VIRTUAL WATER TRADE IN A GENERAL EQUILIBRIUM ANALYSIS

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Abstract

Water problems are typically defined and studied at the level of the river catchment. Yet, 80% of all water is used for agriculture, and agricultural products are traded internationally. A complete understanding of water use is therefore impossible without understanding the international markets for food and other agricultural products, such as textiles. The water embedded in commodities is also called virtual water.

Based on a general equilibrium model this study offers a method for investigating the role of water resources and water scarcity in the context of international trade by analysing virtual water flows. We run four alternative scenarios, some with variants. The first three scenarios are directly concerned with water resource policies. The first two scenarios are quantity scenarios. The third is a water pricing scenario. In the fourth scenario we consider a trade liberalization reform in the agricultural sector. Unlike the first three scenarios, the latter deals with trade policy in water-intensive industries.

Keywords: Computable General Equilibrium, Virtual Water, Water Scarcity

JEL Classification: D58, Q25, Q28

1 Introduction

Water is one of our basic resources, but it is often short. Estimates have shown that the total amount of water available would be sufficient to provide present world population only with a minimum amount of freshwater required. However, the uneven distribution of water (and population) among regions has made the adequate supply critical for a growing number of countries. A rapid population growth and an increasing consumption of water per capita has aggravated the problem. This tendency is likely to continue as water withdrawal for most uses is projected to increase by at least 50% by 2025 compared to 1995 level (Rosegrant *et al.* 2002). One additional reason for concern is (anthropogenic) climate change. Climate change models predict that geographic differences in rainfall are likely to become more pronounced with increased precipitation in high latitudes. The predictions for temperature indicate that the majority of the warming is expected to occur during winter months and in high latitude countries (Intergovernmental Panel on Climate Change, 1998 and 2001).

Water problems are typically defined and studied at the level of the river catchment, if not at a finer spatial scale. This is a valid approach for many applications. Yet, 80% of all water is used for agriculture, and agricultural products are traded internationally. A complete understanding of water use is therefore impossible without understanding the international markets for food and other agricultural products, such as textiles. This study offers a method of studying the role of water resources and water scarcity in the context of international trade.

Under the heading of "virtual water", people have studied the implicit water content of internationally traded commodities. Chapagain and Hoekstra (2004) e.g. calculate a global virtual water flow of 16% of total global water use. However, these studies are descriptive: Virtual water flows are estimated, but changes in either water resources or economic circumstances cannot be assessed, or perhaps only with a linear model. In contrast, our non-linear model allows for the analysis of virtual water flows for many scenarios.

Other studies, notably the work by Rosegrant *et al.*, have used partial equilibrium models for scenario studies. Our general equilibrium approach allows for a richer set of economic feedbacks and for a complete assessment of welfare implications. The analysis is based on countries' total renewable water resources and differences in water productivity. Growing e.g. wheat in an North African country requires more water than growing it in the US. Also, different cop types have different crop water requirements; and regions grow different crop varieties. The production of a ton of rice is e.g. more water intensive than the production of a ton of wheat.

The paper proceeds as follows. Section 2 reviews the literature. Section 3 presents the model used. Section 4 discusses the scenarios. Section 5 analyses the results. Section 6 discusses and concludes.

2 Previous studies

As the supply of water is limited, attempts have been made to economize on the consumption of water especially in regions where the supply is critical. One way to address the problem is to reduce the inefficiencies in irrigation and urban water systems from existing water uses.

For some developing countries the average irrigation efficiency is far below what is achievable. But even for countries not being short of water there seems to be room for improvement (Seckler *et al.*, 1998). Theoretical and empirical studies have shown that an increase in water price is positively correlated with adoption of improved irrigation technology (Dinar and Yaron, 1992). However, in many regions water is subsidized. In urban water systems water for either domestic or industrial use is wasted through leakage. This is particularly pronounced for large cities in Africa, Asia, Latin America and even in the water-scarce Middle East (Rosegrant *et al*., 2002). However, as the inefficiencies are unevenly spread over regions the potential for savings is generally limited.

An alternative to meet the increasing demand for water is the desalination of brackish or seawater. Continues progress in desalination technology has lead to considerably lower costs of water produced by desalination and thereby rapidly expanded the use in arid, semi-arid and water-short regions. Today the costs are competitive with costs of long-distance water transport systems where water is transported from places where it is abundant to places where it is scarce (Ettouney *et al.*, 2002). However, desalination is not a solution for all regions. Zhou and Tol (2005) found that the transportation of desalinated water becomes prohibitively expensive in highlands and continental interiors.

Another possibility to minimize water use in water-short countries is to increase imports of products that require a lot of water in their production. The water embedded in commodities is also called virtual water (Allan, 1992 and 1993).[1] A recent study by the UNESCO-IHE Institute for Water Education on global virtual water trade for the period 1997-2001 revealed that in order to produce e.g. one tonne of rice on average 2,700 m^3 of virtual water are

[1] We use the production site definition introduced by Allan (1992 and 1993). The virtual water content of a product can also be defined as the volume of water that would have been required to produce the product in the place where it is consumed (consumption site specific definition).

necessary (see Chapagain and Hoekstra, 2004).[2] For livestock products the numbers are much higher. Of course, due to differences in climate conditions and animal diets the numbers differ significantly between countries. According to the study, 67% of the global virtual water trade is related to international trade of crops, 23% is related to trade in livestock and livestock products and only 10% is related to trade in industrial products. In total 15% of the water used in the world for domestic and industrial consumption is exported as virtual water. They found countries like the US, Canada, Australia, Argentina and Thailand being the biggest net exporters and countries like Japan, Sri Lanka, Italy, South Korea and the Netherlands being the biggest net importers of virtual water. Of course, relative to a country's water resources the picture is different. Especially countries in the Middle East and North Africa import a lot of virtual water. Although some of those countries are also big exporter relative to their actual water resources (e.g. Kuwait and Tunisia), especially European countries are exporting a significant share of their water.

As the water requirements for food production for future population is huge, virtual water might be seen as an additional source of water to water-scarce countries. And indeed, much of the existing literature stressed the political relevance and emphasized the role of virtual water in providing food security in water-short regions (Bouwer, 2000; Allan and Olmsted, 2003). Some researchers have even argued that virtual water trade could prevent wars over water (Allan, 1997). Others fear that regions become dependent on global trade and vulnerable to fluctuations. Food security might then not be warranted. An alternative would be to support the production of crops that use little water in water-scarce regions. Still, most net importing countries have no explicit strategy for virtual water trade (Yang and Zehnder, 2002). Another branch of the literature has compared the concept of virtual water trade to the economic concept of comparative advantages (see e.g. Wichelns, 2001 and 2004; Hakimian, 2003).

[2] Earlier studies are Hoekstra and Hung, 2002 and 2003; Chapagain and Hoekstra, 2003.

Although the concept of virtual water trade is appealing, the number of empirical studies is limited. Two other studies exist providing estimates on global virtual water trade, one by the World Water Council (WWC) in collaboration with the FAO (Food and Agricultural Organization of the United Nation) and one by a Japanese research group.[3] Although different in data applied and methodologies used the estimates are close to the study carried out by the UNESCO-IHE (see above). Others have investigated why the virtual water trade balance is positive for some countries and negative for others. Yang *et al.* (2003) found evidence that virtual water import for cereals increases with decreasing water resources. Hoekstra and Hung (2002, 2003) compared water scarcity and water dependency and found the results for some countries unexpectedly signed.

One aspect which has not attracted much attention yet are changes in virtual water trade over time. Yang *et al.* (2003) used population predictions to calculate the annual water deficit for water-scarce countries by 2030.[4] Unsurprisingly, they found an exponential increase. Rosegrant *et al*. (2002) used the IMPACT-WATER model to estimate demand and supply of food and water to 2025.[5] In their most recent paper, they included virtual water trade using cereals as an indicator (Fraiture *et al*.,2004). Their results suggest that the role of virtual water trade is modest. While the IMPACT model covers a wide range of agricultural products and regions other sectors are excluded; it is a partial equilibrium analysis. In this paper we use a computable general equilibrium model of the world economy to analyze policies that would reduce the pressure on water resources. More specifically, our policies increase e.g. the price

[3] Results for the first study are reported by Renault (2003) and Zimmer and Renault (2003) and for the second by Oki *et al.* (2003).

[4] Calculations are based on cereal imports.

[5] Projecting for water demand and supply to 2025 are provided by Seckler *et al.* (1998). A detailed analysis of the world water situation by 2025 is given by Alcamo *et al.* (2000).

of water or water-intensive products. We consider various water pricing scenarios, and study the effects on virtual water flows, international trade in agricultural products, and welfare.

3 Modeling framework and data

To assess the systemic, general equilibrium effects on virtual water trade induced by different policy scenarios, we use a multi-region world CGE model, called GTAP-EWF. The model is a further refinement of the GTAP model[6] (Hertel, 1997) in the version modified by Burniaux and Truong[7] (2002). Basically, in the GTAP-EWF model a finer industrial and regional aggregation level, respectively, 17 sectors and 16 regions, is considered, and water resources, as non-market goods, have been modeled.[8] The model is based on 1997 data.

As in all CGE models, the GTAP-EWF model makes use of the Walrasian perfect competition paradigm to simulate adjustment processes. Industries are modeled through a representative firm, which maximizes profits in perfectly competitive markets. The production functions are specified via a series of nested CES functions (*figure A1 in Annex*). Domestic and foreign inputs are not perfect substitutes, according to the so-called "Armington assumption", which accounts for product heterogeneity.

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[6] The GTAP model is a standard CGE static model distributed with the GTAP database of the world economy (www.gtap.org). For detailed information see Hertel (1997) and the technical references and papers available on the GTAP website.

[7] Burniaux and Truong (2002) developed a special variant of the model, called GTAP-E. The model is best suited for the analysis of energy markets and environmental policies. There are two main changes in the basic structure. First, energy factors are separated from the set of intermediate inputs and inserted in a nested level of substitution with capital. This allows for more substitution possibilities. Second, database and model are extended to account for CO_2 emissions related to energy consumption.

[8] See *Annex table A1* for the regional, sectoral and factor aggregations used in GTAP-EWF.

A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labour and capital). Capital and labour are perfectly mobile domestically, but immobile internationally; whereas, land and natural resources are industry-specific. Economic welfare is derived from the allocation of national income between three classes of expenditure: aggregate household consumption, public consumption and savings (*figure A2 in Annex*). The expenditure shares are generally fixed, which amounts to saying that the top level utility function has a Cobb-Douglas specification. Public consumption is split in a series of alternative consumption items, again according to a Cobb-Douglas specification. However, almost all expenditure is actually concentrated in one specific industry: non-market services. Private consumption is analogously split in a series of alternative composite Armington aggregates. The functional specification used at this level is the Constant Difference in Elasticities (CDE) form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods.

In the GTAP model and its variants, two industries are treated in a special way and are not related to any region. International transport is a world industry, which produces the transportation services associated with the movement of goods between origin and destination regions, thereby determining the cost margin between f.o.b. and c.i.f. prices. Transport services are produced by means of factors submitted by all countries, in variable proportions. In a similar way, a hypothetical world bank collects savings from all regions and allocates investments so as to achieve equality of expected future rates of return.

The model computes a money metric measure of economic welfare, the equivalent variation. Its decomposition leads to the following welfare contributions: allocative efficiency, technical efficiency, endowment and terms of trade.

In our modeling framework, water is combined with the value-added-energy nest and the intermediate inputs as displayed in *figure A1 (Annex)*. Note that, at the upper level, the production function of tradeable goods and services has a Leontief structure. Water is supplied to the agriculture (including primary crop production and livestock) and water distribution services sectors. Water as a production factor for processed agricultural products is not considered to avoid double counting. Changes in regional water resource uses are calculated as the sum of weighted changes in water resource uses by industry. Water is assumed to be perfectly mobile amongst the agricultural sectors, including rice (Rice), wheat (Wheat), cereals and crops (CerCrops), vegetables and fruits (VegFruits) and livestock (Animals); whereas, water is assumed to be immobile between the agricultural sectors and the water distribution services.

One determinant of regional water use is the water intensity coefficient. It defines the amount of water necessary for sector *j* to produce one unit (value) of commodity *i*. To derive the water intensity coefficient, we first calculated the total water use per commodity and country for 1997. For the agricultural sector the FAOSTAT database provided information on production of primary crops and livestock. This includes detailed information on different crop types and animal categories. Information on water requirements for crop growth and animal feeding was taken from Chapagain and Hoekstra (2004).[9] The water requirement includes both the use of blue water (ground and surface water) as well as green water (moisture stored in soil strata). For crops it is defined as sum of water needed for evapotranspiration, from planting to harvest and depends on crop type and region. This procedures assumes that water is not short and no water is lost by irrigation inefficiencies. For animals the virtual water content is mainly the sum of water needed for its feeding and to provide drinking water.

[9] This information is provided as an average over the period from 1997 to 2001. By making use of this data we assume that water requirements are constant at least in the short term.

The above information on water was multiplied and aggregated to the 16 GTAP regions to calculate the total water use per agricultural sector and to derive the water intensity coefficient. The water intensity coefficient of the water distribution sector is based on data on a country's industrial and domestic water use provided by AQUASTAT.[10] This information was also aggregated to the 16 GTAP regions.

Water price policies can be implemented in GTAP-EWF through taxes (subsidies) to affect the output price.[11] Precisely, the price for water is included in the equation that determines the producer supply prices: the percentage change in supply prices is equal to the sum of the percentage changes in the market prices, output taxes (subsidies) and the change in the power of the price for water. The impact of changes in water prices on the output is captured by the water price elasticity, which is defined as the percentage change in water demand by industry as a result of a percentage change in the price for water. This responsiveness of water demand to a change in the water price allows us to define the sensitivity of the water intensity coefficients to changes in water prices. That is, the percentage change in the water intensity coefficient is equal to the difference between the percentage change in water demand and the percentage change in output. As the water price elasticity is negative (see *table 1*) it follows that, if the price for water increases (decreases), water-intensive industries decrease (increase) their water intensity rates, becoming more (less) water-efficient. Also, the water tax (subsidy) produces welfare effects: an increase (decrease) in any taxed activity produces a welfare gain (loss); the opposite effect occurs for any subsidised activity.

Table 1 about here

[10] This information is based on data for 2000. By making use of this data we assume that domestic and industrial water use in 2000 are the same as in 1997.

[11] The tax could also be interpreted as a rent.

The flow of virtual water from one region to another is captured by virtual water imports and exports. The percentage change of virtual water imports (exports) from region *r* to region *s,* due to the imports (exports) of the tradeable commodity *i*, is equal to the sum of the percentage change of the imports (exports) of the tradeable commodity *i,* from region *r* to region *s*, and the percentage change in the water intensity coefficient for producing that tradeable commodity *i* in *r*. Furthermore, percentage changes in regional virtual water imports (exports) from region *r* to region *s* are calculated as the sum of weighted changes in virtual water imports (exports) from region *r* to region *s,* due to the imports (exports) of the tradeable commodity *i.*

4 Design of model experiments

The GTAP-EWF model has been specifically designed to simulate water resource policies and is therefore well suited for the analysis of virtual water trade. To study the role of water resources and water scarcity in the context of international trade we run four alternative scenarios, some with variants. The first three scenarios are directly concerned with water resource policies. The first two scenarios are quantity scenarios. The third is a water pricing scenario. In the fourth scenario we consider a trade liberalization reform in the agricultural sector. Unlike the first three scenarios, the latter deals with trade policy in water-intensive industries.

In the first scenario, dubbed Sustainable Water Supply (SWS), we deny the use of fossil groundwater as a source of water. Pumping groundwater from aquifers at a rate faster than it replenishes clearly violates sustainability constraints. Our main interest is in the economic price that would need to be paid to avoid the use of fossil groundwater. We have two variants of this scenario. In the first, optimistic case (SWSo), we subtract the groundwater produced internally from the total renewable water resources per country, as specified by FAO's

AQUASTAT database, to form the sustainable water resources of the 16 regions. This scenario assumes free water transfer within national boundaries, an assumption that is clearly unrealistic for large countries. In the second, pessimistic case (SWSp), we add the sustainable water resources per basin, as specified by Rosegrant *et al.* (2002). In the first scenario water supply is restricted for one region only. In NAF water supply decreases by 44%. In the second scenario water is short in three more regions. In SAS and USA water supply decreases by 1.58%; in CHINA by 3.92%. Again, NAF faces a shortage of 44%. The quantitative restrictions are applied by making the change in the price for water use endogenous and the percentage change in water demand exogenous. This guarantees that the water demand is equal to the sustainable water supply.

In the second scenario, called China Water Transfer (CT), we assume that China succeeds in transferring an annual 48 km^3 of water from the south to the north. The CT scenario has one difference to the SWS scenarios: the water supply is extended, rather than constrained. This feature allows us to illustrate the international repercussions of domestic water resources. The main purpose of the scenario, however, is to test whether the $500 mln investment is worthwhile. Water supply in CHINA would increase by 7%. Again, this experiment is implemented by endogenising the change in water prices and exogenising the change in water demand to the additional water available in CHINA.

In the third scenario, named Water Pricing (WP), we impose a water charge. We use three variants – low, medium and high – with water taxes at $1 mln, $5 mln and $10 mln per km^3 of water. The aim of this scenario is to test how much water saving can be achieved, and at what economic cost. This experiment is simply implemented by setting the change in water price equal to those three values.

In the fourth scenario, dubbed Trade Liberalisation (TL), we remove all trade barriers for agricultural goods. The first significant agreement of trade negotiations was the Uruguay

Round agreement (GATT, 1994), which set up a framework of rules covering many area, such as the reduction of export and production subsidies of agricultural goods, the elimination of voluntary export restraints and Multi-Fibre Arrangement (MFA) protection. Furthermore, trade negotiations aim to contribute to trade and domestic liberalization with substantial reductions in tariffs, domestic support and export subsidies. In particular, in the new agricultural trade negotiations, there is renewed interest to implement a "zero-for-zero" trade policy,[12] which entails removing import tariffs and export taxes. Although, it is unlikely that trade negotiations for those sectors would result in a complete removal of all trade barriers, this experiment has the advantage to provide an upper bound of the effects of trade liberalization on virtual water trade.[13] This scenario is implemented by reducing export taxes (subsidies) and import tariffs to zero in the agricultural sectors respectively. Numbers are presented in *table 2*.

Table 2 about here

5 Simulation results

5.1 Sustainable water supply

The optimistic sustainable water supply scenario reduces the water availability in North Africa (NAF) by 44%. The marginal cost of water reduction, that is, the change in real water tax (or price) that would have to be imposed, ranges from \$14 mln, for the water distribution services, to \$17 mln per km^3 of water for the agricultural sectors (*table 3*). This difference in marginal costs between the two sectors is due to the fact that water use for agricultural

[12] For "*zero-for zero*" trade policy see WTO (2001) and, for its applications, see Elbehri *et al.* (2001).

[13] Note that this experiment is focused on trade liberalization and not on domestic liberalization, which would imply a removal of protection on output.

production is more efficient compared to the water distribution services sector; especially for wheat and animal production.

Table 3 about here

As expected, the virtual water imports increase in the NAF region and to sustain the domestic demand of goods and services virtual water exports decrease. This is an indirect effect caused by the relatively more expensive production of e.g. agricultural goods in the NAF region. Compared to other regions they are less competitive. As a result the virtual water trade balance for this region is negative (*table 3*). This is consistent with the results of the theoretical analysis of virtual water trade: water-short countries can meet their demand of water-intensive products by importing them (Wichelns, 2004). In all other regions, the virtual water trade balance is positive. Those regions that are now relatively more competitive increase the production of water-intensive products and offset the reduction in output in the NAF region.

Although for all water intensive industries in NAF the water demand decreases, for some of them, the production increases, such as the production of vegetables and fruits (not displayed). This is because this industry becomes more water efficient; in fact, its water intensity coefficient decreases by about 0.28%. Furthermore, it is beneficial for NAF to increase the production in all non-water intensive sectors.

The change in output affects the market prices. The price of water-intensive products in NAF increases as their supply decreases. Furthermore, the reduced production in those sectors decreases the demand of primary factors and, hence, their price also decreases.

The contribution of the water tax revenues to the welfare change is positive in the NAF region, but the welfare changes are negative (*table 3*). This is mainly caused by the positive trade balance. In fact, although the virtual water trade balance is negative in NAF, its trade balance is positive. Increases in exports of goods and services not being water intensive are more pronounced. The negative welfare effect is accompanied by a negative change in real GDP. This is mainly caused by a decrease in domestic expenditure on water intensive goods and services.

In the pessimistic scenario, water supply is restricted for three more regions, United States (USA), South Asia (SAS) and China (CHI). The marginal abatement costs range from about \$0.3 mln (water distribution services in SAS) to about \$30 mln per km^3 of water (agricultural sector in CHI) as shown in *table 4*. USA and SAS have the same water supply constraints, but of the resulting real water tax are different. The reason is that in a more water efficient country, such as the US, the marginal costs rise faster. CHI has the highest change in real water tax for agricultural production because it is one of the countries with the highest water price sensitivity in those sectors. Thus, increasing its water efficiency has a strong effect; in particular for the production of wheat, cereals and crops.

Table 4 about here

The impacts of the pessimistic scenario on NAF’s economy and water resource demand by sector are almost the same compared to the optimistic scenario. For the other regions with water constrains, the virtual water trade balance becomes significantly negative; whereas, for the unconstrained countries the virtual water trade balance is positive.

The reductions in output in the constrained countries tend to be offset by the increase in production in the other countries. The price effect follows almost the same pattern as before, except for capital and labour costs in the USA. In the US the production and the exports of water extensive products and services that are mainly capital and labour intensive increase.

In terms of welfare changes, both CHI and SAS have substantial welfare losses. For the US the positive contribution of water tax revenues and the negative trade balance implies an improvement in welfare (*table 4*).

5.2 CHINA water transfer

Different to the previous experiments, this scenario involves an increase in water availability in CHINA. In terms of virtual water trade, the trade balance is positive as virtual water exports increase more than virtual water imports (*table 5*). In most other regions, the virtual water trade balances are negative, except for Japan and Korea (JPK). This is caused by the decrease of virtual water imports in China (CHI). The positive virtual water trade balance for JPK is caused by an increase in virtual water exports to Europe, especially to WEU and EEU. Furthermore, the increase of virtual water exports from CHI lowers the growth of water demand in the other regions as water demand in some water-intensive sectors decreases. The combination of increased water availability in China (CHI) and the decrease of water demand in others regions causes an increase in world water demand of about 0.4%.

Table 5 about here

Although China's virtual trade balance is positive, in terms of trade the balance is negative. Exports of all goods and services produced by water extensive industries decrease. In fact, as the production of water intensive products increases, the production in almost all other sectors decreases. The opposite happens in the other regions. In terms of market prices, the effects of an increase in water availability are opposite to the cases in which water availability is constrained (see previous scenarios).

An increase in water availability produces welfare losses, because the water transfer is sustained by an output subsidy (*table 5*). This effect is offset by a negative trade balance. The final positive welfare change is not accompanied by a positive real change in GDP. This is mainly due to the decrease of the domestic expenditure in non-water intensive goods and services.

5.3 Water taxes

Since the results of the three different levels of real water taxes are qualitatively similar, *table 6* reports only the results for a water tax of \$10 mln per km^3 of water.

The increase in water prices leads to a decrease in water demand in all regions, except in WEU. WEU is a low water-intensive region and shows little sensitivity to changes in prices for water. Consequently, although water prices increase, it is more profitable to raise production and to export water intensive products to other regions, than to reduce the demand of water resources, and hence, the production (*figure 1*). Consider also that in a global context, changes in output in some countries have to be offset in others. NAF e.g. shows the highest reduction in water demand. Again, this is because the water-efficiency of this region is low. The low impact of water price policies on water demand and virtual water trade balance in ROW can be explained by a combination of being a low water intensive country and having little sensitivity to water price changes. The market prices of all water-intensive goods and services increase. In terms of welfare changes, in many regions the positive contribution of water tax revenues are offset by a positive trade balance (*table 6*). The regions that loose are mainly those with low water productivity.

Figure 1 about here

Table 6 about here

5.4 Trade liberalization

A negative (positive) value in the first half of *table 2* indicates an export subsidy (tax). If an export subsidy (tax) is removed, the domestic market price decreases (increases). The second half of *table 2* reports the values of the regional import tariffs. If an import tariff is removed, the domestic market price decreases. The change in market prices of agricultural products follow mainly the expected pattern of a removal of an export (tax) subsidy.

The change in market prices due to the trade liberalization scenario affects the production. Lower market prices reduce the production of agricultural goods mainly in JPK and MDE as well as in WEU and EEU. In the latter regions, the decrease in production is mainly due to the removal of agricultural export subsidies. By construction, water demand follows the pattern of the production in the agricultural sectors. In total, the world water demand decreases by about 0.3%. The main importers of virtual water are those countries that face significantly lower market prices by removing their relatively high import and/or export barriers, such as JPK, MDE, WEU and EEU. The increase in virtual water imports and water intensive goods has a positive effect on terms of trade and welfare in JPK, MDE and EEU (*table 7*). Abolishing export taxes, CAN and SAM show the highest positive virtual water trade balance. It increases their allocative efficiency and leads to positive welfare changes.

Table 7 about here

A trade liberalization policy of water intensive sectors has positive effects on the world welfare, without increasing the total demand for water. In particular, the results suggest that water-scarce countries could enhance trade liberalization policies in water-intensive sectors. This would reduce total water demand, but not the welfare, such as in NAF. In terms of virtual water trade, this will increase the imports of water-intensive goods and, hence, virtual water. In terms of welfare gains, issue-linkages between water policies and agricultural trade liberalization policies could be more effective for obtaining the main objectives of a more sustainable water use policy, compared to an isolated water policy.

6 Discussion and conclusion

The paper has illustrated how detailed information on water resources and water use can be implemented in a general equilibrium model. As water resources are scarce in many regions a number of attempts have been made to economize on the consumption of water, especially in regions where the supply is critical. Regional differences in climate and conditions of productions influence the water content of products. This makes it beneficial for water short countries and those with low water productivity to import water-intensive products and to produce more water extensive-products domestically.

To our knowledge this is the first attempt to analyse the role of water resources and virtual water trade in a general equilibrium setting. Sector specific water resources are introduced as production factors in the agricultural sectors and the water distribution service sector. Water is mobile between the different agricultural sectors, but immobile between those sectors and the water distribution service sector. As water is mainly required for agricultural production, we disaggregated agricultural production into five different sectors. This allows us to gain a wider inside into the implications of different water resource policies.

Our results justify the use of a general equilibrium model to analyse water resource policies. Compared to a partial equilibrium model we find e.g. a positive effect for GDP for the US when applying the pessimistic sustainable water scenario. In a partial equilibrium model a decrease in water availability would have resulted in a negative effect for GDP. Similar is the CHINA water transfer scenario where the effect on GDP for CHINA is negative.

Especially the results of the last scenario (trade liberalisation) are interesting. Although trade liberalisation decreases total water demand, the water demand in some regions increases. These are e.g. regions where water supply was restricted under the pessimistic water supply scenario (USA, SAS and CHI). In NAF, the other water short region, water demand decreases. Consequently, trade liberalisation can help reducing water problems in some regions, in others an additional water resource policy would be warranted.

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Annex

Table A1. Aggregations in GTAP-EWF

A. Regional Aggregation

1. USA - United States

2. CAN - Canada

3. WEU – Western Europe

4. JPK – Japan and Korea

5. ANZ – Australia and New Zealand

6. EEU – Eastern Europe

7. FSU – Former Soviet Union

8. MDE – Middle East

9. CAM – Central America

10. SAM – South America

11. SAS – South Asia

12. SEA – Southeast Asia

13. CHI - China

14. NAF – North Africa

15. SSA – Sub-Saharan Africa

16. ROW – Rest of the world

B. Endowments

1. Land

2. Labour

3. Capital

4. Natural Resource

C. Sectoral Aggregation

1. Rice - Rice

2. Wheat - Wheat

3. CerCrops - Cereals, crops

4. VegFruits - Vegetable, Fruits

5. Animals - Animals

6. Forestry - Forestry

7. Fishing – Fishing

8. Coal - Coal Mining

9. Oil – Oil

10. Gas - Natural Gas Extraction

11. Oil_Pcts - Refined Oil Products

12. Electricity – Electricity

13. Water - Water collection, purification and distribution services

14. En_Int_ind - Energy Intensive Industries

15. Oth_ind - Other industry and services

16. MServ - Market Services

17. NMServ - Non-Market Services

Figure A1 – Nested tree structure for industrial production process

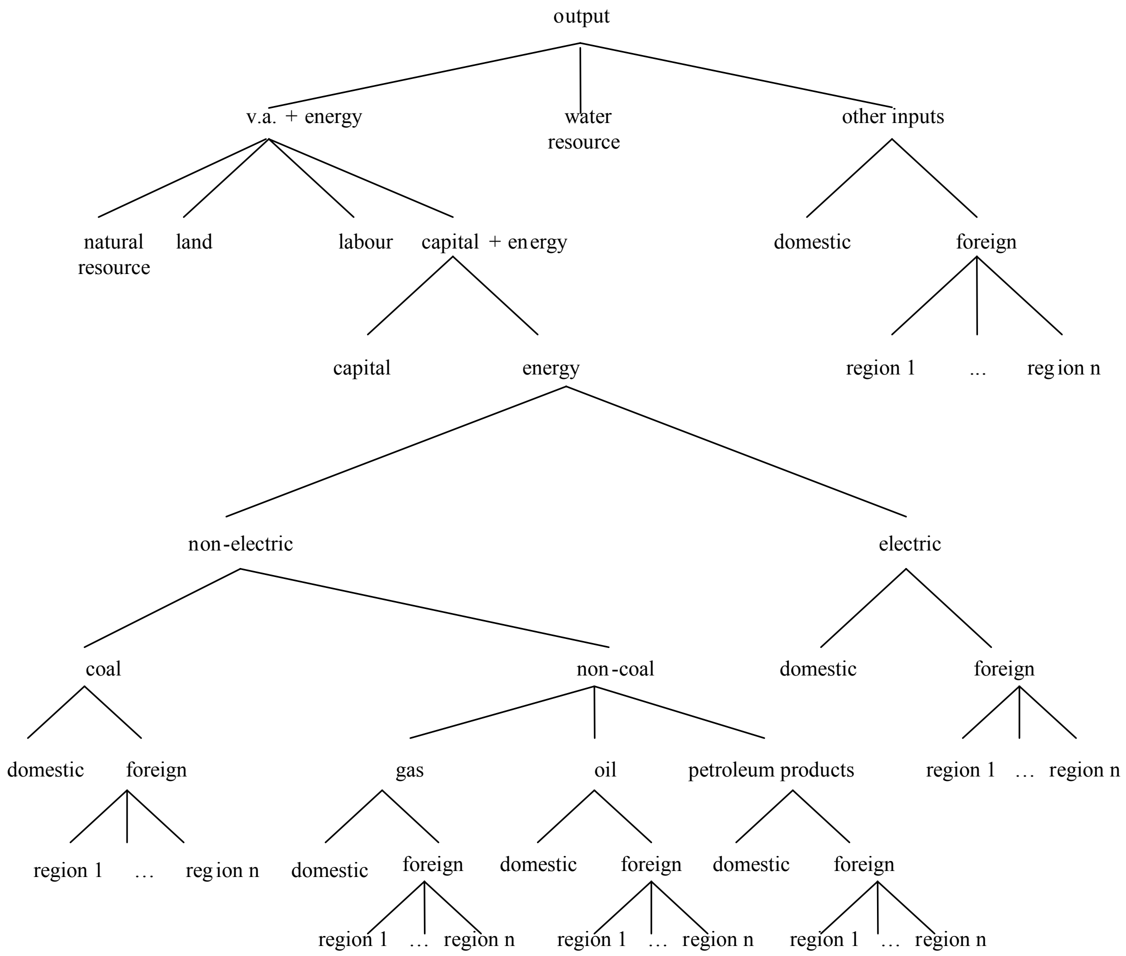
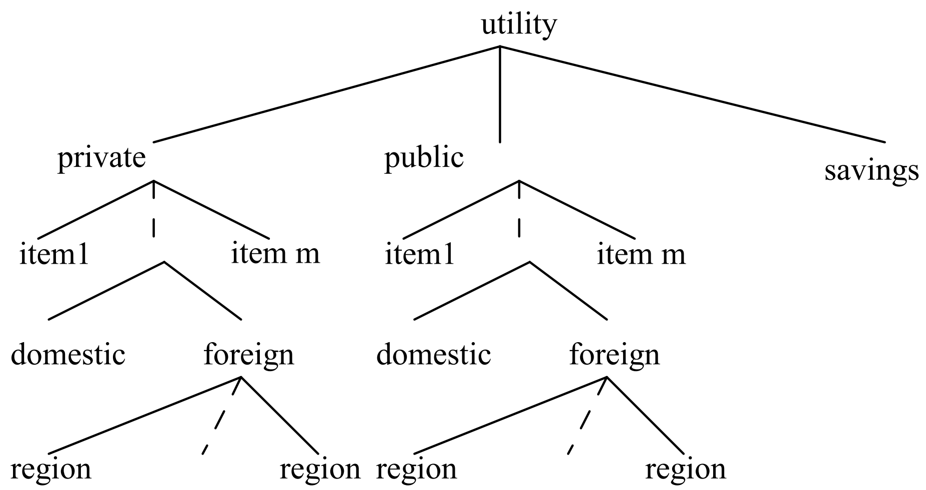


Figure A2 – Nested tree structure for final demand



Figures and Tables

Table 1. Water price elasticities

	Agricultural sectors	Water distribution services
1 USA	-0.14	-0.72
2 CAN	-0.08	-0.53
3 WEU	-0.04	-0.45
4 JPK	-0.06	-0.45
5 ANZ	-0.11	-0.67
6 EEU	-0.06	-0.44
7 FSU	-0.09	-0.67
8 MDE	-0.11	-0.77
9 CAM	-0.08	-0.53
10 SAM	-0.12	-0.80
11 SAS	-0.11	-0.75
12 SEA	-0.12	-0.80
13 CHI	-0.16	-0.80
14 NAF	-0.07	-0.60
15 SSA	-0.15	-0.80
16 ROW	-0.20	-0.85

Source: Rosegrant et al.(2003).

Table 2. Average change in export taxes (subsidies) and import tariffs

	Export taxes (subsidies)					Import tariffs				
	Rice	Wheat	CerCrops	VegFruits	Animals	Rice	Wheat	CerCrops	VegFruits	Animals
USA	0.00	0.00	-0.01	0.00	0.00	-4.06	-2.33	-16.18	-5.69	-0.72
CAN	0.00	0.20	0.20	0.20	0.20	0.00	-36.13	-2.85	-1.54	-12.60
WEU	-10.81	-7.48	-6.30	-0.78	-0.03	-37.35	-41.19	-7.40	-11.03	-11.73
JPK	0.98	0.00	2.43	1.95	1.26	-78.60	-56.99	-28.21	-31.95	-16.06
ANZ	1.10	1.54	0.49	0.09	1.41	-0.75	0.00	-2.37	-1.76	-0.56
EEU	0.00	-1.45	-0.23	-0.44	-0.74	-25.88	-32.38	-16.12	-19.29	-21.50
FSU	0.00	0.16	0.73	1.90	0.01	-2.57	-10.25	-5.70	-6.27	-18.31
MDE	0.00	-4.61	0.00	-0.67	3.37	-12.67	-43.89	-29.99	-40.83	-29.49
CAM	0.00	-1.65	4.82	0.16	1.98	-14.92	-22.20	-11.46	-10.32	-9.45
SAM	0.00	-0.64	8.36	3.54	5.82	-13.40	-8.12	-9.05	-9.57	-6.81
SAS	0.00	0.00	1.55	0.00	0.00	-2.69	-3.47	-20.24	-17.05	-17.68
SEA	3.94	0.01	0.84	0.49	0.00	-6.18	-4.22	-17.85	-10.73	-6.95
CHI	0.00	0.00	0.00	0.00	0.00	-0.03	-24.88	-11.95	-9.60	-5.82
NAF	0.00	3.03	1.47	27.93	6.67	-19.11	-10.54	-19.24	-21.32	-25.46
SSA	0.00	-1.60	0.00	-0.37	-0.31	-2.95	-13.07	-13.03	-14.55	-6.77
ROW	0.00	-0.43	2.74	0.59	0.25	-2.12	-2.94	-4.42	-4.73	-2.16

Table 3. Optimistic sustainable water supply

	Water resources demand (%)	Real water tax (mln $ per km^3 of water)		Virtual water import (%)	Virtual water export (%)	Virtual water trade balance (change in km^3)	GDP (%)	Trade balance (change in mln $)	Welfare change (mln $)	Contribution of total water tax value to welfare change (mln $)
		Agricultural sector	Water distribution							
USA	0.35	0.00	0.00	0.31	3.08	368.51	-0.001	-583	399	0
CAN	0.56	0.00	0.00	-0.31	1.49	78.58	0.000	-63	25	0
WEU	0.53	0.00	0.00	-0.30	3.33	395.61	0.003	-1194	736	0
JPK	0.03	0.00	0.00	-0.35	1.70	29.51	0.001	-680	232	0
ANZ	0.64	0.00	0.00	-0.82	1.43	44.61	0.001	-45	30	0
EEU	0.23	0.00	0.00	-0.26	5.89	39.85	0.003	-23	35	0
FSU	0.25	0.00	0.00	-0.11	1.05	66.89	-0.005	-22	-93	0
MDE	0.59	0.00	0.00	-0.14	3.22	64.47	-0.002	-55	-123	0
CAM	0.28	0.00	0.00	-0.40	1.16	45.93	-0.002	-15	-10	0
SAM	0.45	0.00	0.00	-0.15	3.43	239.82	0.005	-150	236	0
SAS	0.08	0.00	0.00	-0.10	2.48	63.53	0.000	-27	72	0
SEA	0.06	0.00	0.00	-0.01	2.49	87.12	0.001	7	34	0
CHI	0.10	0.00	0.00	-0.33	2.97	57.52	-0.002	-51	28	0
NAF	-44.00	17.71	14.70	76.27	-32.84	-2208.51	-0.855	2937	-3219	5718
SSA	0.82	0.00	0.00	-0.04	4.61	609.31	0.008	-21	126	0
ROW	0.07	0.00	0.00	-0.56	1.83	17.26	0.002	-17	11	0

Table 4. Pessimistic sustainable water supply

	Water resources demand (%)	Real water tax (mln $ per km^3 of water)		Virtual water import (%)	Virtual water export (%)	Virtual water trade balance (change in km^3)	GDP (%)	Trade balance (change in mln $)	Welfare change (mln $)	Contribution of total water tax value to welfare change (mln $)
		Agricultural sector	Water distribution							
USA	-1.58	11.25	3.82	2.98	-2.31	-458.33	0.002	-1271	1270	6427
CAN	2.50	0.00	0.00	-0.43	6.46	333.76	-0.001	-229	124	0
WEU	0.99	0.00	0.00	-0.88	5.56	756.24	0.004	-3742	1200	0
JPK	0.30	0.00	0.00	-0.12	8.57	12.11	-0.012	-1922	-424	0
ANZ	4.01	0.00	0.00	-1.09	9.73	291.25	0.003	-158	150	0
EEU	0.39	0.00	0.00	-0.57	8.06	58.71	0.006	-155	59	0
FSU	0.65	0.00	0.00	0.12	3.02	180.74	-0.005	-181	-105	0
MDE	1.38	0.00	0.00	-1.10	5.82	146.68	-0.013	-250	-349	0
CAM	1.02	0.00	0.00	-3.08	3.45	184.46	-0.012	-31	-68	0
SAM	0.91	0.00	0.00	-1.27	6.46	485.74	0.012	-622	527	0
SAS	-1.58	4.73	0.31	8.79	-5.51	-318.36	-0.010	1037	-196	8787
SEA	0.24	0.00	0.00	-0.68	5.0	213.97	-0.004	77	-147	0
CHI	-3.92	29.32	1.17	9.45	-27.58	-751.61	0.011	4703	-711	15223
NAF	-44.00	17.86	14.69	76.27	-30.78	-2200.62	-0.882	2932	-3388	5788
SSA	1.37	0.00	0.00	-0.21	7.59	1005.20	0.017	-121	282	0
ROW	0.29	0.00	0.00	-3.28	5.36	60.05	0.004	-66	10	0

Table 5. CHINA water transfer

	Water resources demand (%)	Real water tax (mln $ per km^3 of water)		Virtual water import (%)	Virtual water export (%)	Virtual water trade balance (change in km^3)	GDP (%)	Trade balance (change in mln $)	Welfare change (mln $)	Contribution of total water tax value to welfare change (mln $)
		Agricultural sector	Water distribution							
USA	-0.32	0.00	0.00	0.12	-2.18	-279.65	0.000	1853.75	-691	0
CAN	-0.98	0.00	0.00	0.06	-2.45	-125.58	-0.001	134.44	-48	0
WEU	-0.29	0.00	0.00	0.26	-1.35	-196.56	-0.002	2306.59	-492	0
JPK	-0.26	0.00	0.00	-0.25	-5.79	19.23	0.017	1101.67	856	0
ANZ	-0.99	0.00	0.00	0.79	-2.65	-80.57	-0.003	103.14	-54	0
EEU	-0.11	0.00	0.00	0.23	-1.23	-11.64	-0.003	118.76	-23	0
FSU	-0.30	0.00	0.00	-0.14	-1.13	-65.17	0.000	143.44	16	0
MDE	-0.35	0.00	0.00	0.18	-1.08	-26.37	0.003	239.87	116	0
CAM	-0.34	0.00	0.00	0.27	-1.60	-56.32	0.001	87.67	-7	0
SAM	-0.23	0.00	0.00	0.22	-1.73	-126.09	-0.006	417.84	-219	0
SAS	-0.06	0.00	0.00	0.37	-2.51	-69.68	0.000	107.74	-51	0
SEA	-0.18	0.00	0.00	1.39	-1.80	-143.41	0.002	-51.44	144	0
CHI	7.00	-52.90	-1.94	-13.26	66.35	1494.84	-0.112	-6771.26	7	-25900
NAF	-0.35	0.00	0.00	0.48	-2.68	-23.13	0.002	72.44	20	0
SSA	-0.40	0.00	0.00	-0.12	-1.99	-261.51	-0.009	101.80	-173	0
ROW	-0.22	0.00	0.00	5.95	-1.85	-48.40	-0.002	33.57	13	0

Table 6. Water taxes

	GDP (%)	Trade balance (change in mln $)	Welfare change (mln $)	Contribution of total water tax value to welfare change (mln $)
USA	-0.003	-4718	1766	7418
CAN	0.016	-72	449	1481
WEU	0.011	-4865	1136	7421
JPK	0.001	-3960	816	1843
ANZ	0.008	-197	394	739
EEU	-0.028	663	-280	1391
FSU	-0.024	1092	-712	2864
MDE	-0.024	1913	-1448	3047
CAM	0.012	57	102	2145
SAM	0.004	93	582	4848
SAS	-0.069	2644	-842	19998
SEA	-0.029	1862	-781	9521
CHI	-0.011	2006	-365	6619
NAF	-0.119	1097	-1123	3186
SSA	-0.115	2278	-428	7674
ROW	-0.004	107	-112	1901

Table 7. Trade liberalization

	Water Resources Demand (%)	Virtual water imports (%)	Virtual water exports (%)	Virtual water trade balance (change in km^3)	GDP (%)	Trade balance (change in mln $)	Welfare change (mln $)
USA	2.15	31.37	28.20	1756.87	0.00	7285	647
CAN	12.03	10.88	42.32	2080.82	0.00	391	1053
WEU	-4.02	11.52	-6.98	-3623.39	0.02	5007	590
JPK	-10.90	51.72	91.91	-4212.84	0.17	-11039	6826
ANZ	10.21	15.66	34.71	985.98	-0.01	556	422
EEU	-1.09	28.35	63.41	-173.35	0.13	-927	607
FSU	-1.14	8.59	-5.06	-536.40	0.01	202	79
MDE	-11.97	65.61	63.99	-1140.38	0.37	-4601	3103
CAM	0.95	21.00	29.54	390.31	0.02	286	-26
SAM	4.09	20.38	43.06	2220.40	0.04	1449	546
SAS	0.30	32.45	49.27	546.27	0.02	404	-40
SEA	-0.22	12.16	33.17	451.33	0.02	-7	-141
CHI	1.28	68.49	175.53	528.91	0.13	457	1474
NAF	-5.22	24.46	141.41	-140.13	0.16	27	40
SSA	0.19	34.88	8.37	623.80	0.02	216	172
ROW	0.71	7.75	37.17	241.80	0.00	293	-8

Figure 1 - Virtual water trade balance