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Assessment of Regional Trade and Virtual Water Flows in China

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Abstract

The success of China's economic development has left deep marks on resource availability and quality. Some regions in China are relatively poor with regards to water resources. This problem is exacerbated by economic growth. Flourishing trade activities on both domestic and international levels have resulted in significant amounts of water withdrawal and water pollution. Hence the goal of this paper is to evaluate the current inter-regional trade structure and its effects on water consumption and pollution via 'virtual water flows'. Virtual water is the water embedded in products and used in the whole production chain, and that is traded between regions or exported to other countries. For this assessment of trade flows and effects on water resources, we have 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. The findings show that the current trade structure in China is not very favorable 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 while accepting generation of large amounts of wastewater in producing exports for other regions' consumption. By contrast, South China - a region with abundant water resources - is importing virtual water from other regions while these imports are creating wastewater polluting other regions' aquatic-ecosystems.

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Dabo Guan is a PhD candidate of the School of Earth and Environment at the University of Leeds. He joined the Young Scientists Summer Programme at the International Institute of Applied Systems Analysis, Austria, in the summer of 2004 to develop a water accounting framework by extending input output analysis and apply it to China's regions. Dabo has been contributing on various international research projects establishing ecological footprints and other environmental indicators for regions in China.

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Dabo Guan and Klaus Hubacek

1. The 'Economic Miracle' and Virtual Water Flows

Water Shortage and its Competing Usage

The latter half of the 20th century is considered the period of the 'economic miracle' for East Asia, achieving industrialization and urbanization in a relatively short time period. China, in particular, accelerated its economic development with an annual GDP growth rate of almost 10% after economic reforms were started in 1978. In comparison, the world average was 3.3% during the same period. By 2005, China's GDP had reached 1.13 trillion US dollars, which put China among the four largest economies in the world. China's economic reform has created very competitive and favorable circumstances for domestic and foreign investors in terms of cheap labor costs, a huge domestic market, low workers safety standards and environmental standards. These and other reasons, such as the undervalued Yuan, have led to large amounts of capital flowing into China, especially in the southern and eastern parts, which has made China one of the largest manufacturers and exporters in the world. However, Deng's 'ladder-up' strategy of economic developments has increased income inequality between regions and urban and rural areas. This is also reflected in differing regional development policies, economic production structures, unequal spread of foreign direct investment, and huge differences in people's lifestyle patterns.

These developments have left deep marks on China's natural resource availability and especially with regards to water resources. China is trying to meet the needs and wants of 1.3 billion inhabitants. This amounts to 22% of the total world population with only 7% of the world's arable land, and 6% of the world's fresh water resources. Water is already considered the most critical natural resource in many parts of China in terms of the low availability of per capita volume. The average water availability is about 2,300 m^3, which is roughly about 1/3 of the world's average value. But China's water resources are also unevenly distributed: North China has only about 20% of total water resources in China, but is supporting more than half of the total population. As a result, per capita water availability in North China is as little as 271 m^3 or 1/8 of the national level and 1/25 of the world average. Furthermore the rapid economic development in this region has been extracting significant amounts of water from the environment, and it is also discharging pollution to the water supply sources, which further contributes to water-scarcity. Flourishing trade activities on both domestic and international levels have contributed to ever increasing levels of water consumption.

These socio-economic and environmental issues facing China in the 21st century call for careful evaluation of China's resource consumption caused by its present production and consumption and associated trade structure. Due to these trade activities, significant amounts of 'virtual water', i.e. water embedded in products and used in the whole production chain, are traded between regions or exported to other countries. The goal of this paper is to evaluate the current regional economic structure and the resulting inter-regional trade patterns in China and its effects on water consumption and pollution via 'virtual water flows'.

Virtual Water Flows

The idea of virtual water was derived from the concept of 'embedded water' applied to agriculture in Israel by Fishelson et al. (1994). Their study pointed out that exporting Israeli water embedded in water-intensive crops was not sustainable. The term 'virtual water' was first proposed in 1994 by J. Anthony Allan (Allan 1994). Allan defines virtual water as the water used to produce food crops that are traded internationally. He found that a few countries characterized as water-scarce have secured their food supply by importing water-intensive food products, rather than producing all of their food supply with inadequate water resources. Limited water resources should be used efficiently by not allocating the majority of the water resources to the production of water-intensive products (e.g. crops, paper etc.) but rather water should be made available for other economic purposes that can contribute more to regional value added by consuming less water (Allan 1998; 2002).

Most of the studies on virtual water flows have been conducted in drought areas such as the Middle East and North Africa and have emphasized the amount of water embedded in different agricultural products related to food security, with agriculture being the largest water consumer.

Similarly, in China, agricultural irrigation has accounted for the majority of water use in the past, however, along with the large-scale industrialization and urbanization since 1980, domestic, municipal, and industrial water consumption joined the competition for limited water resources. Many industrial products also carry substantial amounts of virtual 'freshwater' as well as contaminated 'wastewater' from the production of paper, fertilizer and cement, which are then exported to other regions or countries.

Due to increasing importance of other industrial products and services and their effects on water consumption, we extend the concept of virtual water flows to comprise all types of commodities including agricultural goods, industrial products and services. We distinguish between two categories of virtual water: freshwater and wastewater. Virtual freshwater is the amount of freshwater consumed during the production of exports. Virtual wastewater is the amount of polluted water discharged to the ecosystem, i.e. the amount of emissions generated and left in the respected region in order to feed consumption in other regions or countries. Due to the importance of the agricultural sector in terms of water consumption we further differentiate between rainfed and irrigated agricultural products. This is based on the rationale that rain water used for agricultural products would not be readily available for any other economic production.

Virtual Water as a Factor of Production

The notion of virtual water as a necessary input to production and consumption activities leads us to the notion of factors of production or factor endowments. In our case we focus on water as a special input to production but are also interested in the question of how production and associated trade structures affect the availability of water resources. Early economic theorists such as Adam Smith and David Ricardo were concerned with differences in factor endowment, 'the comparative advantage', as one of the main reasons for trade and regional inequalities and as a source for the wellbeing of nations. The focus shifted to the negative sides of trade; and only rather recently, scholars started to advocate re-designing trade structures from the perspectives of social and environmental sustainability. In the following we will look at selected key publications to see how factor endowments and environmental resources have been treated in the trade literature and how that links to our question.

Heckscher (1919) and Ohlin (1933) incorporated the endowment of factors of production into the principle of comparative advantage, and consequently was referred to as the Heckscher-Ohlin (HO) theorem. The HO theory of international trade was able to explain that the differences of productivity in various countries are dependent on relative factor endowments. Leontief (1951 and 1954) calculated the labor and capital content of the exports of the United States to test the HO theory. The US seemed to be endowed with more capital relative to labor than any other country at that time. Therefore in terms of the HO theory, the US should have exported capital-intensive products and imported labor-intensive commodities. However, Leontief's test surprised the academic field as he reached a paradoxical conclusion that the US exported relatively more labor-intensive commodities and imported capital-intensive goods. These results received a great deal of attention and became known as the Leontief Paradox and have led to numerous studies discussing and critiquing the approach (see, for example, Stolper and Roskamp 1961; Bharawaj 1962).

If we apply classical trade theory to environmental studies, a country may have a comparative advantage if it is endowed with certain resources or if it can produce a product with relatively low costs to the environment. Since the 1970s, numerous theoretical studies have been conducted to research the linkage of trade and the environment by adopting the principle of comparative advantage. For example, Pethig (1976), Siebert (1977), McGuire (1982) and Brander and Taylor (1997) treated a country's emission / resource management standards as factor endowment, and their results showed that countries with less stringent environmental policies could increase their comparative advantage in the production of pollution and natural resource-intensive products (quoted after Huang and Labys 2001). However this view is challenged by more recent research. Porter and van der Linde (1995) argued that strict environmental policies may not be a comparative disadvantage. In contrast, it may be an advantage to drive the producers and the whole economy to become more competitive in world markets by improving efficiency or innovating better environmental technologies. These conflicting views have led to a heated debate, and the empirical results are ambiguous (e.g. Huang and Labys 2001).

The important point to emphasize here is that environmental goods and services such as available water resources can be a factor of production and therefore a source of comparative advantage. Thus, if a region is well endowed with environmental resources and in our case water resources, one could assume that this region's exports will have a larger share of water-intensive products. Applied to China, we would assume that water-scarce North China would import water-intensive products and the water-rich South China would export products which would need lots of water inputs. In the following we will test this hypothesis and investigate if these Chinese regions take full advantage of virtual water flows. We will specifically build on the work of Leontief and use the input-output approach to assess regional and trade flows in China and their effects on virtual water flows.

2. Virtual Water Flows Accounting and Modeling Framework

Structure of the Water Input-output Model

The fundamental purpose of the input-output model is to analyze the interdependence of economic sectors. Its extensions include social institutions (Stone 1971) and the environment (Leontief 1970; Victor 1972; Duchin and Lange 1994). Frequently input-output analysis has been applied to water consumption and pollution issues (see, for example, Thoss and Wiik 1974; Bouhia 2001; Hubacek and Sun 2005).

The traditional IO table is an $n \times n$ matrix describing the flows of goods between economic sectors in monetary units. We extend the matrix to $(n + 1) \times (n + 1)$ by adding 1 row in physical units[1] to measure the amounts of freshwater consumed and wastewater discharged by economic production processes.

The extended water IO table is presented in Table 1. It provides a detailed economic accounting scheme for economic activities $(\mathbf{x})$, primary inputs $(\mathbf{v})$, households and governmental final consumption $(\mathbf{y})$, trade flows $(\mathbf{e})$, net water consumption $(\mathbf{f})$ and wastewater discharges $(\mathbf{r})$.

Table 1: Extended Water Input-output Table

	Activities Intermediate Demand	Final Demand		Total Output	**Wastewater**
		Households & Governments	Exports		
Economic Activities	$\mathbf{x}_{ij}$	$\mathbf{y}_{ij}$	$\mathbf{e}_{ij}$		$\mathbf{r}_i$
Primary Inputs	$\mathbf{v}_{ij}$				
Imports					
Total Inputs	$\mathbf{x}_j$				
Fresh water (Net consumption)	$\mathbf{f}_j$				

As mentioned previously, water as a primary input is involved in economic production. This connection can be captured in freshwater consumption coefficients for each

[1] For clarity, matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters, and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime (e.g. $\mathbf{x}'$). A diagonal matrix with the elements of vector **x** on its main diagonal and all other entries equal to zero are indicated by a circumflex (e.g. $\hat{\mathbf{x}}$).

industrial sector. The direct freshwater consumption coefficient, f_j is calculated by dividing the total amount of consumed water of the j^{th} sector by total input to that sector x_j. Therefore, the unit for the coefficient of fresh water consumption is m^3/Yuan. This coefficient represents the direct or the first round effects of the sectoral interaction in the economy (Bouhia 2001; Hubacek and Sun 2005). However, water is not only consumed directly but also indirectly. For instance, to produce paper necessary inputs are wood, chemicals, electricity and water (direct consumption). But also the production processes of each of these inputs need water (indirect consumption). Therefore, in order to combine both direct and indirect water consumption, we generate the total water consumption multipliers by multiplying direct water consumption coefficients **f** with the Leontief inverse $\mathbf{(I\text{-}A)^{-1}}$, which represents an indicator of the total water consumption throughout the production chain for each sector, shown in Equation 1

$$\textbf{Total Water Consumption} = \hat{f}\,\mathbf{(I - A)^{-1}\,y} \qquad \text{Equation (1)}$$

Similarly, we employ the direct wastewater coefficient r_i to represent the amount of wastewater released to produce a unit of output in the i^{th} production sector. Therefore, we obtain Equation (2) to measure the total amounts of wastewater generated in an economy by increasing one unit of final consumption:

$$\textbf{Total Wastewater Generation} = \hat{r}'\,\mathbf{(I - A)^{-1}\,y} \qquad \text{Equation (2)}$$

This represents the flows from the economy to original water resources (e.g. rivers, lakes or groundwater), i.e. the emissions of wastewater after production activities. These discharged wastewater flows from agricultural and industrial production can contain large amount of noxious pollutants which damage the hydrological system.

Hydro-economic regions and datasets

Due to considerable regional differences in water supply and demand, and the need to assess regional trade flows, it is necessary to model water consumption on a regional level. Therefore we divide China into eight hydro-economic regions to establish water accounts for each region (shown in Figure 1) based on watersheds and provincial level administrative boundaries[2] (see Hubacek and Sun 2001). In this paper, we calculate and analyze the virtual water flows for two of China's regions: North China, which is characterized as water-scarce, and South China which has abundant water resources[3].

The dataset for this study consists of two categories: detailed economic data (input-output tables) – to investigate the flow of goods and services between producers and consumers and the linkages between all production sectors; and hydrological data – comprising four sub-categories: water availability, fresh water utilization and fresh

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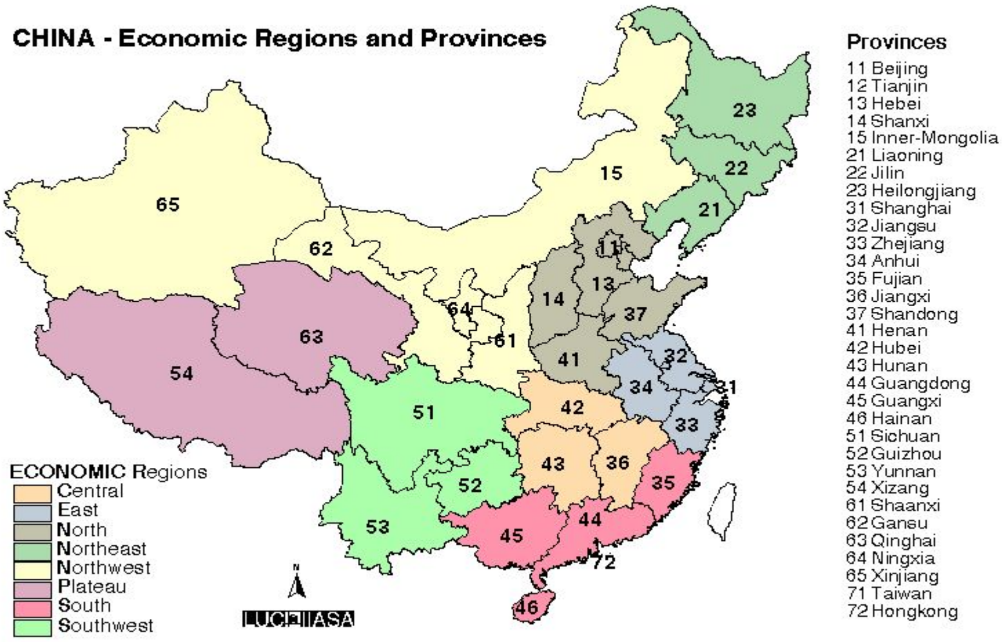
[2] The eight hydro-economic regions were distinguished in the "Land Use Change (LUC)" model, conducted by the LUC Group, International Institute for Applied Systems Analysis (IIASA). The eight regions are as follows: *North*, including Beijing, Tianjin, Hebei, Henan, Shangdong, and Shanxi; *Northeast*, including Liaoning, Jilin, and Heilongjiang; *East*, including Shanghai, Jiangsu, Zhejiang, and Anhui; *Central* including Jiangxi, Hubei, and Hunan; *South*, including Fujian, Guangdong, Guangxi, and Hainan; *Southwest* including, Sichuang, Guizhou, and Yunnan; *Northwest*, including Nei Mongol, Shananxi, Gansu, Ningxia, and XinJiang; and *Plateau*, representing Tibet and Qinghai.

[3] South China consists of Guangdong, Fujian and Guangxi, but we had only access to the data in Guangdong. Therefore in this study use Guangdong is used to represent South China.

water consumption coefficients and wastewater discharge coefficients for each of the economic sectors.

Figure 1: Hydrological – Economic Regions in China



(Source: Land Use Change Group at IIASA[4])

Economic Data

In our analysis we generate two regional input-output tables[5] (North and South China) by merging seven provincial input-output tables[6] for 1997 in terms of the classification of hydrological-economic regions (shown above, Figure 1). The provincial input-output tables, each representing 40 economic sectors, were compiled by the State Statistical Bureau of China and published in 2000. The "value-added" categories in the table include: capital depreciation, labor compensation, taxes, and profits. "Final use" at the national level comprises of six categories: rural households, urban households, and government consumption, fixed investment, inventory changes, and net exports.

Hydrological Data

The dataset for water availability of different regions is generated by employing a hydrological model, *Climate and Human Activities – sensitive Runoff Model* (CHARM), developed by Wiberg and Strzepek (2000). A basic problem in modeling water use

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5 Due to the lack of data, we could not construct a regional input-output table for the Plateau region.

6 Six provincial input-output tables for North China and one in South China (Guangdong).

within an economic framework arises from the discrepancy between economic regions and watershed regions. Demand figures for water use are based on economic boundaries and are derived from the input-output tables. The water supply figures have to be based on hydrological conditions. The hydrological model CHARM is used to redistribute the water resources from watershed regions to economic regions. CHARM is applied to the nine major water resource regions of China to estimate the natural available water supply which is then reallocated to the respective economic regions. The resulting water supply figures are an essential part of the regional water accounting tables and are also used to characterize the respective hydro-economic regions with regard to the water availability (see Table 2 below)

To calculate the water consumption side we need to know the amount of net water consumption from fresh water sources to produce a unit of output of a product or service – so-called fresh water consumption coefficients. Therefore in order to calculate the coefficients, this dataset consists of two sub-datasets: the total volume of net water consumption for each economic sector between seven regions; and the total output in monetary term for each sector correspondingly. The data of total output for each sector is given in the input-output tables. The dataset of water withdrawn for each sector was taken from *"China's Regional Water Bulletin*[7]*" in 1997*, *Regional Water Statistics Yearbook in 1999*[8] and annual reports on hydrology from various provincial hydrology-ministries. The economic sectors in the survey can be matched with the categories in the IO tables and updated to match the respective years.

In a similar fashion we proceed to calculate the effects on the wastewater side. Final wastewater discharge coefficients represent the amount of wastewater discharged to produce 10,000 Yuan of a certain product or service. The wastewater dataset is extracted from the *"Third National Industrial Survey" in 1995* and *"Regional Water Statistics Yearbook in 1999" and* various other authoritative sources (Dong 2000; Zhang 2000; Li 2003).

3. Interregional Virtual Water Flows in China

Water problems in China have been investigated in depth in a number of studies, especially with regards to the disparities of regional water availability in China (Wang and Davis 2000; Wiberg 2002; 2003). Table 2 lists and compares the per capita water availability for each of the economic regions. Generally speaking, anything below one thousand cubic meters per capita is considered as a seriously water-scarce region.

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[7] Published annually by Ministry of Hydrology in China
[8] State Statistical Bureau (1999), State Statistical Publishing House, Beijing, China

Table 2: Availability of Water Resources

Region	*Total fresh water resource ($10^8 m^3$)*	*Population in 2000 (in 1000s)*	*Per capita water resources (in m^3)*
North	*843.5*	*311,100*	*271.1*
Northeast	*1,529*	*106,334*	*1,437.9*
East	*1,926.2*	*198,149*	*972.1*
Central	*2,761.2*	*167,256*	*1,650.9*
South	*5,190.8*	*129,942*	*3,994.7*
Southwest	*6,389.8*	*243,414*	*2,625.1*
Northwest	*2,115.6*	*111,128*	*1,903.8*
		China Average	**2,271.0**
		World Average	**6,981.0**

(Source: Wiberg 2002 and China's Statistical Yearbook 2001)

The northern part of China is not endowed with abundant water resources, and thus from a resource conservation point of view, North China should import more water-intensive goods such as agricultural products and export less water-intensive goods in order to maintain a favorable trade balance while optimizing the utilization of water resources. Following this idea, we will look at North China, the most water-constraint region and compare it with South China, a region with abundant water resources,[9] by tracing the virtual water flows created by the interregional trade patterns in China.

Virtual Freshwater Flows

By employing Equation 1 to exports – **Total Water Consumption =** $\hat{f}\,(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{e}$**,** we are able to quantify virtual freshwater flows between economic sectors triggered by trade between various regions in China and abroad[10]. Thus we can show how much water is necessary to produce certain goods that are then exported to other regions, including both direct and indirect water consumption for producing the exports. This amount of water used in the production chain is thus not available for water consumption for other purposes within that region. Similarly, the import of certain goods into a region causes water withdrawal and consumption in other regions or outside of China[11]. The calculation of virtual water flows is conducted by multiplying the net exports vector (**e**) and the total fresh water consumption coefficient matrix ($\hat{f}$). The results are shown in Table 3 for North China and Table 4 for Guangdong.

[9] For South China we had only the data for Guangdong province; however it will not affect the general tendency of the results as the remaining two provinces (Fujian and Hainan) are in a similar situation as Guangdong with regards to economic conditions, trade patterns and water availability.

[10] Where, $\hat{f}$ represents the diagonalized vector containing freshwater consumption coefficients. And the final demand (**e**) represents the net exports of goods and services.

[11] Note: a more precise quantification would require bilateral trade information so that trade flows could be weighted with the direct water coefficient of the respective country of trade origin.

Table 3: Total Water Import / Export in North China

Region: North China	Net flows of goods and services (10,000 Yuan)	Direct freshwater Coefficient (m^3/10,000 Yuan)	Virtual freshwater Net Exports (Million m^3)	Value added/Water (Yuan/ m^3)
Rainfed Agriculture	1,859,505	862.0	3,055.1	8.1
Irrigated Agriculture	2,607,575		4,284.2	
Coal mining and processing	1,359,847	5.2	2.3	441.7
Petroleum and natural gas	864,149	5.1	1.5	428.8
Metal ore mining	546,304	4.8	0.4	344.7
Non-ferrous mineral mining	-2,430,346	4.7	-12.9	256.9
Food and tobacco processing	2,944,350	10.5	57.7	111.3
Textile goods	3,060,261	12.2	67.4	84.8
Wearing	2,431,617	4.0	11.6	308.0
Sawmills and furniture	619,342	5.0	3.8	348.3
Paper and products	993,460	18.0	28.6	83.3
Petroleum processing	-1,647,543	1.1	-2.5	693.6
Chemicals	-347,419	17.8	18.8	51.4
Non-metal mineral products	2,304,248	4.5	7.2	421.9
Metals smelting and pressing	-406,689	8.8	-17	98.2
Metal products	2,443,533	2.5	5.1	416.1
Machinery and equipment	-4,825,647	7.5	-53.3	167.7
Transport equipment	-312,987	3.2	-2	237.9
Electric equipments	-1,183,115	2.1	-9.6	201.2
Telecommunication equipment	-2,858,957	1.9	-31.5	104.1
Instruments	-552,792	2.3	-4.3	149.4
Maintenance machinery	-1,118,056	2.1	-5.9	116.3
Other manufacturing	2,742,628	8.5	25.9	215.7
Scrap and waste	-411,395	8.5	-3.7	355.7
Electricity	-3,589,807	41.5	-147.9	45.5
Gas production and supply	-49,679	10.0	-0.6	77.2
Water production and supply	-522,085	5.7	-5.5	181.9
Construction	-2,517,219	5.0	-12.1	503.7
Transport and warehousing	260,878	3.1	0.7	470.1
Post and telecommunication	245,262	2.4	1.4	881.8
Wholesale and retail trade	-1,749,342	2.2	-4.4	428.6
Eating and drinking places	47,464	2.2	0.2	877.5
Passenger transport	295,368	3.2	1.1	746.3
Finance and insurance	3,938,707	2.2	16.6	872.4
Real estate	-203,528	2.2	-0.2	1,251.7
Social services	278,293	1.8	2.1	723.3
Health services, social welfare	-182,955	3.3	-0.5	784.9
Education and culture	-1,341,098	3.1	-5.3	1,087.7
Scientific research	-12,857	2.4	-0.4	700.6
General technical services	1,533,501	4.0	6.5	1,321.3
Public and other services	205,888	5.0	1.7	815.0
Total Exports	31,582,180		4545.0	
Total Imports	-26,263,516		-319.6	
Net Exports	5,318,664		**4225.4**	

Note: the negative figures represent the inflows (imports) for both monetary and freshwater terms, and positive figures mean outflows (exports) for both monetary and freshwater terms.

Table 4: Total Water Import / Export in South China

Region: Guangdong	Net flows of goods and services (10,000 Yuan)	Direct freshwater Coefficient (m^3/10,000 Yuan)	Virtual freshwater Net Exports (Million m^3)	Value added/Water (Yuan/ m^3)
Rainfed Agriculture	-642,700.5	784.0	-228.9	8.8
Irrigated Agriculture	-982,407.5		-349.4	
Coal mining and processing	-1,507,207	4.4	-6	27.3
Petroleum and natural gas	-227,718	4.9	-9.6	223.0
Metal ore mining	-369,356	4.2	-3	96.5
Non-ferrous mineral mining	-622,501	4.0	-2.7	443.8
Food and tobacco processing	1,138,328	9.9	15.8	133.4
Textile goods	-1,827,158	11.3	39.7	112.4
Wearing	11,054,187	3.9	46.6	537.2
Sawmills and furniture	-892,070	4.9	-2.7	167.2
Paper and products	2,920,391	16.8	77.6	67.0
Petroleum processing	-2,950,551	1.3	-3.1	426.2
Chemicals	-3,848,076	16.7	0.1	42.4
Non-metal mineral products	333,439	4.9	2	383.8
Metals smelting and pressing	-6,187,180	8.2	-48.3	37.9
Metal products	1,332,070	2.7	4.7	507.0
Machinery and equipment	-1,276,310	6.9	-8.9	88.3
Transport equipment	802,771	2.9	2.7	544.7
Electric equipments	7,150,944	1.9	40.5	263.8
Telecommunication equipment	1,263,254	1.7	21.6	74.2
Instruments	2,108,399	2.1	11.3	193.8
Maintenance machinery	-8,916	1.6	0.1	413.5
Other manufacturing	-517,380	7.9	1.5	280.9
Scrap and waste	11,115	7.5	0.9	495.5
Electricity	160,907	37.9	5.3	38.9
Gas production and supply	-3,290	9.3	0	133.8
Water production and supply	-11,741	5.7	0.3	206.5
Construction	0	4.8	1.1	566.7
Transport and warehousing	-2,900,271	2.7	-11.1	331.8
Post and telecommunication	101,923	2.8	1.5	693.3
Wholesale and retail trade	-111,226	2.3	7.7	453.3
Eating and drinking places	337,216	2.3	3.9	548.3
Passenger transport	530,143	2.7	2.4	911.9
Finance and insurance	-1,289	2.1	2.5	614.6
Real estate	0	2.8	2.2	958.0
Social services	791,523	1.9	4.8	753.0
Health services, social welfare	0	3.2	-0.2	675.4
Education and culture	0	2.8	0	1,258.6
Scientific research	0	2.2	0.3	505.5
General technical services	0	3.6	0	702.9
Public and other services	0	4.6	0	592.3
Total Export	30,036,610		296.7	
Total Import	-24,887,348		-444.8	
Net Export	5,149,262		**-148.1**	

Note: the negative figures represent the inflows (imports) for both monetary and freshwater terms, and positive figures mean outflows (exports) for both monetary and freshwater terms.

The column of ‘net flow of goods and services’ in both Table 3 and 4 provides details of the commercial trade activities in the respective regional economy. The column of ‘direct freshwater coefficient’ gives the comparison of the direct water consumption levels for each production sector. For example, the coefficient for paper production measures the amount of freshwater directly consumed by paper-making industries to produce 10,000 Yuan of paper products. We can see from the tables that agriculture in both regions is the most water-intensive sector; and food processing, paper and textiles require more water per unit of output than the other industrial sectors. The column of ‘virtual freshwater net exports’ shows the amount of freshwater embedded in goods and services and exported to other regions or countries via trade. The term ‘value added/per unit of water’ in the last column of both tables assesses the amount each economic sector contributes to GDP per cubic meter of freshwater.

Based on our calculations we find that North China imported a number of water intensive products and services. For example, North China spent 35.89 billion Yuan to purchase extra electricity from other regions in 1997, which means a virtual import of 147.9 million cubic meters of water which is withdrawn and used up in production processes in other regions. Another example is agriculture: North China received 44.67 billion Yuan through the export of agricultural products, and with it 7,339.3 million cubic meters of virtual water have been transported to other regions. However, we have to consider that much of the agricultural land is rainfed in North China, which produces about 42% of total agricultural outputs. The amount of rainwater embedded in agricultural products would not be readily available for other economic production even if crops were not grown on this land. Therefore, the effective exportation of virtual water in the agricultural sector only consists of irrigated water, which is 4,284.2 million cubic meters. Annually, 4,545.0 million cubic meters of fresh water virtually flow out of North China (which is used in the production of exports) excluding rainwater in the agricultural production. On the other hand, the import of virtual water was only 319.6 million cubic meters, which reduces the net flow to other regions to 4,225.4 million cubic meters. From a water conservation point of view, North China, characterized as water-scarce, should import water-intensive products rather than produce them. According to this analysis, North China used up more than 5% of its total water resources for producing exports to other regions, mainly through the trade of water-intensive commodities such as agricultural crops, processed food, textiles and chemical products. By contrast, Guangdong is endowed with rich water resources, but virtually imported 444.8 million m^3 of freshwater, 79% of which are through the trade of water-intensive products (e.g. irrigated agricultural products). On the other hand, Guangdong exports relatively water non-intensive commodities such as electric equipment and many commercial and social services.

By summarizing the virtual freshwater flows of both North and South China, we find that the trade patterns are apparently inconsistent with our original hypothesis: water-scarce regions in China produce and export water-intensive products but import water non-intensive commodities. Meanwhile, water-abundant South China imports water-intensive goods. One of the possible explanations could be that water has not been recognized as an important factor of production in China’s economy as there are very low costs associated with the utilization of water resources for most of the production. Another reason could lie in the fact that North China has suitable climatic condition, soil and land for many agricultural crops (Heilig, Fischer et al. 2000). A third reason refers to the design of economic policies: Guangdong is subject to more favorable policies and better circumstances for investments in industry and services sectors than other regions. Since the economic reform in 1978, many locations in South China (including Guangdong) have been established as "Special Economic Development Zone", which brought many commercial opportunities and triggered a regional economic boom. This is also reflected in changing water consumption patterns. These economic incentives led to a restructuring of the regional economy to higher value added products with relatively lower levels of resource inputs. Thus Guangdong imports and exports of virtual water reflect the economic structure of the more developed regional economies within these special economic zones. On the other hand, North China has a relatively lower economic growth rate and stronger focus on low value added and high water intensive production without these special policies.

If we consider multiple factors relevant for the existing production and trade structure such as endowment (e.g. soil quality), land prices and other socio-economic or political factors we see that North China has a 'comparative advantage' for producing and exporting agricultural products. In terms of water conservation it is important to effectively balance these factors. North China may sustain the export of rainfed agricultural goods as rainwater cannot be effectively used by other production sectors. On the other hand, North China might want to reconsider the level of exports of irrigated agricultural products in order to make the scarce water resources (e.g. surface or ground water) available for other purposes which can contribute more to the economy and society in terms of value added and jobs.

From a water efficiency point of view, North China with limited water resources, should produce and export the commodities which have high value added per unit of water. By looking at the column of 'value added/water' in tables 3 and 4 North China has a comparative advantage in the production sectors of coal mining and processing, production of sawmill and furniture, machinery equipment, and many service sectors. Guangdong has an advantage in producing agriculture, textiles, and metal products. Obviously this statement needs to be qualified by looking at other factors such as the availability of skilled labor and other essential factors of production, but the focus on water can provide a useful starting point.

Virtual Wastewater Flows

Similar to the virtual freshwater flows, wastewater is also created through trade related production. The pollutants and wastewater generated for producing exported goods will stay in or pass through the exporting region leading to negative effects in terms of water availability and quality. In other words, the exporting region virtually accepts the discharge of wastewater from other regions by exporting goods. Similarly to virtual freshwater flows, we can calculate virtual wastewater flows consumed by producing exports for both North China and Guangdong. By employing Equation 2 – **Total Wastewater Generation =** $\hat{r}\,(\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{e}$**,** we are able to quantify virtual wastewater flows triggered by imports and exports between various regions in China and abroad. The direct wastewater coefficient refers to the amount of wastewater per unit of output. The results are shown in Table 5 for North China and in Table 6 for Guangdong.

Table 5: Total Wastewater Import / Export in North China

Region: North China	Net flows of goods and services (10,000 Yuan)	Direct wastewater Coefficient (m^3/10,000 Yuan)	Virtual wastewater New flows (Million m^3)	Value added/wastewater (Yuan/ m^3)
Agriculture	4,467,080	79.4	354.8	125.9
Coal mining and processing	1,359,847	10.2	4.7	220.8
Petroleum and natural gas	864,149	10.6	3.0	214.4
Metal ore mining	546,304	21.6	1.6	82.1
Non-ferrous mineral mining	-2,430,346	4.2	-10.4	321.1
Food and tobacco processing	2,944,350	4.2	20.1	320.0
Textile goods	3,060,261	6.9	39.9	143.4
Wearing	2,431,617	1.9	3.3	1071.3
Sawmills and furniture	619,342	1.3	2.5	539.1
Paper and products	993,460	19.2	27.2	87.7
Petroleum processing	-1,647,543	3.2	-5.0	346.8
Chemicals	-347,419	18.8	16.9	57.1
Non-metal mineral products	2,304,248	2.9	4.2	730.1
Metals smelting and pressing	-406,689	10.8	-15	111.6
Metal products	2,443,533	6.9	3.1	693.4
Machinery and equipment	-4,825,647	9.3	-49.8	179.5
Transport equipment	-312,987	4.6	-0.7	706.5
Electric equipments	-1,183,115	3.4	-5.4	357.0
Telecommunication equipment	-2,858,957	3.4	-17.7	184.7
Instruments	-552,792	5.2	-4.2	155.0
Maintenance machinery	-1,118,056	2.6	-2.3	304.6
Other manufacturing	2,742,628	6.6	18.9	295.7
Scrap and waste	-411,395	6.7	-2.7	480.0
Electricity	-3,589,807	0	0	0.0
Gas production and supply	-49,679	16.2	-1.0	47.1
Water production and supply	-522,085	16.9	-9.0	110.9
Construction	-2,517,219	8.3	-19.6	312.1
Transport and warehousing	260,878	4.4	0.6	534.2
Post and telecommunication	245,262	4.4	1.2	1002.0
Wholesale and retail trade	-1,749,342	2.5	-2.4	793.7
Eating and drinking places	47,464	2.9	0.2	1300.0
Passenger transport	295,368	2.6	0.7	1105.7
Finance and insurance	3,938,707	2.3	11.2	1292.4
Real estate	-203,528	2.1	-0.2	1854.3
Social services	278,293	2.1	1.4	1071.6
Health services, social welfare	-182,955	2.6	-0.4	1162.8
Education and culture	-1,341,098	1.7	-3.6	1611.4
Scientific research	-12,857	2.1	-0.3	1037.9
General technical services	1,533,501	1.8	4.4	1957.4
Public and other services	205,888	2.1	0.8	1811.2
Total wastewater associated with exports			520.7	
Total wastewater (generated in other regions) associated with imports			-149.7	
Net virtual wastewater			**371.0**	

Note: Negative figures for "net flows of goods and services" represent imports; for "virtual wastewater net flows" negative figures indicate the amount of wastewater generated (in the country) for producing such imports. Positive figures mean respectively value of exports and wastewater generated in conjunction with production of exports.

Table 6: Total Wastewater Import / Export in South China

Region: Guangdong	Net flows of goods and services (10,000 Yuan)	Total wastewater Coefficient (m^3/10,000 Yuan)	Virtual wastewater New flows (Million m^3)	Value added/wastewater (Yuan/ m^3)
Agriculture	-1,652,108	70.1	-149.4	142.5
Coal mining and processing	-1,507,207	9.5	-15.1	10.9
Petroleum and natural gas	-227,718	9.7	-23.9	89.2
Metal ore mining	-369,356	19.9	-15.8	18.4
Non-ferrous mineral mining	-622,501	3.5	-2.7	443.8
Food and tobacco processing	1,138,328	3.3	6.3	333.5
Textile goods	-1,827,158	6.4	27.0	165.3
Wearing	11,054,187	1.9	15.3	1634.9
Sawmills and furniture	-892,070	1.6	-2.5	181.2
Paper and products	2,920,391	17.3	86.7	59.9
Petroleum processing	-2,950,551	2.9	-9.3	142.1
Chemicals	-3,848,076	17.9	0.1	35.4
Non-metal mineral products	333,439	2.9	1.5	516.6
Metals smelting and pressing	-6,187,180	9.6	-53.2	34.4
Metal products	1,332,070	6.7	3.6	676.0
Machinery and equipment	-1,276,310	8.9	-8.9	88.2
Transport equipment	802,771	4.6	1.0	1510.0
Electric equipments	7,150,944	3.5	25.1	425.5
Telecommunication equipment	1,263,254	3.7	13.4	119.7
Instruments	2,108,399	4.9	12.0	182.8
Maintenance machinery	-8,916	2.7	0	984.5
Other manufacturing	-517,380	6.2	1.9	226.5
Scrap and waste	1,115	6.5	0.7	629.2
Electricity	160,907	0.0	0	0.0
Gas production and supply	-3,290	14.7	0	73.5
Water production and supply	-11,741	15.4	0.5	113.3
Construction	0	7.6	1.7	351.1
Transport and warehousing	-2,900,271	4.0	-9.8	377.0
Post and telecommunication	101,923	4.1	1.3	787.9
Wholesale and retail trade	-111,226	2.6	4.2	839.4
Eating and drinking places	337,216	2.7	2.6	812.3
Passenger transport	530,143	2.9	1.6	1351.0
Finance and insurance	-1,289	2.1	1.7	910.6
Real estate	0	1.9	1.5	1419.3
Social services	791,523	1.9	3.2	1115.6
Health services, social welfare	0	2.4	-0.1	1000.5
Education and culture	0	1.5	0	1864.5
Scientific research	0	1.9	0.2	748.8
General technical services	0	1.6	0	1041.3
Public and other services	0	1.9	0	1316.2
Total wastewater associated with exports			213.1	
Total wastewater (generated in other regions) associated with imports			-290.7	
Net virtual wastewater			**-77.6**	

Note: Negative figures for "net flows of goods and services" represent imports; for "virtual wastewater net flows" negative figures indicate the amount of wastewater generated (in the country) for producing such imports. Positive figures mean respectively value of exports and wastewater generated in conjunction with production of exports.

A number of pollution-intensive industries (e.g. metal ore mining, paper and chemical production) are concentrated in North China. Imports of North China lead to the generation of 149.7 million m^3 of wastewater in other regions where these commodities were produced. However, North China's exports resulted in 520.7 million m^3 of wastewater, of which 32% is industrial wastewater and 68% is agricultural wastewater. Hence, the net wastewater balance for North China was 371.0 million m^3. The discharge of high-concentrated pollution to surface flows from pollution-intensive production sectors (e.g. paper, chemicals and textiles) has led to the fact that the water of many major rivers in North China no longer supports any type of usage due to the low water quality levels; and more than 50% of groundwater has been seriously degraded due to the overuse of fertilizers and pesticides (Dong 2000).

Looking at the situation in the southern provinces we see that Guangdong's imports cause 149.4 million m^3 of agricultural wastewater and 141.3 million m^3 of wastewater from industrial and service sectors that pollute other regions' hydrological ecosystems. The industrial wastewater mainly originates from paper, textiles and electric equipment production sectors. On the other hand, Guangdong accepts 213.1 million m^3 of wastewater by producing exports for other regions. Hence the water-rich Guangdong region has a net wastewater balance of -77.6 million m^3 being virtually discharged to other regions.

Thus from the above figures for wastewater virtual trade, we can find a similar trade contradiction as with the virtual freshwater flows. A water-rich region such as Guangdong externalizes the problems of wastewater production to other regions through importing wastewater intensive products while water-short regions such as provinces in North China are putting additional pressure on their water resources and aquatic ecosystems through the creation of wastewater in conjunction with producing exports.

4. Conclusions

The economic success in China has come at the expense of over-exploitation of natural resources and huge impacts on the environment and especially water resources. In North China, water scarcity has become a major bottleneck for regional economic development. In this paper we have looked at the economic and trade structure of the water-scarce northern regions of China vis-à-vis the water abundant southern regions of China, and we assessed the implications for water resources in those regions by employing an extended regional input-output model for the hydro-economic regions in China. This study was one of the very first to use the concept of virtual water flows not only for agricultural products but also industrial and service production. In addition, we accounted also for wastewater flows and distinguished between rainfed and irrigated agriculture, which is of special significance with regard to water use. A major shortcoming of the wastewater flow analysis is the undifferentiated treatment of very different qualities of water inputs and wastewater categories.

Our starting point was the assumption that from a water conservation point of view, a region/country that is endowed with vast amounts of water resources should export relatively more water-intensive/polluted products such as agricultural crops, paper and chemicals. However, the results of virtual freshwater flows show that water-scarce North China predominantly produces and exports water-intensive products but imports less-water-intensive commodities. In comparison, water-abundant Guangdong in South

China imports water-intensive goods but exports less-water-intensive products. A similar situation can be found when considering wastewater: the water-scarce North generates more wastewater for export production than is virtually created (in other regions) through its imports; and similarly, the water-abundant South externalizes wastewater problems by importing wastewater-intensive products from other regions.

With regard to the magnitude of the virtual water flows, our results seem to indicate that the current structure of economy and trade do not pose much of a problem in terms of freshwater consumption as in North China only about 5% of total available water can be attributed to net virtual water flows, which is relatively small in comparison to other wasteful and unproductive water consumption, e.g., such as water losses due to infrastructural inefficiencies. Nevertheless, the water-scarce North China does not take full advantage of the possibilities of importing water-intensive products to ameliorate its own water problems. The same seems to be true for the wastewater situation.

To reflect on a more theoretical level, economic production and consumption use inputs of materials and resources from the environment. However, environmental resources are currently highly undervalued as there are often little or no costs associated with their use. Therefore, water usually does not play a sufficiently important role in production and consumption decisions. This is also reflected in current trade theories largely ignoring the environment as a factor of production. The same is true from a policy point of view; export-oriented policies often directly conflict with water-saving policies leading to so-called perverse incentives. On the other hand, given the relative inflexibility in changing production structures in comparison to technical improvements these findings emphasize the need for increased investments in water transportation infrastructure and water treatment plants. From a sustainability point of view it is important to emphasize that direct and indirect (virtual) water consumption needs to be incorporated in decision-making processes and public policies, especially for water-scarce regions such as North China, in order to achieve sustainable consumption and production in the future.

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