are seen to outweigh the virtual water exports in other industrial production sectors such as the Fishery, Manufacturing and Services. In other words, Zhangye ran into serious virtual water trade deficit by exporting water-intensive but economically inefficient agricultural products and importing water-efficient manufacturing and industrial products.

The economic structure and the import-export policy of Zhangye can be considered not able to circumvent its regional disadvantages and deficiency. The relatively huge food exports could attenuate the seriousness of the already over-exploited water resources, thus adversely affecting its regional long-term water and food security.

4. SCENARIOS STUDY

An economy with low technological level and less developed industry will rely more heavily on exporting primitive products such as farm and food products for an exchange of imported manufactured and service products. As farm products are relatively water-intensive, exporting farm products in exchange for imports of industrial products is disadvantageous in terms of virtual water trade. The industrialization of Zhangye region is still in a starting stage in which agriculture and farming dominate its economic activities. In 2000, the value added of farm produce makes up 41.8% of the total value added of the region while industrial production and service industry represent 29.2% and 29.0% of the total value added respectively. These facts explain the current virtual water trade deficit of Zhangye and reveal a need of her attention to the optimal use of water resources in order to maximize her sustainable welfare of her population.

For long term development and sustainability, Zhangye should adopt some mechanisms that would adjust the optimal allocation of various inputs to production processes. A flexible water pricing policy that would drive the substitution of water towards other inputs is preferable. The utilization of virtual water trade strategy is also a feasible and workable mechanism for water short regions such as Zhangye to alleviate their water shortage problems and the pressure on economic development caused by water shortages. We have therefore simulated the efficiency of employing such a strategy in Zhangye under two different scenarios.

Scenario 1: There are no imports or exports so that the deficit of virtual water trade is set at zero.

Scenario 2: There are no exports of farm crops and food so that the virtual water trade arising from crops and food is set at zero. Other imports and exports remain the same as before.

The simulated results are shown in Table 4. Had Zhangye adopted one of these strategies for its virtual water trade it would have consumed 2.68×10^8 m^3 less water at least, greatly alleviating its already scarce water resources. The local water thus saved could have otherwise been used for economic activities with higher ecological, social and economic returns to sustain longer-term development.

5. CONCLUSION

Our foregoing study has suggested that input-output analysis is a simple and workable tool to estimate virtual water transfers. The method bypasses the estimation of the water content that is contained in a commodity. It only requires the water consumption statistics of various economic or industrial sectors and an input-output model relating the transfers of products between these sectors. The computations involved are relatively simple and readily operational. Provided reliable water usage statistics are available and the input-output interrelations are correctly specified the estimates made should be reliable and accurate.

Water scarcity has always been a serious problem impinging on food production and water security of many water short regions and nations. Virtual water may be considered as a new form of water resources which, if intelligently utilized could be employed to alleviate the water shortage pressure that a region or nation is facing. The adoption of virtual water trade strategy in a nation or region may only be effective when the adoption is coupled with an appropriate transition or restructuring of its economic or production composition. Adverse effects could be a mismatch of labour skill within industries leading to massive labour force surplus or shortage of particular industrial sectors. Transition of an economy from one state to another is also a long time process, making virtual water strategy difficult to be implemented promptly and effectively. A flexible water pricing policy that would automatically adjust various input substitutions is preferable. Nonetheless, a water scarce nation or region may set a long-term goal of re-allocating the resources of her economy resulted from the impact of virtual water trade with an aim of achieving long-term water security.

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Table 1. Production (Billion RMB) and water consumption (10^8 m^3) of eight broad industry sectors in 2000

Sector	Value Added	Total production	Imports	Exports	Water consumption
Crops	2,151.90	3261.84	145.99	1141.64	18.43
Forestry	58.27	101.44	44.52	22.76	1.67
Livestock	461.24	811.99	93.16	406.00	0.21
Fishery	7.37	21.06	39.52	5.40	0.29
Manufacturing	1,270.09	4548.53	1730.77	1453.59	0.43
Power and Fuel	97.58	204.63	400.61	0.00	0.03
Construction	502.44	1442.04	99.59	788.91	0.04
Service	1,860.00	3556.48	1840.52	649.79	0.00

Table 2. Intermediate input (Million RMB) of industrial sectors

	Production sector								
	Crops	Forestry	Live-stock	Fishery	Manufact-uring	Power & Fuel	Construct-ion	Service	Total
Crops	454.07	1.36	222.61	8.34	561.14	.003	0.00	11.47	1259.00
Forestry	1.96	23.60	.29	0.09	1.68	.0001	0.00	3.18	30.73
Livestock	0.00	0.00	8.52	0.00	108.34	0.00	0.00	5.43	122.29
Fishery	0.00	0.00	0.00	1.01	0.00	0.00	0.00	11.46	12.47
Manufacturing	312.38	9.04	69.48	2.06	1431.67	37.28	636.96	564.51	3063.39
Power and Fuel	45.62	0.64	0.99	0.46	338.07	7.77	7.76	71.36	472.67
Construction	0.00	0.00	0.00	0.00	33.67	13.30	148.08	381.11	576.16
Service	295.91	8.54	48.86	1.73	803.88	48.69	146.80	648.01	2002.42
Total input	1109.94	43.18	350.75	13.69	3278.45	107.04	939.60	1696.53	7539.12

Table 3. Estimation of virtual water trade (10^8 m^3) of Zhangye in 2000

Industry	$W_v = (Y_E - Y_M)' F^t$			Actual water consumption
	Exports	Imports	Net Imports	
Crop	7.81	1.00	-6.81	18.43
Forestry	0.50	0.97	0.47	1.67
Livestock	0.95	0.22	-0.73	0.21
Fishery	0.09	0.69	0.60	0.29
Manufacturing	2.47	2.94	0.47	0.43
Power & fuel	0.00	0.27	0.27	0.03
Construction	0.74	0.09	-0.65	0.04
Services	0.39	1.09	0.70	0.00
Total	12.96	7.28	-5.68	21.10

Table 4: Efficiency of virtual water trade strategy under two different scenarios

Scenario	Virtual water saved (10^8 m^3)	Value added increased (Billion RMB)
No imports or exports	5.68	21.24
No crop exports	13.49	504.5

Note: Industrial water usage efficiency of Zhangye in 2000 is RMB37.4/ m^3, US$1 ≈ RMB8.0