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Historical Trends in China's Virtual Water Trade

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Abstract: *Increasing water scarcity in China demands a more detailed analysis of water use in different sectors. In this paper, China's food import and export levels are analyzed in light of water availability. Their contributions to national water management in the form of virtual water are also evaluated. The findings show that the virtual water trade has developed unconsciously. This trend has been greatly influenced by micro- and macro-economic conditions, as well as fluctuations in weather conditions. Given the intensification of water scarcity, future food policy should promote an active application of virtual water strategies (such as virtual water trade and agricultural structure adjustment) to improve food security and sustainable water uses. With the progressive liberalization of food markets in China, virtual water trade is likely to play a more important role in future water resources management.*

Keywords*: crop water requirement; water value; water scarcity; food trade*

Introduction

Water resources and food production are closely interrelated. To guarantee food security for a population of some 1.3 billion, agriculture has been given a high priority in China (China's agenda 21, 1994). Water has and will continue to play an important role in increasing food production. In the past, irrigation has been crucial for achieving high crop yields and facilitating the application of new technologies and more intensive cultivation (Huang et al., 2002a). Yields increase between 30 % and 100 % when a cultivated area is irrigated (Huang et al., 2002b). At present, about three quarters of grain production comes from irrigated land. This, however, only accounts for 40 % of China's total arable land (Zhang, 1999).

On national average, China's per capita water resources availability is currently around 2200 m^3/year. This figure is about one-fourth of the world average (MWR, 1999; World Bank, 2000). The increasing water scarcity and the competition from other sectors have put agricultural water use under great pressure (Yang and Zehnder, 2001). There has been a reallocation of agricultural water to the industrial and domestic sectors and a compromise of environmental water needs (Yang and Zehnder, 2001). The share of agricultural water use has declined from 83.4 % of the total water uses in 1980 to 69.2 % in 1999 (Liu and Chen, 2001). The implementation of pricing and market mechanisms in water resources management will likely exacerbate this trend. Increasing water scarcity may constrain future yield rises (Huang et al., 2002a). As a consequence, food production can be affected. It is currently estimated that the average annual water deficiency in agriculture amounts to about 30 km^3/yr, decreasing food production by 25 Mt/yr (1Mt = 1 million ton) (Liu and Chen, 2001).

The negative impact of water scarcity on food production has led to growing concerns over China's food production, food security, as well as its competitiveness on the global food market (Liu and He, 1996; Shi, 1997; Brown and Halweil, 1998; Huang and Chen, 1999). By contrast, the role of virtual water trade in water resources management has rarely been addressed in China. The concept of virtual water describes a situation in which water scarce countries attempt to mitigate water shortage problem by importing food from other countries through international food markets (Allan, 1998; Yang and Zehnder, 2002; Yang et al., 2003). The study by Yang et al. (2003) strongly suggests, based on a vigorous statistical analysis, a direct link between water availability per capita and food imports when water becomes scarce. A number of other studies have also shown the importance of virtual water trade in compensating global water scarcity (Yang and Zehnder, 2002; Hoekstra and Hung, 2003; Zimmer and Renault, 2003; Oki et al., 2003; Yang et al., 2003; Chapagain and Hoekstra, 2004; Ma et al., 2005). So far, studies specifically focused on virtual water trade in China remain scarce, despite the country's struggles with increasing water scarcity. Thus, the question posed here is whether China should produce all food products domestically or if it could import part of the water-intensive food products. To answer this question, an extensive study on China's historical trends in virtual water trade is necessary.

Crop water requirement is the basis for estimating virtual water flows. In the few existing studies on the magnitude of virtual water trade in China, however, the accuracy of the crop water requirement value employed is rather poor. For example, the studies by Hoekstra and Hung (2003) and Zimmer and Renault (2003) assume that the water requirement of a particular crop is evenly distributed in China. Similarly, they calculate crop water requirements based exclusively on the climatic conditions of Beijing City. Of course, these assumptions are not appropriate. First, the water requirement of any crop differs greatly depending on climatic conditions. Considering the large variety of climatic conditions, average crop water requirement of China can not be determined based on one specific location (Zhang, 2003). Second, Beijing is not a suitable representative site for this kind of study. It is an industrialized city rather than a major agricultural area in China.

The crop water requirement for different crops has been comprehensively studied using measured data from experimental stations in China (Chen et al., 1995). We believe that it is most suitable to use the crop water requirement data from experimental stations as they have a good coverage of the major agricultural areas in China.

The present study provides an overview of the virtual water trade during the last four decades in China. The crop water requirement is based on the measured data from experimental research in China. The historical

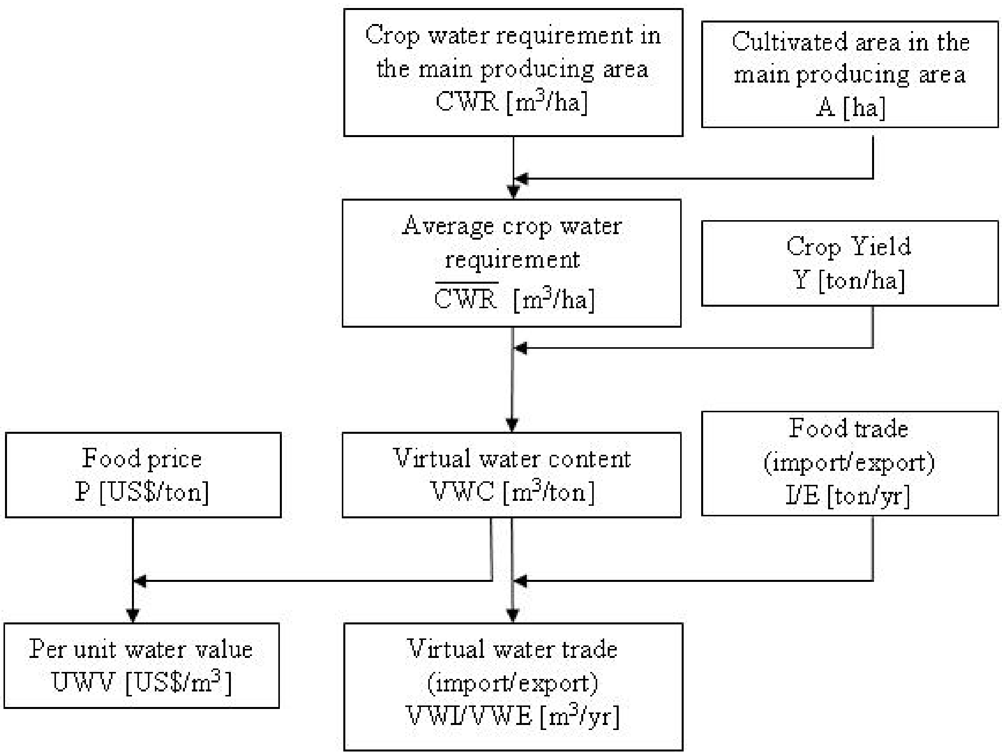

Figure 1. Steps to calculate the virtual water trade (import/export) for the major grain crops. Definition of the abbreviations are given in the text.

evolution of the virtual water trade (1961-2001) is then analyzed in the context of increasing water scarcity and changes in Chinese food and trade policies.

Methodology

The virtual water trade (import/export) was calculated as the food trade volume (ton/yr) times its virtual water content (m^3/ton). Thirty-two crops were taken into consideration in this study. These include 8 grain crops (rice, wheat, maize, soybean, millet, sorghum, potato, and barley), 6 fruit crops (apple, citrus, pear, water melon, banana, and grape), 8 vegetable crops (tomato, cabbage, carrot, cucumber, lettuce, onion, pea, spinach) and 10 other cash crops (cotton, pepper, groundnut, rapeseed, sunflower, sesame, sugar beet, sugarcane, tobacco, and tea). These crops constitute more than 80 % of the total harvested area of the primary crops in China (FAOSTAT, 2003). In this paper, we separated fruits and vegetables from other cash crops. The category "other cash crops", therefore, refers to cash crops except for fruits and vegetables. In China's statistics, the term "grain" refers to a mix of wheat, rice, maize, soybean, potatoes, millet, sorghum, and other miscellaneous crops (Yang, 1999). In this paper, we used this traditional definition and treated soybean as a grain crop.

The steps to calculate the virtual water trade (import/export) for the major grain crops, such as rice, wheat, maize and soybean, are depicted in Fig 1. For other grain crops, fruits, vegetables, and other cash crops, an average crop water requirement was used. Per unit water value (UWV), which refers to the value produced by one unit of water, was calculated for the analysis of virtual water strategy in China.

Crop Water Requirement (CWR)

Crop Water Requirement (CWR) refers to the accumulated crop evapotranspiration ET over the complete growing period with a unit of m^3/ha or mm. The crop water requirement for a certain crop in various years is not the same due to fluctuations in weather conditions. However, as yearly crop water requirement data are not available, we assume the same water requirement for a certain crop in different years in the same producing region.

For the major grain crops, such as rice, wheat, maize and soybean, the national crop water requirement average was calculated based on the crop water requirement in the main producing regions and the corresponding cultivated areas. The process of calculation was conducted as follows: for each crop concerned, major producing provinces were selected. Crop water requirement in these provinces was then determined based on the data in the literature. The national crop water requirement average of these crops was calculated with weighted average method shown in Eq. (1) (the weight is the cultivated area in the representative provinces).

$$\overline{CWR[c,j]} = \frac{\sum_{i=1}^{n} (CWR[c,i,j] * A[c,i,j])}{TA[c,j]} \quad (1)$$

Where $\overline{CWR[c,j]}$ is the national average crop water requirement for crop c in year j in China(m^3/ha), CWR[c,i,j] the crop water requirement for crop c in year j in main producing province i (m^3/ha), A[c,i,j] the cultivated area of crop c in the main producing province i in year j(ha), TA[c,j] the total area for crop c in year j in the selected main producing provinces (ha).

Crop water requirements in the main producing provinces can be obtained from "Main crop water requirement and irrigation of China" (Chen et al., 1995), which is the most authoritative literature for crop water requirements in China. Crop cultivated areas in the main producing provinces were taken from various volumes of the China Statistical Yearbook (NBSC, 2000; NBSC, 2001; NBSC, 2002).

For fruits, vegetables, and other cash crops, we used their average crop water requirement in the main producing regions in China. First, the range of crop water requirement was determined based on data in different experimental locations. The average crop water requirement was then estimated with the average value of the range.

Virtual Water Content (VWC)

Virtual water content (VWC) can be calculated by dividing crop yield by the average crop water requirement:

$$VWC[c,j] = \frac{\overline{CWR[c,j]}}{CY[c,j]} \quad (2)$$

Where VWC[c,j] is the virtual water content for crop c in year j (m^3/ton) and CY[c,j] the crop yield for crop c in year j (ton/ha). All other symbols have been defined earlier.

It should be pointed out that for this paper the virtual water content for rice was calculated with the total water requirement instead of the specific crop water requirement. Total water requirement refers to the sum of crop water requirement and the loss of water through percolation into the ground. For other crops, percolation is considered as a water loss. Efficient irrigation water management thus aims at reducing this kind of water loss. For rice, however, percolation does not mean a pure loss. It is necessary for achieving high rice yield in an anaerobic soil environment. Recent results from northern China have recorded "anaerobic" rice yields of 8.0-8.8 ton/ha in flooded lowland systems, which are much higher than the recorded "aerobic" rice yields of 4.7-6.6 ton/ha (Bouman et al., 2002). Many experiments in China have shown that sufficient percolation is needed for higher rice yields (Chen et. al., 1995). Using total water requirement in the calculation of CWP for rice is therefore reasonable.

Per Unit Water Value (UWV)

Per unit water value (UWV) refers to the value produced by one unit quantity of water [US$/$m^3$]. The following formula was used to calculate the per unit water value of crop *c* in year *j*:

$$\mathrm{UWV}[c, j] = \frac{\mathrm{NV}[c, j]}{\mathrm{VWC}[c, j]} \qquad (3)$$

Where UWV[j, c] is the per unit average water value for food item c in year j (US$/$m^3$), NV[j, c] the net value for food item c in year j (US$/ton). The net value is the difference between total output value and total costs. In this paper, only the material costs are considered. Labor cost is not taken into account because of the large number of surplus laborers. The opportunity cost of labor in China is low (Scott et al., 2002). The output value and material costs for various crops are obtained from SPB (2001).

Virtual Water Trade

Virtual water import (VWI) and virtual water export (VWE) were calculated based on Eq. (4) and Eq. (5), respectively. The net virtual water import (NVWI) was calculated based on Eq. (6):

$$\mathrm{VWI}[c, j] = VWC[c, j] \times I[c, j] \qquad (4)$$

$$\mathrm{VWE}[c, j] = VWC[c, j] \times E[c, j] \qquad (5)$$

$$\mathrm{NVWI}[c, j] = \mathrm{VWI}[c, j] - \mathrm{VWE}[c, j] \qquad (6)$$

Where VWI[c, j] is the virtual water import of food item c in year j (m^3/yr), VWE[c, j] the virtual water export of food item c in year j (m^3/yr), NVWI[c, j] the net virtual water import of food item c in year j (m^3/yr), I[c,j] the annual import of food item c in year j (ton/year) and E[c,j] the annual export of food item c in year j (ton/year). All other symbols have been defined earlier.

In this paper, the same VWC was used for estimating both VWI and VWE. This is in light of the fact that food export is a process of transferring virtual water from China to clients abroad, while food import can mitigate China's water scarcity by reducing water use in domestic food production.

The total virtual water import (TVWI) and total virtual water export (TVWE) were calculated with Eq. (7) and (8), respectively.

$$\mathrm{TVWI}[j] = \sum_{c=1}^{M} (\mathrm{VWI}[c, j]) \qquad (7)$$

$$\mathrm{TVWE}[j] = \sum_{c=1}^{N} (\mathrm{VWE}[c, j]) \qquad (8)$$

Where TVWI[j] is the total virtual water import in year j (m^3/yr), TVWE[j] the total virtual water export in year j (m^3/yr), M is the number of considered imported food items, N the number of considered exported food items.

Total net virtual water import (TNVWI) refers to the difference between total virtual water import and total virtual water export:

$$\mathrm{TNVWI}[j] = \mathrm{TVWI}[j] - \mathrm{TVWE}[j] \qquad (9)$$

Where TNVWI[j] is the total net virtual water import in year j (m^3/yr).

The volumes of imports and exports of grains, fruits, vegetables, and cash crops were obtained from

FAOSTAT (2003).

Estimation of Crop Water Requirement (CWR), Virtual Water Content (VWC), Per Unit Water Value (UWV) for Different Crops

Crop Water Requirement for Different Crops in China

Rice, wheat and maize are the three major grain

Crops	Experimental locations	Range of CWR (m^3/ha)	Average value $\overline{CWR}$ (m^3/ha)[a]
Rice	Hunan, Jiangsu, Jiangxi, Sichuan, Hubei and Anhui provinces	2500-6670	4550
Wheat	Henan, Shandong, Hebei, Anhui and Jiangsu provinces	3250-5500	4300
Maize	Shandong, Jilin, Henan, Hebei and Liaoning Provinces	3000-6000	4000
Soybean	Heilongjiang, Jilin, Henan, Neimenggu and Anhui Provinces	3500-5500	4900
Millet	Shanxi province	4230-4650	4440
Sorghum	Shanxi, Shaanxi and Henan provinces	3000-5000	4000
Potato	Shanxi province	3036	3040
Barley	Beijing	4100	4100
Apple	Liaoning province	3700-5300	4500
Citrus	Sichuan, Hunan and Guangdong provinces	7500-10000	8850
Pear	-	3700-6000	4850
Water melon	Qingdao city	3400	3400
Banana	Guangzhou city	11000-14800	12900
Grape	Zhangye city	5940	5940
Tomato	Shanxi province	3996-5502	4750
Cabbage	Shanxi province	3618-4400	4010
Carrot	Beijing	5601	5600
Cucumber	Shanxi province	4061-5747	4900
Lettuce	Beijing	3216	3220
Onion	Beijing	5687	5690
Pea	Shanxi province	4300-4562	4430
Spinach	Shanxi province	1599-3294	2450
Pepper	Shanxi province	3090-4413	3800
Cotton	Huanghe and Changjiang river basins	5000-6500	5750
Groundnut	North china, north-west, north-west and south regions	3000-6000	4500
Rapeseed	Sichuan, Shaanxi and Liaoning provinces	1370-4800	3090
Sunflower	Liaoning province	3850-4330	4090
Sesame	-	2800-4000	3400
Sugar beet	-	4600-5700	5150
Sugarcane	-	7500-10950	9230
Tobacco	-	4500-5500	5000
Tea	South-west regions	6000-13000	9500

Table 1.Crop water requirement for different crops in China. Source: Values for barley and grape are from Zhang (2003); other data are from Chen et al. (1995).

crops in China. Rice is the largest grain crop cultivated in China. It is also the traditional Chinese food, especially in the southern parts of the country. Hunan, Jiangsu, Jiangxi, Sichuan, Hubei and Anhui are the six main rice producing provinces. In 2001, rice production in these six provinces accounted for more than half of the nation's total rice production (NBSC, 2002). Wheat is the major "fine" grain in China, especially for the northern people (Yang, 1999). Wheat is mainly planted in northern and central parts of China. Henan, Shandong, Hebei, Anhui and Jiangsu are the five main producing provinces, accounting for nearly 70 percent of the total wheat production in China (NBSC, 2002). After rice and wheat, maize is the third most important grain. As a major feed grain, the proportion of maize will continue to increase with the growing demand for meat (Tong et al., 2003). Maize production is mainly located in the northeast and north parts of China, and in some parts of central China. Shandong, Jilin, Henan, Hebei and Liaoning are the five main maize producing provinces. More than half of the total annual maize production in China is from these five provinces (NBSC, 2002).

Soybean is mainly produced in the Northeast Plain and the Huang-Huai Plain. Heilongjiang, Jilin, Henan, Neimenggu and Anhui are the five main soybean-producing provinces. Soybean production in these five provinces accounts for nearly half of the total soybean production in China (NBSC, 2002).

The national average crop water requirement (CWR) is determined for the above four major grain crops based on Eq. (1), and the results are shown in Table 1. For other crops, the range and the average value of CWP are also given in Table 1.

Based on our calculation, *CWR* for rice is about 4550 m^3/ha. Percolation for rice ranges from 1106 m^3/ha to 5778 m^3/ha in China (Chen et al., 1995). An average of 3450 m^3/ha is used here. Therefore, the national average of 8000 m^3/ha (4550 plus 3450) will be used as the water requirement of rice in China.

Virtual Water Content (VWC) and Per Unit Water

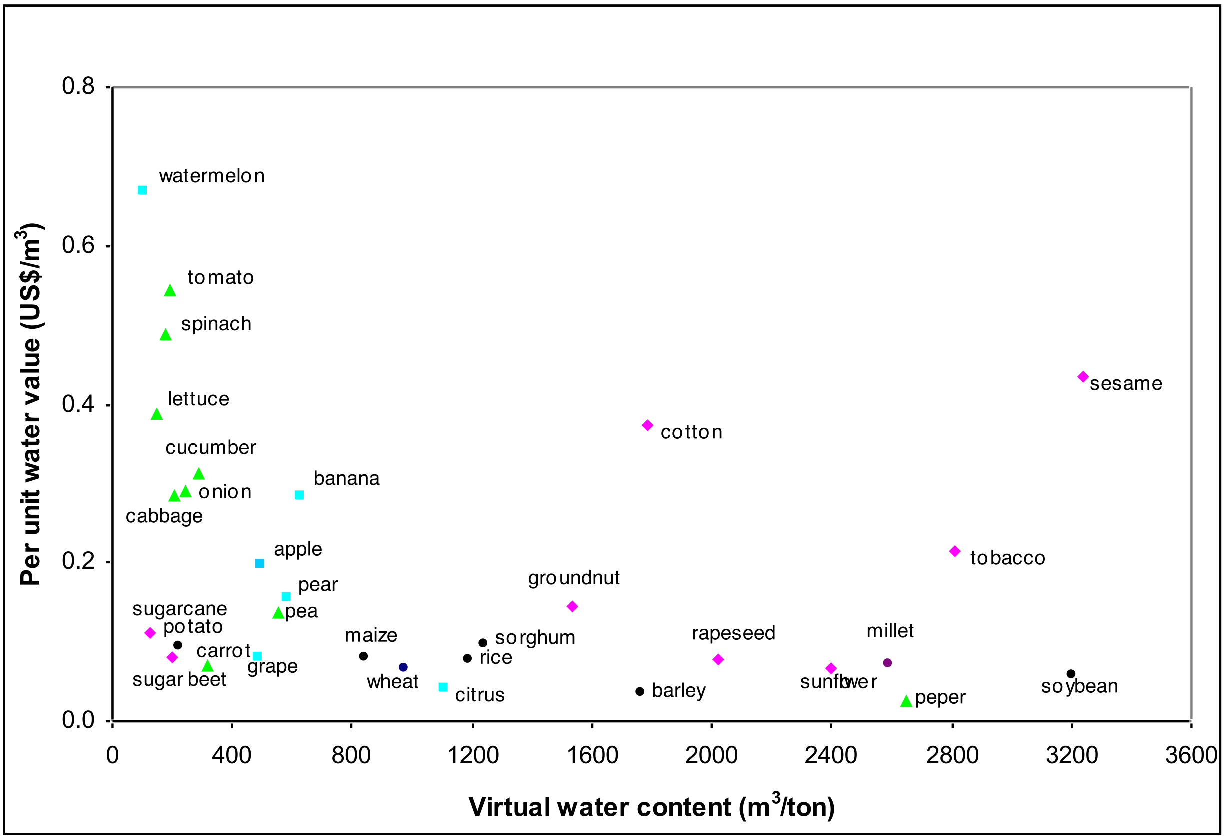

Figure 2. Average virtual water content (from Appendix A) and per unit water value for different crops in China (1999-2001. Full circles indicate grain crops, full squares indicate fruits, full triangles indicate vegetables, and full diamonds indicate other cash crops.

Value (UWV)

Virtual water content (VWC) was calculated based on Eq. (2) for the grain crops, fruits, vegetables and other cash crops. VWC for crops varies with the fluctuating crop yield in various years. The average VWC (1999-2001) was calculated by dividing the crop water requirement with the average crop yield during this period. Annual virtual water content was used for calculating virtual water trade in different years. For rice, wheat, maize and soybean, the average yields in the major producing areas are used. For other crops, the national average yields are used. The crop water requirement was based on the results shown in the previous section. The net value of the studied crops was derived from MAC (1999; 2000; 2001).

The VWC values for grain crops (except rice) are generally higher than those reported in Chapagain and Hoekstra (2004). The higher values of VWC are due mainly to the higher CWR values used in this study. For example, the estimated CWR value for wheat by Chapagain and Hoekstra (2004) is only 2560 m^3/ha, which is smaller than even the minimum value found in the literature for the major producing regions (see Table 1).

Per unit water value (UWV) was calculated based on Eq. (3). The average UWV (1999-2001) was calculated by dividing the average price by the average VWC during this period. Prices for different crops were obtained from FAOSTAT (2003). The VWC and UWV for different crops are given in Appendix A.

Generally speaking, fruits and vegetables have a relatively high UWV compared to grain crops and many other cash crops, while their VWC is relatively low (Fig 2). The economic output per drop of water attained in fruits and vegetables is typically higher. The results suggest that agricultural structure adjustment towards high water use value crops in water scarce countries is a way to optimize agricultural water use. Such an adjustment is also justified by the fact that China has an abundant labor force compared to many other countries in the world (Garnaut et al., 1996). China thus has a comparative international advantage in the production of labor-intensive goods, such as fruits and vegetables (Huang, 2000; Huang and Chen, 1999). In addition,

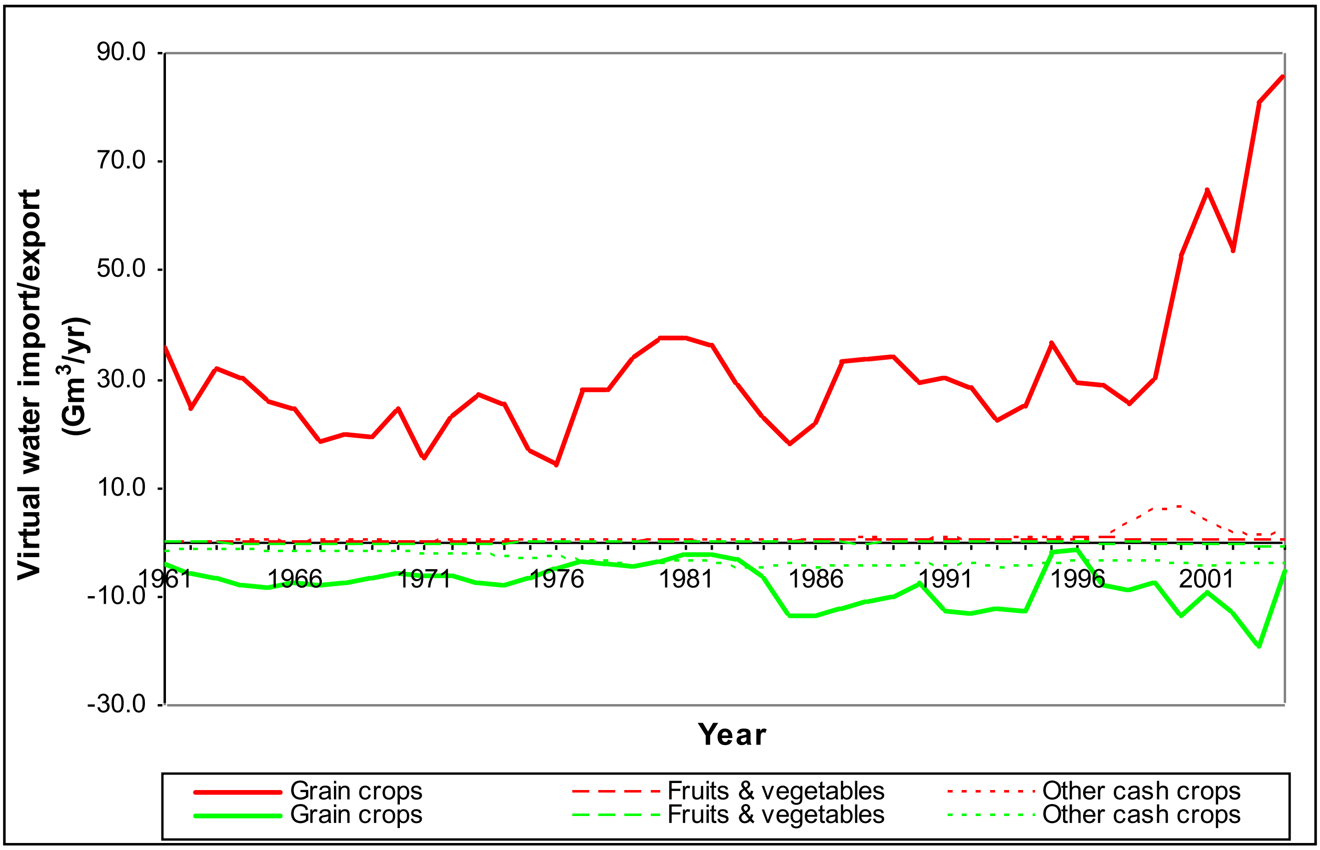

Figure 3.Virtual water import (VWI) and virtual water export (VWE) of different crops in China (1961-2004). Red lines indicate virtual water import, while green lines indicate virtual water export.

fruits and vegetables are more suited to water-saving irrigation practices, such as drip irrigation and spray irrigation (Lohmar et al., 2003). When water becomes a major constraint and economic cost factor to agricultural production, improving per unit water value through agricultural structure adjustment is one of the rational options to increase water use efficiency.

Historical Trend of Virtual Water Trade in China

Grain crops were overwhelmingly dominant in virtual water import (VWI) in any given period observed (Fig. 3). The VWI of grain crops accounted for over 95% of total VWI for the entire study period, except for recent years such as 1999, 2000, and 2001. VWI of fruits and vegetables has been marginal. VWI of cash crops was also small before 1997. After that, it increased and reached a peak in 2000 and then declined. The dominance of grain crops in virtual water export (VWE) was not as evident as in VWI. But VWE of grain crops was still quite important except for certain periods, namely 1976-1984, 1991, 1995 and 1996. VWE of fruits and vegetables was small, while VWE of other cash crops was significant. Tea was the most important cash crop for VWE, accounting for approximately 66% of the total VWE of cash crops. Next to tea, groundnut, tobacco, sesame and sunflower added significantly to VWE.

The annual total virtual water import (TVWI) of all crops saw a general increase, with an average of 25.5, 32.0, and 44.9 km^3/yr during the periods 1961-1980, 1981-1990 and 1991-2004, respectively. The annual TVWI has increased dramatically in recent years, from 30.2 km^3/yr in 1997 to 88.1 km^3/yr in 2004.

The annual total virtual water export (TVWE) of all crops also saw an increase, with an average TVWE of 9.0, 12.7, and 14.3 km^3/yr during the periods 1961-1980, 1981-1990 and 1991-2004, respectively.

China had a significant total net virtual water import (TNVWI). The annual TNVWI of all crops was 16.5, 19.3, and 30.6 km^3/yr during the periods 1961-1980, 1981-1990 and 1991-2004, respectively. It is worth noting that in this study the annual average TNVWI was 31.5 km^3/yr during the period 1997-2001. This value is

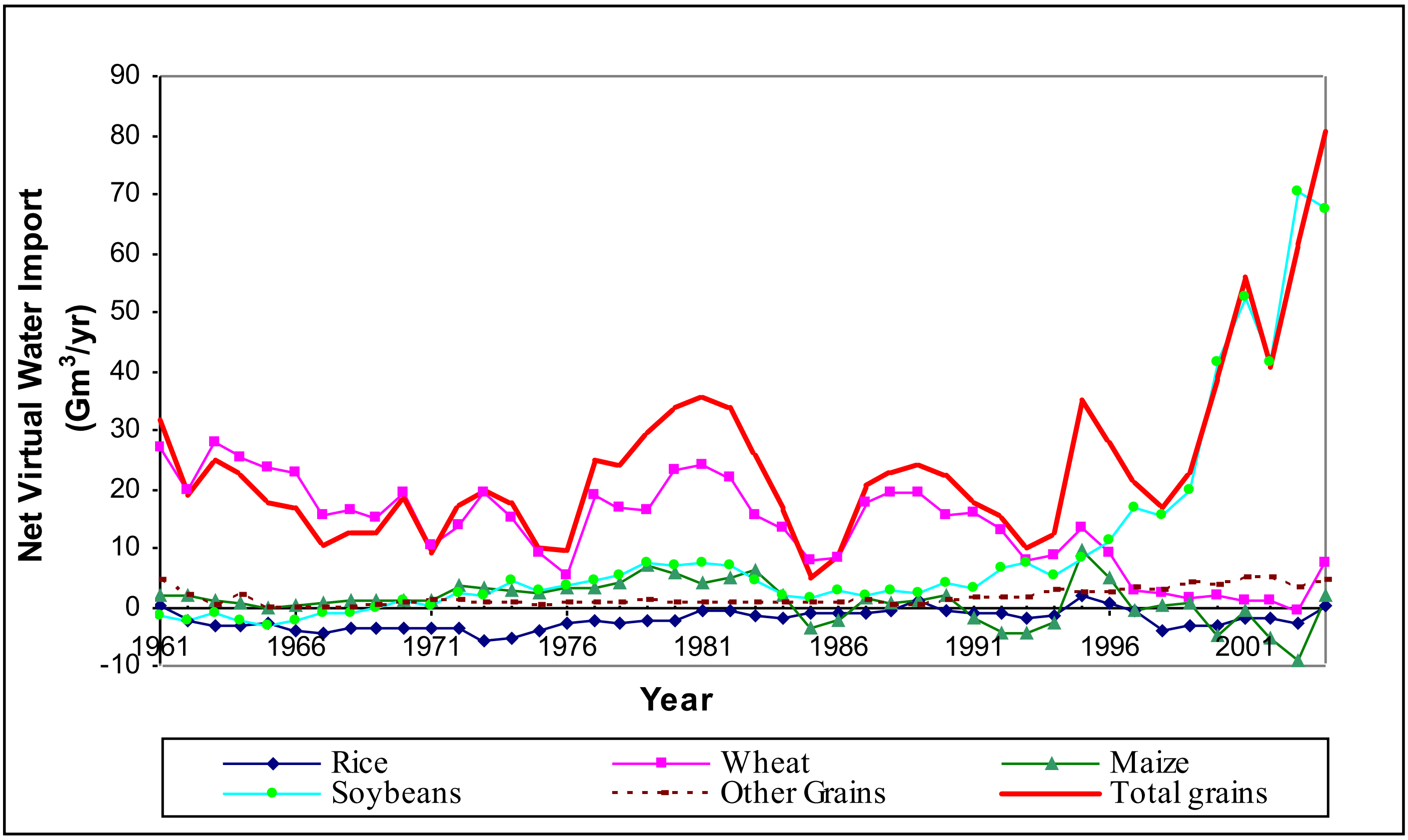

Figure 4. Net Virtual Water Import (NVWI) of different grain crops in China (1961-2004). Red line without marks indicates the TNVWI of all grains.

much higher than 18.8 km^3/yr for the annual average TNVWI in the same period estimated by Chapagain and Hoekstra (2004). The difference is due mainly to the different VWC used in the calculation.

There was a remarkable peak in the net virtual water import (NVWI) of individual crops in 1995 (Fig. 4). The NVWI of total grains increased by a factor of 2.7, while the TNVWI of all crops increased by a factor of 3.4. This can be explained by changes in micro- and macro-economics, as well as weather fluctuations. First, the two-digit inflation rates in 1992-1995 resulted in higher grain stocks by farmers, thereby reducing market supply (Lin, 1997). Second, as farmers in grain-deficit coastal provinces lost their comparative advantage in grain production, grain cultivation declined (Lin, 1997). Thirdly, there was a serious drought in the main grain producing regions in 1994, decreasing total grain production by 2.5 % (NBSC, 1995). The shrinking supply combined with the continuing increase in demand led to a price hike; indeed, the grain price increased by 31% in 1993, 51% in 1994, and 36% in 1995, over the previous years (Lin, 1997). The situation resulted in more food imports from the international market. In 1995, for example, China imported 20 Mt of grain (FAO, 2003), leading to the dramatic increase in TNVWI.

In 1995, Brown (1995) published a pessimistic projection on China's food situation. He stated that by the year 2030, China would have a grain shortfall of approximately 200 million tons, which could not even be filled by the grain surplus from the rest of the world. The pessimistic projection imposed a great pressure on the Chinese government. In early 1995, the central government introduced a so-called 'rice bag program,' whereby the provincial governors were made responsible for grain production and supply. Partly due to this policy, grain production and market supply recovered to some extent afterwards. The NVWI for rice, wheat and maize has shown roughly a declining trend since the mid 1990s.

Despite the improved rates of grain production and supply, the tightened governmental control was mainly applied to staple food grains. In contrast, since the mid 1990s, the market control on soybean was significantly relaxed; indeed, since that time, trade for soybeans has been more open and competitive. Restrictions against importing soybeans were almost completely removed during 2000 and 2001 (Carter and Rozell, 2001). As a result, the NVWI for soybean has increased continuously since that time. In 2004, NVWI of soybean reached 67.3 km^3/yr, eight times of the amount in 1995.

Soybean is a water-intensive and low water use value crop. Given China's relatively unfavorable water endowments (Albersen et al., 2002; Wang et al., 2002; Yang and Li, 2000; Yang and Zehnder, 2001), the increase in the soybean import is inevitable when state intervention in the soybean trade is reduced. Soybean imports, for example, increased sharply from 2.9 Mt/yr in 1995 to 16.4 Mt/yr in 2001 (FAOSTAT, 2003). This was a significant contribution to the TNVWI,, which increased to 55.3 km^3/yr in 2001. In 2004, TNVWI reached to a historical peak of 78.1 km^3/yr.

This study suggests that the virtual water trade has only been conducted unconsciously. For food security, the government pays more attention to food self-sufficiency than to water use efficiency. Food self-sufficiency is overwhelmingly favored by the Chinese government, which regards reliance on international food markets as a threat to domestic security (Yang and Huang, 1997). Although they have relaxed this stance to some extent, the government still insists on maintaining a self-sufficiency rate at above 95% (State Council, 1996). When market supply was tight, the government quickly responded by implementing a series of measures to encourage domestic food production and supply, including the 'rice bag program' initiated in early 1995. In the short run, these measures do lead to an improvement in domestic food production. However, in the long run, these measures may not be viable.

Water scarcity has become an increasingly pressing constraint to agricultural production in China. The competition from industrial and domestic sectors only intensifies this situation. In addition, self-sufficiency policy may result in more unsustainable water uses at the expense of environmental deterioration. This is detrimental to long-term food security (Cheng et. al, 1996; World Bank, 1997).

China is in rapid transition from a socialist system to one in which an increasing proportion of its goods and services, including food, are being allocated by market forces (Rozelle et al., 1995; Sicular, 1995). The trade pattern has been, and will continue to be, influenced by the transition. The soaring NVWI of soybean, for example, is a result of this change. With China's accession to WTO in 2001, the government is obliged to gradually remove the food trade intervention. A more free food trade is expected in China in the future. This may allow for a conscious and wise use of virtual water trade to improve national food security and sustainable water uses in the long run.

Concluding Remarks and Policy Implications

Increasing water scarcity gives rise to the need to study the virtual water trade in China. Our investigation shows that the total net virtual water import (TNVWI) of crops has seen large annual fluctuations over the past 40 years, but has increased significantly in recent years. In 2004, the TNVWI reached a historical peak of 78.1 km^3/yr, which was equivalent to 11 % of the total water requirement for domestic crop production in China.

The analysis suggests that China's food trade has been responding unconsciously to its relatively poor water endowment, despite the government's inattention to virtual water trade. With the intensification of water scarcity, decision makers should take China's water resources situation into consideration when making food trade policies, e.g. to relax the restriction on the imports of high water-intensive crops (for example, soybean) and encourage exports of high water use value crops (such as fruits and vegetables).

Apart from virtual water trade, agricultural structure adjustment is another important approach for the application of the virtual water strategy. From the perspective of both the Chinese government and of scholars, agricultural structural adjustment includes structure changes among agricultural commodities, quality improvement of major commodities and the promotion of regional specialization (Huang and Rozelle, 2002). The goal of the agricultural structural adjustment is to achieve the so-called "three-high" agriculture: high output, high quality and high efficiency. The findings in this paper show that most high water value crops, such as fruits and vegetables, are low water-intensive crops. They are also more suited to water-saving irrigation. Thus, shifting to high water value crops can increase farmers' incomes without increasing agricultural water consumption. This is clearly conducive to a more efficient use of agricultural water.

Given the highly uneven distribution of water resources in China, the virtual water strategy could be a promising measure in dealing with regional water scarcity. It is worth noting that the Chinese government has paid increasing attention to economic development and ecosystem protection in the western regions (the so-called "Western Development Strategy" launched in 1999). Since water is a major limiting factor for the western regions, the virtual water strategy could be applied as a policy option to improve the economic situation in these regions. In recent years, the Chinese government has launched a 'Grain for Green Project' to adjust agricultural structure in the western regions. Farmers receive subsidies in the form of grain after they turn cultivated land into forest and pasture. This project presents essentially another facet of the virtual water strategy to save agricultural water use for ecological and environmental purposes.

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Crop Items	*CWR (m^3/ha)*	*Yield (ton/ha)*	*VWC (m^3/ton)*	*Net Value (US$/ton)*	*UWV (US$/$m^3$)*
wheat	4300	4.41	975	64.30	0.06
maize	4000	4.74	844	68.25	0.08
soybean	4900	1.53	3203	184.65	0.06
rice	8000	6.72	1190	91.91	0.07
millet	4440	1.72	2586	190.37	0.07
sorghum	4000	3.23	1240	121.72	0.10
potato	3040	13.53	225	21.06	0.09
barley	4100	2.33	1760	65.72	0.04
apple	4500	9.09	495	97.80	0.20
citrus	8850	8.00	1106	47.45	0.04
pear	4850	8.30	584	91.25	0.16
watermelon	3400	32.00	106	71.19	0.67
banana	12900	20.60	626	178.00	0.28
grape	5940	12.19	487	40.00	0.08
tomato	4750	25.13	189	102.60	0.54
cabbage	4010	19.25	208	59.24	0.28
carrot	5600	17.79	315	22.00	0.07
cucumber	4900	16.97	289	90.56	0.31
lettuce	3220	21.47	150	58.00	0.39
onion	5690	23.47	242	70.00	0.29
pea	4430	8.05	550	75.07	0.14
spinach	2450	13.63	180	87.43	0.49
peper	3800	1.43	2651	70.00	0.03
cotton	5750	3.23	1782	667.76	0.37
groundnut	4500	2.94	1532	221.70	0.14
rapeseed	3090	1.53	2020	157.23	0.08
sunflower	4090	1.70	2401	161.74	0.07
sesame	3400	1.05	3238	1412.10	0.44
sugar beet	5150	25.54	202	16.14	0.08
sugarcane	9230	74.40	124	13.96	0.11
tobacco	5000	1.78	2809	604.97	0.22
tea	9500	0.78	12227	581.88	0.05

Appendix A. Crop water requirement (CWR), virtual water content (VWC), and per unit water value (UWV) for different crops (1999-2001 average).

Source: Yields for rice, wheat, maize and soybean are from NBSC (2001) and represent the average yields in the major producing areas; yields for other crops are from FAOSTAT (2003) and represent the national average yields. CWR of rice is the sum of crop water requirement and percolation.