Can National Water Endowment Explain Global Bilateral Flows of Virtual Water?

Very Preliminary, Please Do Not Quote

Jean-Louis Combes, Pascale Combes-Motel[§], Chloé Fernandez and Alexandru Minea

Abstract

This paper aims at highlighting the role of national water endowment on a country's virtual water exports. The latter can be defined as the indirect volumes of water necessary to the production of imported or exported services and goods of a given country. Virtual water can be divided into two categories: green water, moisture naturally present in soils, and blue water, classified as "liquid water", usable by man and present in rivers or groundwater. The Heckman estimations, in order to resolve the bias due to the high number of zeros in the dependent variable, conclude to a positive and significant correlation between renewable water resources and a country's exports. These results justify the use of a Heckscher-Ohlin-Samuelson model of comparative advantages, including water services to the capital factor. Once desegregated we can see a few differences in the results. Green water, benefitting from lesser opportunity costs, has a higher impact than blue water on virtual water exports. However, a well water endowed partner country will reduce his imports in blue water intensive goods more than in green water goods. The international dependence to the latter appears to be more important. These results can be explained by the divergence in technology and research, which are less advanced in enhancing soil productivity (better usage of green water) than in blue water extraction from its multiple sources.

Keywords : *virtual water, trade, green water, blue water, comparative advantages, gravity model*

[§] Corresponding Author: CERDI & School of Economics (University of Auvergne), 65 Boulevard François Mitterrand, BP 320, 63009 Clermont-Ferrand Cedex 1, France. Email: pascale.motel_combes@udamail.fr.

Introduction

Economic globalization has a considerable impact on water use conditions, leading to a geopolitical approach of water management in the past decades. Constrained by the resource's scarcity, water repartition can create either conflict or treaties between countries on common water basins. More than physical water distribution, countries must also share the rare resource via international trade. Behind commodities' bilateral trade, water flows are hidden, which are intrinsic to the goods and necessary to their production. Water exploitation goes therefore with a delocalization of its consumption: water isn't only a resource of proximity.

Around 70% of water extraction is done for agricultural means, a common error is then to think that policies aiming at reducing domestic consumption are sufficient to ensure water quality and longevity. Moreover, demographic growth and economic development, go hand in hand with an increase of food demand and thus fresh water. Considering the share of agricultural trade in the world, it is essential to think beyond physical water and to find a solution in order to take into account the water amount incorporated all along the production chain.

In the 90's, John Anthony Allan introduced the virtual water concept in order to quantify the traded flows throughout the world. It refers to the indirect volumes of water necessary to the production of imported goods and services of a given country. Virtual water is therefore intimately tied to the notion of 'water footprint', developed by Professor Hoekstra (UNESCO-IHE) in 2002. This indicator measures direct and indirect fresh water consumption of a producer. The water footprint of a household, firm of State, is defined as the total volume of water necessary to the production of goods and services consumed by individuals or produced by firms. It is measured in terms of consumed water volumes (evaporated of incorporated in a product). (Water Footprint Network).

Subsequently, an arid or semi-arid country could find interest in importing water intensive products and exporting goods less dependent on the resource. Such flows imply net virtual water import, representing a lesser cost than "real" water import, while reducing pressure on national water resources. On a world scale, virtual water flows, regarding trade of goods and services, represent 1, 625 km^3/yr (270 m^3/habitant/yr), while the total water footprint is estimated at 7, 450 km^3/yr (1, 240 m^3/habitant/yr). Differences between countries are important: the United States' (USA) mean footprint is of 2, 480 m^3/habitant/yr, of which 470 m^3/habitant/yr are imported, while India's mean footprint is of 980 m^3/habitant/yr, of which 16 m^3/habitant/yr are imported (Hoekstra & Hung, 2002). Currently, the main virtual water transfers are from the USA towards Central America, Western Europe, North Africa and Central and Southern Asia; from South America towards Western Europe; and from Oceania towards Central and Southern Asia. The majority are associated to agricultural products (695 km^3/yr or 43% of virtual water flows).

The virtual water analysis suggests various stakes. On the one hand, one must keep in mind the dichotomy between blue and green water, respectively the 'liquid' water found in basins, rivers, ground layers and canalizations etc., and water present in soils, in the form of humidity/moisture, and which benefits agriculture through the natural process of transpiration (Falkenmark & Rockström, 2006). The latter's potential is not much exploited. As of yet, economies have preferred investing in capital, bettering access to rivers or underground water (via dams etc.). However, to satisfy the growing needs of the world population, it is necessary to increase agricultural productivity. Research aiming at bettering soil quality and limiting evaporation is a crucial solution, particularly for developing countries in tropical regions.

On another hand, it is questioned if it is possible to diminish endowment disparities between countries through virtual water flows. Exports of countries rich in water towards others suffering from scarcity can serve to rebalance the resource at a global level, but also to water saving if the exporting country is more productive than the importing one, i.e. if he needs less water factor to produce the commodity.

Despite these stakes, considering water as a global resource is uncommon. In 2000, the Global Water Partnership (GWP) wrote: 'To obtain efficient and equitable sustainable water management, a major institutional change is necessary. A participation from top to bottom, but also from bottom to top must be promoted -from nation level to the village one, or from the catchment basin to rivers-. Global water governance doesn't exist.'

Of our knowing, no empirical papers have yet been done regarding the virtual water subject. It is thus, in this context, that this paper has for objective to present estimations of bilateral virtual water flows according to various variables. We are looking to see if water trade relies on comparative advantages in a Heckscher-Ohlin-Samuelson (HOS) model with two factors of production: capital and water. This study is done through a Gravity Model representing bilateral virtual water flows throughout the world, for the nine most water intensive agricultural commodities: seed cotton, soybeans, wheat, cocoa beans, coffee (green), oil palm fruit, maize, rice (paddy), and sugar cane. These products as a whole represent 61.2% of global virtual water flows. The sample is composed of 134 countries forming 18, 090 dyads. It is a cross-country study on the data mean of the 1996-2005 time period. The work aims at estimating the impact of national water endowment on virtual water exports of a country. The study relies on a Heckman estimator in order to limit any bias problems due to high presence of nil flows -of zeros- in the dependent variable. The results are promising, being well endowed in water promotes exports, justifying the comparative advantage theory with the water factor. We find innovative results, once the dependent variable disaggregated for, we see differences between blue and green virtual water flows. The latter has a more determinant role on exports, an impact that is most certainly linked to its weaker opportunity cost (Mekonnen & Hoekstra, 2010). Conversely, when it comes to a partner country, resource wealth suggests a relatively more important reduction of blue virtual water imports. This implies a higher dependence to the rest of the world in terms of green water intensive goods. Scarcity in green water can less likely be compensated by human technology (contrary to progress in terms of dams or irrigation). This situation justifies the growing share of green virtual water flows in the world (Aldaya, Allan, & Hoekstra, 2010).

The paper follows the following form: in a first step will be presented a bibliographical review in order to better conceptualize the subject. Then will be put in light both the theoretical and empirical models used in this study, before presenting the estimation results. Finally we will conclude with the limits, political implications and prolongations of this model.

Bibliographical Review

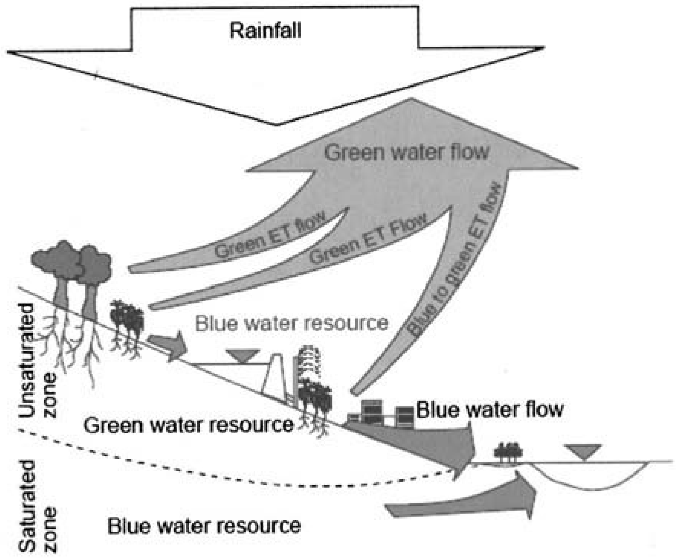
As of yet, the concept of virtual water has mostly interested scientists and international institutions. Economic analyses of the subject are a recent development, which explains the lack of empirical publications. Thus, in the first part of this bibliographical review will be presented the concept of virtual water, and in a second part, the theoretical and statistical publications will be drawn together with the recent economic research.

A. Context

1. The blue and green water dichotomy

When studying the economic value of water, it is essential to put in light the difference between *blue* and *green* virtual water. Green water refers to precipitations that seep and stock in non-saturated soils to take the form of moisture (Falkenmark & Rockström, 2006). It is the water resource for non irrigated agriculture. On the other hand, blue water, flows from rivers to oceans, and can be found in lakes, ground-water sheets and canalizations. It can be qualified as 'liquid' and is used for irrigated agriculture.

Graph 1 :Blue and green water resources

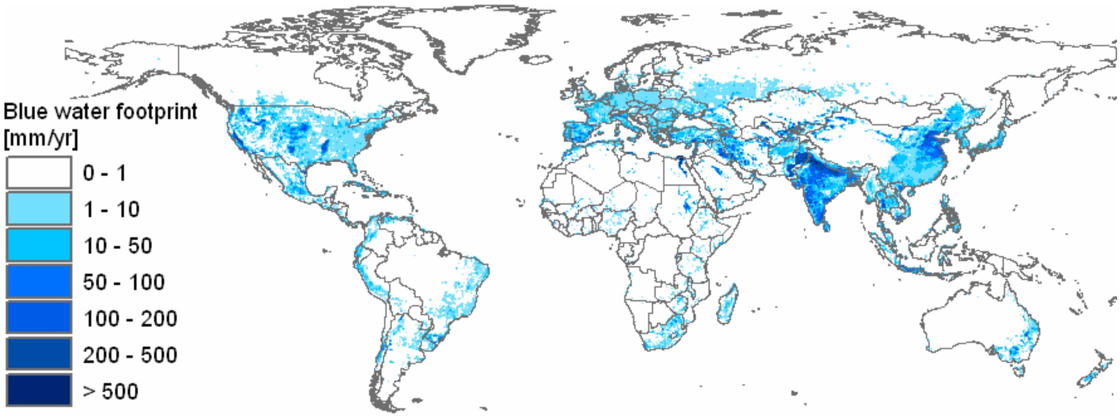


Source : Falkenmark & Rockström, 2006

Since the 1992 Dublin Conference, blue water is considered as an economic good. When it comes to green water, the discussion is still of the present in terms of market value. This is due to the encountered difficulties to measure its opportunity cost (Novo, Garrido, & Varela-Ortega, 2009.). The latter is considered higher when speaking of blue water as it is relatively easier to use it for other purposes (Mekonnen & Hoekstra, 2010). In this light, from an economic point of view, only blue virtual water exports can be valued. It is almost impossible to attribute a marginal profit -*the will to pay for an extra unit of water*- to green water. Households, firms and States are thus less aware of the green water cost than the blue water one.

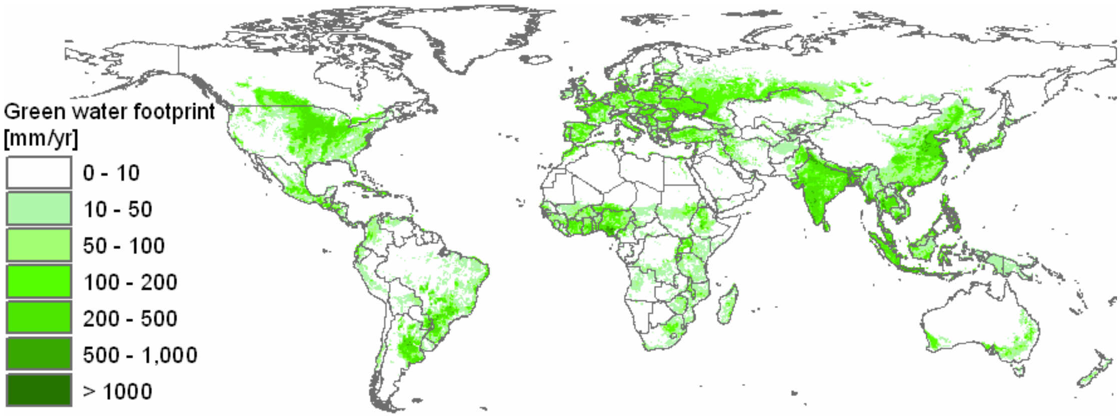
This dichotomy becomes of outmost importance when referring to agriculture in Developing Countries and world population growth. The latter implies a higher need for food and consequently, in water. The necessary water amount to eradicate hunger before 2030 in developing countries is of 4, 200 km³/ year (Falkenmark & Rockström, 2006.). If covered by irrigation, water extraction of aquifers and rivers will have to be more than doubled, an unbearable prevision for ecosystems. Moreover, it must be pointed out that loss in water due to agriculture is considerable, with a water efficiency - *the ratio of well consumed water by irrigated agriculture to the extracted water from its source*- of only 30% in developing countries today. This situation leads to thinking of a solution *via* better management of green water, consisting in limiting rain evaporation and/or increasing ground water absorption. In this context, many authorities draw attention to green water importance, regarding food security, promoting production support through precipitations (Falkenmark & Rockström, 2004).

Graph 2 : Blue Water Footprint



Source : Mekonnen & Hoekstra, National water footprint accounts: the green, blue and grey water footprint of production and consumption, 2011.

Graph 3: Green Water Footprint



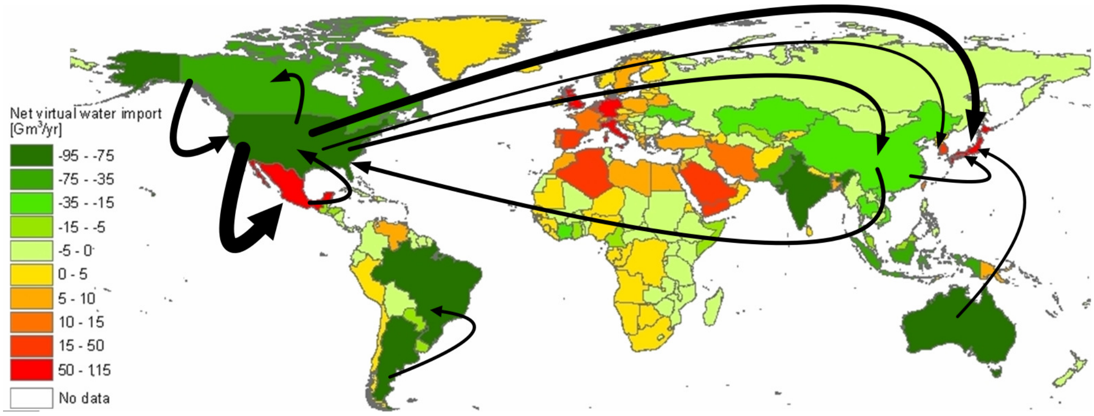
Source : Mekonnen & Hoekstra, National water footprint accounts: the green, blue and grey water footprint of production and consumption, 2011.

It is admitted that green water represents the majority of world virtual water flows, exports going from countries wealth in green water towards blue water economies (Aldaya, Allan, & Hoekstra, 2010). In this light, it is assumed that virtual water flows, intrinsic to the agricultural trade, could lead to better management of natural resources. Good production for trade can be favorable, as in Ghana, Côte d'Ivoire or Brazil, where water, being majorly green, stimulates economies. On the other hand, in a country such as Thailand, which exports 28 Gm³/year, high agricultural production involves a non negligible pressure on blue water resources (Chapagain, Hoekstra, & Savenije, 2006).

2. What are world virtual water flows?

International trade indirectly suggests redistribution of water resources. By shifting production to regions with high water productivity and low opportunity costs, rare water resources could be reallocated to activities with better economic value (Wichelns, 2004). It is therefore considered that water transfers involve resource saving on a global scale. For example, the total water amount that would have been necessary in importing countries, if all imported goods were to be produced on national ground, is of 1605 Gm³/year. However, these goods are produced with only 1253 Gm³/year in exporting countries, suggesting a total water saving of 352 Gm³/ year (Chapagain, Hoekstra, & Savenije, 2006).

Graph 4 : Virtual Water Net Import



Source : Mekonnen & Hoekstra, National water footprint accounts: the green, blue and grey water footprint of production and consumption, 2011.

Fresh water globalization leads to both risks and opportunities. The highest risk is if consumption indirect effects are externalized to other countries: while water in the agricultural sector is always at lower price than its real cost, an increasing quantity is used to produce exportable goods. Water extraction costs in the exporting country are not included in the final good's price of the importing country. Consumers are often reckless and don't pay for the water problems inherent to country where goods are produced. If we refer to economic theory, a pre-condition to efficient and equitable trade is that consumers must bear the total cost of production and its impact. A second risk is that many countries are gradually more dependent on intensive water commodity imports. In the case of Jordan, the country yearly imports a virtual water volume which is five times higher than its own renewable water resources. Consequently, while Jordan saves its own resources, it also amplifies its dependence on other States.

B. Virtual water in economic theory

It is important to note that, even if there exists many statistical and descriptive reports on the subject, there are, however, only few economic papers, and even less empirical ones that treat virtual water concepts. Even if the principal of virtual water trade is inherent to economic theory, it isn't born in its literature and is often criticized.

Novo, Garrido, & Varela-Ortega (2009) did a national study on virtual water flows affecting Spain. In their paper, they took into account exports, not only in absolute amounts but also in terms of economic value. Nevertheless, this work can only be done on blue water, opportunity costs regarding green virtual water not being measurable. Resource value is measured by the difference between national water price and the shadow price. The authors conclude that the green/blue water dichotomy is very important. Indeed, the shadow price progresses in a different direction than the exported quantity if the product in question, such as wheat, depends more on the transpiration[1] effect than on irrigation.

Ansink (2010) refutes two central theories on virtual water. The first one, according to the HOS model, concerns comparative advantages in order to judge of the role of virtual flows on global water saving. Factor abundance being expressed in relative terms, the author concludes that trade can lead to water saving under one condition: *if the country that has a comparative advantage in water also has an absolute advantage in the resource*. In this context, if the exporting country has a relative advantage, while the importing country has an absolute one, then the latter will increase his already important water resources. This can explain confusing results, such as how Norway is a net virtual water importer regardless of its abundant endowment. This is explained by the fact that this developed country is rich in the second factor of production: capital. Norway thus has a *comparative advantage in non water intensive goods*. Moreover, what this country has in water, it lacks in arable land. Kumar & Singh (2005) emphasize on the positive correlation between a country's virtual water exports and the amount of arable land per capita. In the same aspect, Ansink (2010) denies Allan's (1998) hypothesis of 'international trade mechanisms continue to operate with a proved efficiency aiming at improving water resources, uneven throughout the regions of the world'. There is conflict with Hoekstra & Hung's (2005) observation, according to whom, a country with insufficient water will tend to be dependent on other nations.

Reimer J. J. (2012) tries to demonstrate that Ansink's (2010) critic is false, and that an economic approach regarding virtual water flows is justified. According to Reimer, the problem is that if the foreign country has more water in absolute terms but not in relative terms, then it also has to have more capital both in absolute and relative terms. The country is therefore 'bigger' and, most especially, benefits from more water but *consumes relatively little of it compared to the rest of the world*. Once the borders open, relative factor consumption of the foreign country will near its partner's, it will balanced itself out. Ansink then refutes the theory by assuming that a small country, specialized in 'water', can always be a net importer of virtual water, if it imports enough capital intensive goods. Reimer (2012) thus tries to prove that water export, intrinsic to the water intensive good, will never be cancelled out by the

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[1] Transpiration is the evaporation of water into the atmosphere from the leaves and stems of plants

water found in the capital intensive good. According to his studies, the existence of this limit is due to the consumers budgetary constraint.

The use of HOS model in this context can be criticized. It is admitted that protectionist policies have an important role in world water distribution (Zeitou *et al.*, 2010). Many studies show that agricultural imports are not necessarily linked to relative water scarcity (Yang et al., 2003; Brichieri-Colombi, 2004; De Fraiture et al.,2004; Ramirez-Vallejo & Rogers, 2004; Kumar & Singh, 2005). Regarding exports, flows can even be counter-intuitive. Trade choices depend of relative prices and various resource production productivity, water being one of the scarcest in agriculture. For example, in spite of important resources around the Nile Basin, the majority of Egypt's agricultural imports come from North American and European subsidized agriculture (Berritella *et al.*, 2007).

Chilchilnisky (1994) accentuates the fact that, in a situation of badly defined property rights, virtual water trade can be harmful. In those countries, the social cost of water extraction isn't taken into account. In a HOS model, this suggests that the country with weak property rights will be more productive in the water intensive sector. Merrett (2003) finds the 'virtual water flow' term too vague and suggests that authors simply write of 'food imports'. However, Reimer (2012), reaffirms that 'water trade' is specific to economic theory. Goods only represent the service -*factor*- necessary to their production (Vanek, 1968). Thus, the best term should be ' the import of the service of water'. Wichelns (2004) insists on the fact that virtual water trade can't entirely rely on the comparative advantages theory. Virtual water addresses resource endowment but not technology. Nonetheless, the latter has a non negligible role in determining water intensive commodity specialization. Technology has an important transfer cost, most especially in agriculture where rates are high, implying strong diversity between States.

It seems important to end this review by insisting on the fact that it will never be suggested that countries with net virtual water import necessarily seek to save their own water resources (Chapagain & Hoekstra, 2008). Agricultural trade depends on many more significant factors, such as arable land, labor, knowledge, capital, competition (comparative advantages) in certain sectors, subsidies, protectionist policies *etc.* Yang et al. (2003) have however shown that under a certain water availability threshold, a relationship can be established between a country's cereal imports and his renewable water resources per capita.

Empirical Model

This paper relies on a two factor -*capital and water*- HOS model (cf. appendix) and on both empirical Gravity and Heckman models. The objective is to verify if the comparative advantage theory is valid regarding the water factor. In other words, if a country with a comparative advantage in water is a net exporter of the resource.

1. The gravity model

Tinbergen (1962) was a pioneer regarding the traditional gravity equation. In the latter, trade flows from country *i* to country *j* are proportional to the GDP product of both countries, and conversely, proportional to the distance that separates them. The first microeconomic formalization was born in 1979 thanks to Anderson and was based on Armington's assumption that a country specializes in the production of only one good.

We use as reference Anderson and van Wincoop's (2003) heightened version which puts forward an estimation bias. We are in an economy with one sector and where consumers have utility functions with constant substitution elasticity, $(\sigma > 1)$, common to all goods.

$$(1)\quad \log X_{ij} = c + \log y_i + \log y_j + (1-\sigma)\rho \log d_{ij} + (1-\sigma)\log b_{ij} + (1-\sigma)\log \pi_i + (1-\sigma)\log P_j + \varepsilon_{ij}$$

$$(2)\quad X_{ij} = \frac{Y_i Y_j}{Y_w}\left(\frac{t_{ij}}{\pi_i P_j}\right)^{1-\sigma}$$

$$(3)\quad P_j^{1-\sigma} = \sum_i \pi_i^{\sigma-1}\theta_i t_{ij}^{1-\sigma}, \qquad \forall j$$

$$(4)\quad \pi_i^{1-\sigma} = \sum_j P_j^{\sigma-1}\theta_j t_{ij}^{1-\sigma}, \qquad \forall i$$

With X_{ij} representing exports from country *i* to *j*, Y_i GDP of country *i*, , Y_w world GDP, d_{ij} distance between country *i* and country *j*, b_{ij} a dummy that takes the value of 1 of countries share a border , t_{ij} trade costs, π_i all countries' openness to country *i*'s exports and P_j country *j*'s openness to imports regardless of trading partner.

π_i and P_j are thus perceived as multilateral resistances to trade of countries *i* and *j* respectivily. They are the mean resistance to trade between a country and his partners. When trade costs are symmetrical $(t_{ij} = t_{ji})$, then $\pi_i = P_i$, equation (2) becomes :

$$(5)\quad X_{ij} = \frac{Y_i Y_j}{Y_w}\left(\frac{t_{ij}}{P_i P_j}\right)^{1-\sigma}$$

In such a case, ratio between economy size as well as t_{ij}, i.e. trade barriers between *i* and j, and the product of multilateral resistances of trade partner countries (P_i and P_j) impact X_{ij}'s value. However, P_i and P_j aren't directly observable and their omission entails an estimation bias. In order to solve for this problem, Anderson and van Wincoop suggest two solutions: fixed effects or estimation of multilateral resistances.

2. Heckman estimation model

There exists a multitude of estimators used in gravity models in order to solve for high presence of zeros in the dependent variable's distribution[2] , entailing that simple linear models are impossible. The chosen estimator here is the Heckman Method, as favored by Gómez Herrera (2010), which relies on a two step selection model. In a first step, a Probit estimation is done to see to what extent two countries are suceptible to trade, and in a second step, the trade flows' expected values, under stipulation that two countries trade, are estimated in OLS. In order to identify the parameters, the model must have at least one selection variable. These exclusion variables must only influence the decision process and thus, be correlated with a country's propensity to export but not with his actual level of exports. The advantage of this model is that the decision to trade isn't independent from the decision of amount traded. It permits a positive correlation between the two error terms in order to better represent the decision process. According to Neyman & Scott (1948), a Probit or Tobit estimation with fixed effects isn't possible due to the incidence parameter problem. In this light, in a Heckman model, we will not include specific effects to resolve for the multilateral resitence problem.

The Heckman model is formulated as follows:

(1) Selection equation : Propensity to trade $z_i^* = f(w_i, \beta_i) + \mu_i$
(2) Intensity equation : Amount traded $y_i = f(x_i, \alpha_i) + \varepsilon_i$

$E(\mu_{ij}) = 0 \,; E(\varepsilon_{ij}) = 0$
$\mathrm{Cov}\,(\mu_i, \varepsilon_i) = \rho \quad |\rho \neq 0$

Where x_i and w_i are exogenous vectors of regressors, β_i and α_i are vectors of parameter $K_j{}^*1$, u_i and ε_i are error terms following respectively a Normal Law $N(0;1)$ and $N(0;\sigma)$, and z_i^* is a latent variable defined by equation (1), non observable when negative or equal to 0, and equal to y_i otherwise. Y is censured to the left :

$$\begin{cases} y_i \text{observable} & \text{if } z_i^* > 0 \\ y_i = 0 & \text{if } z_i^* \leq 0 \end{cases}$$

There exists a coefficient representing the correlation of the error terms, 'ρ ', which takes the value of zero when OLS estimation of equation (2) isn't biased. In this case, the residues of both equations aren't correlated and the selection model looses sense: both decisions are now

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[2] We have chosen to not use the log-linearization method due to the important frequency of zeros in our database (representing absence of trade between two countries).The alternative method of truncating the sample, suppressing all the zeros in the database, leads to a selection bias risk. Another possibility, is to add a unit to the dependent variable before transforming it into a logarithm. However, Gómez Herrera (2010) critize the method as it leads to a non minimal variance even if the estimator is unbiased., According to Santos, Silva & Tenreyro (2006), Jensen's inequality -*The expected value of the logarithm of a random variable is different than the logarithm of the expected value*- entails that OLS estimations in log-linear models are absurd in the presence of heteroscedasticity. Anderson and van Wincoop's (2003) solution of fixed effects or multilateral resistance estimation do not solve for this problem. The proposed estimator is the PPML (Poisson Pseudo-Maximum Likelihood). It gives less importance to observations with large variances while protecting from observations susceptible of suffering from measure errors. Nonetheless with a high presence of zeros in the distribution this estimator is biased (Martin & Pham, 2008).

independent. Alongside the *twostep* method, there exists the Maximum Likelihood Heckman Model. The latter, however, has difficulty converging, particularly in the presence of over-identification -*introduction of too many exogenous instruments*-. The Heckman Model relies on the Inverse Mills Ratios (IMR): the ratio between the probability density function and the cumulative distribution function. The latter is extracted from the selection equation and reintegrated into the intensity equation, hence solving for selection bias.

Econometric Model Specification

We are looking to study the impact of a country's water endowment on his bilateral virtual water exports. The estimations are run on a sample of 134 countries, with a database that takes the form of a gravity model, with a total of 18 090 observations i.e. dyads. The study is of cross-sectional form on the mean of the 1996-2005 period. As our dependent variable's distribution -virtual water exports- is composed of 77.71% of zeros[3] the econometric study will rely on the Heckman Maximum Likelihood Method in order to limit bias. To see if the model is robust we will then proceed to a Heckman t*wostep,* as well as a log-linear, estimation. In the latter, we will be able to control for multilateral resistance by adding fixed effects in the form of country dummies.

Variables

1. Explained variable : Virtual water exports

In order to create a variable that represents virtual water exports, it was chosen to study trade of nine agricultural commodities which are the most intensive in water: seed cotton, soybeans, wheat, cocoa beans, coffee (green), oil palm fruit, maize, rice (paddy), and sugar cane. Their contribution to global virtual water flows are all above 2%. We consider that they represent a good proxy of virtual water flows as they represent 61.2% of traded virtual water in the world (Mekonnen, M.M. and Hoekstra, A.Y. , 2011).

The bilateral trade flows for these goods (in ton) were found thanks to the UN Commodity Trade Statistic Database (HS nomenclature), where an average of the flows (in ton) was calculated for the designated period of 1996-2005. The time period was chosen according to the available data on virtual water necessary for the production of each commodity in each individual country. To measure the amount of water traded via the agricultural goods,

Mekonnen & Hoekstra (2010)'s database was used. We extracted the water amount (in m^3

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[3]
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        Xvw |      Freq.     Percent        Cum.
------------+-----------------------------------
          0 |     14,057       77.71       77.71
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and on the same period of 1996-2005) necessary to the production of a ton of each of the chosen commodities at a national level, disaggregated into green and blue water. Was then multiplicated the water amount by country (total, blue and green), necessary to the production of each good, by the world bilateral exchanges in ton of these same products.

$$gWX_{xij} = gWprod_{xi} \times Qton_{xij}$$

gWX_{xij} : Green water exports, intrinsic to good x, from country *i* to country *j*
$gWprod_{xi}$: Cube meters of green water necessary to the production of good x in country *i*
$Qton_{xij}$: Tons of good x traded from country *i* to country *j*

$$bWX_{xij} = bWprod_{xi} \times Qton_{xij}$$

bWX_{xij} : Blue water exports, intrinsic to good x, from country *i* to country *j*
$bWprod_{xi}$: Cube meters of blue water necessary to the production of good x in country *i*
$Qton_{xij}$: Tons of good x traded from country *i* to country *j*

The sum of green and blue water flows gives us the total disaggregated footprint by product:

$WX_{xij} = bWX_{xij} + \boldsymbol{gW}X_{xij}$

Thus, giving us the total water exported -*green and blue*- from country *i* to country *j*, through the chosen agricultural commodities.

$$WX_{ij} = \sum_{x=1}^{9} gWX_{xij} + \sum_{x=1}^{9} bWX_{xij}$$

2. Interest variables

National water endowment

In order to judge of the comparative advantage of a country, the interest variable must represent water input of each country. Was chosen from the Aquastat database (Food and Agriculture Organization (FAO)), the Total Actual Renewable Water Resources (TRWR_actual) for each country on the 1996-2005 period. The TRWR_actual is the sum of internal renewable water resources (IRWR) and external actual renewable water resources (ERWR_actual). It corresponds to the maximum theoretical yearly amount of water actually available for a country at a given moment.

Calculation Criteria**:** [Water resources: total renewable (actual)] = [Surface water: total renewable (actual)[4]] + [Groundwater: total renewable (actual)[5]] - [Overlap between surface water and groundwater]

Other variables of control

Typical gravity model control variables were chosen. They were extracted from the CEPII Gravity Dataset (Head, K. Mayer and J. Ries , 2010) and were adapted to a cross-sectional subject implying that was calculated their average value between 1996 and 2005.

- Population of country of origin and destination, '*pop*', (World Bank's World Development Indicators, WDI)
- GDP per capita of country of origin and destination, *'GDP_cap*', (World Bank's World Development Indicators, WDI)
- A bilateral variable measuring the distance between each dyad, '*distw*', (*CEPII distance database*)

As all three variables are continuous they will be transformed into logarithms. Bilateral dummies were also included:

- A Regional Trade Agreement dummy, '*RTA*', equal to 1 if presence of trade agreement (Baier, Bergstrand, & Jeffrey, 2007 ; Frankel, 1997 and the WTO)
- A contiguity dummy, '*contig*', that takes the value of 1 if countries share a border (*CEPII Distance Database*)

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[4] This is the sum of the internal renewable surface water resources and the total external actual renewable surface water resources. (FAO)

[5] This is the sum of the internal renewable groundwater resources and the total external actual renewable groundwater resources. In general natural and actual external (entering) renewable groundwater resources are considered to be the same. (FAO)

- A common language dummy, '*comlang_off*', that takes the value of 1 if countries share same official language (*CEPII Distance Database*)
- A '*colony*' dummy, if countries ever had colonization history
- A Common Legal Origin dummy, '*Comleg*', that takes the value of 1 if countries have same legal origin (Shleifer)

Finally according to Kumar & Singh (2005), a continuous variable controlling for arable land per capita[6] (in 1000 hectares) was added:

- '*Arableland*' (Aquastat, FAO)

Distance should increase transportation costs and thus reduce trade. Conversely, if two countries are contiguous, share a common language, a trade agreement, a colonial past or common legal origins it should reduce transaction costs. In terms of unilateral variables, GDP per capita of country of origin (destination) should increase (decrease) exports. Demographic population should limit country of origin's exports, as it will have more domestic needs, while on the other hand, destination country's population should increase demanded exports of country of origin. Finally, arable land per capita should act as a heightening factor of exportations for the country of origin, while on the other hand, if the partner country has an important quantity of land it should reduce the exports.

Model

The econometric model takes a bilateral form and follows the following Heckman method:

(1) Selection equation : Propensity to trade

$$z^*_{rp} = \beta_0 + \beta_1 \log \mathrm{GDPcap}_r + \beta_2 \log \mathrm{GDPcap}_p + \beta_3 \log \mathrm{pop}_r + \beta_4 \log \mathrm{pop}_p + \beta_5 \log WR_r + \beta_6 \log \mathrm{WR}_p + \beta_7 \mathrm{arableland}_r + \beta_8 \mathrm{arableland}$$

(2) Intensity Equation : Amount traded

$$[\log \mathrm{Xvw}]\_rp = \alpha\_0 + [\alpha\_1\ \log]\ [[\mathrm{GDPcap}]\_r\ ] + \alpha\_2\ \log\ [[\mathrm{GDPcap}]\_p\ ] + [\alpha\_3\ \log]\ [[\mathrm{pop}]\_r\ ] + [\alpha\_4\ \log]\ [[\mathrm{pop}]\_$$

With z^*_{rp}, a dichotomic variable of trade propensity and the variable $\log \mathrm{Xvw}_{rp}$ observable only when z^*_{rp}>0.

Exclusion restrictions :

contig_{rp} ; $\mathrm{comlang\_off}_{rp}$; colony_{rp} ; comleg_{rp} ; $\log \mathrm{distw}_{rp}$

According to the model's conditions, the exclusions restrictions must only be present in the selection equation (1), and while they influence the decision to trade, they can't impact

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[6] Land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included. Data for arable land is not meant to indicate the amount of land that is potentially cultivable. (FAO)

amount of flows estimated in equation (2). This seems justified regarding contiguity, common language, colonial relationship, legal origin and distance between two countries.

As the empirical model doesn't differentiate between comparative and absolute advantage, we can wonder: What happens when a country has a comparative advantage in capital while being well endowed in the water resource (Ansink, 2010)? This would suggest that in the empirical results, big developed countries with high water endowment won't necessarily export said services if they have a relative advantage in the capital factor.

Results

According to a simple log-linear regression, there is presence of heteroscedasticity (cf. table 5, model (1), appendix), a common problem in bilateral gravity models. In order to solve for this, it's preferable to use a Maximum Likelihood Heckman Estimator *versus* a twostep estimator, considering that the presented regressions had no difficulty converging.

A. Benchmark estimation : Total virtual water exports

The results refer to models presented in table 3. Even if there are no problems regarding coefficients of the 'Outcome' step -OLS estimation of the intensity equation- it must be noted that those of the 'Restriction' step -Probit estimation of the selection equation- do not represent the marginal effects. After correction, it can be read in table 3 **the marginal effects of the expected values of the dependent variable conditional to its observation -*E(y | y observed*)-.**

Estimation (2) does not differentiate the considered water type. Is measured here the total virtual water (m^3) exported from the reporter country to his partner country for the nine commodities previously presented. We are looking to test the comparative advantage theory regarding the water factor. In the gravity model all the variables are significant. The more the reporter -exporting country- is rich in water, the more he will be able to export agricultural goods intensive in said resource. An increase in 1 % of the water input is correlated with an increase of virtual water exports of 0,82%. Conversely, if the partner -importing country- is well endowed in water, exports of reporter country will diminish. An increase of 1% of national resources is correlated with a reduction of exports of country of origin of 0,20%. These results follow Allan (1998) and Reimer (2010) theory.

In terms of arable land, Kumar & Singh (2005)'s theory is validated. The more arable land a country has, the more he will tend to export (a unit of arable land increases exports of 1.34%), conditional to the fact that importing country does not have much arable land himself. GDP per capita leads to an interesting result, when country of origin is well developed his virtual water exports diminish of 0.59%. This can be explained by the fact, that developed countries are generally specialized in capital intensive goods. Thus, even with an absolute advantage in water, they will prefer to import virtual water, creating a disequilibrium of the resource at global level (Ansink, 2010). These results validate the comparative advantage theory versus the absolute advantage one, in regards to the water service.

It is important to temperate these results as water is not the driving force of global trade decisions. If we study the control variable results, all have the expected sign: contiguity, regional agreements, common language or law, all act in favor of exchange between two partner countries. While, on the other hand, distance will play as a barrier and will be assimilated as an extra transaction cost to trade. Finally an increase of 1% of population in country of origin is correlated with a reduction of 0.03% of exports, in order to preserve the high domestic pressure. While, on the other hand, in the partner country, high demographic pressure is correlated with an increase in imports.

For each estimation, the Wald test rejects the hypothesis of omitted variable, thus making it impossible to reject the hypothesis of a badly specified model. In definitive, the χ^2 statistic, in order to test if ρ -error correlation term of both equations- is significantly different than 0, enables us to reject the nil hypothesis, stating that the intensity equation is independent from the selection equation. It can therefore be affirmed that an OLS estimation would of given biased results, justifying the Heckman Method.

B. Disaggregating Virtual Water

Estimations (3) and (4) respectively represent green and blue virtual water exports. Coefficient signs similar to those obtained in model (2). Reporter country's GDP per capita varies, as it loses significance when estimating on blue virtual water exports. This could mean that a developed country, well endowed in green water, will take advantage of its low opportunity cost. He will be less inclined to invest in irrigation systems and will prefer to specialize in capital intensive goods, using his 'liquid' water to other means. Alongside GDP, demographic pressure also varies, as its impact on blue virtual water exports is now positive (+0.62%). This difference can be explained by the high labor demand for blue water exploitation (dam construction etc.). High demography is therefore an incentive to irrigated agricultural production but it has no impact on soil's natural moisture (as in model (2) the impact on green virtual water stays negative).

Regarding arable land, as in model (2), it is correlated with higher exports. However the impact is stronger on blue virtual water with an increase of 1.97 exported units (versus 1.28 for green water). Following this same principal, the more a destination country has arable land the more he will diminish his blue virtual water imports relatively to green imports. It is possible that this is due to the fact that a country is more flexible in its decision to produce irrigated agricultural commodities (through dams etc.), while it will be harder for him to reproduce satisfactory conditions when it comes to green water dependent agriculture. He is therefore more dependent on the rest of the world for this category of goods.

What interests us here is the difference in influence of a country's water endowment. For the reporter country, water input will be more determinant in green water exports (+0.91% versus 0.21% for blue water), this is probably due to its opportunity cost. It is more profitable for a country to produce thanks to water naturally present in the ground than to extract resources that can be used for other means. In the same light, the partner country, will diminish his imports of blue water intensive goods rather than the green water intensive ones. This can be justified by the same arguments than those regarding arable land. It is harder to reduce imports of green virtual water, dependence to these commodities being higher, a country not being able to imitate another's natural environment. Moreover, it must be added that technology and research have, as of now, being orientated towards bleu water, and that it is easier for a country, even relatively poor in the resource, to exploit it (ground water extraction or dam construction). However to this date, research in regards to water evaporation and soil efficiency are limited.

When it comes to bilateral control variables, all have the same sign as in estimation (2), respecting the trade model theory. And once again, as in the previous model, Wald's test of variable omission, as well as the test of independence of equations, both reject their nil hypothesis.

Table 1: Heckman ML Results

Variables	(2)	(3)	(4)
	logXvw	logXvw_green	logXvw_blue
Outcome			
$\log GDPcap_r$	-0.591***	-0.618***	-0.0703
	(-9.85)	*(-10.37)*	*(-1.28)*
$\log GDPcap_p$	0.552***	0.560***	0.276***
	(17.30)	*(17.49)*	*(5.29)*
$arableland_r$	1.340***	1.283***	1.976***
	(8.20)	*(7.47)*	*(9.37)*
$arableland_p$	-0.852***	-0.842***	-1.075***
	(-5.48)	*(-5.36)*	*(-4.44)*
$\log POP_r$	-0.0327	-0.0919	0.617***
	(-0.64)	*(-1.74)*	*(6.96)*
$\log POP_p$	0.737***	0.733***	0.632***
	(16.45)	*(16.20)*	*(9.25)*
$\log WR_r$	0.829***	0.906***	0.219**
	(18.13)	*(19.18)*	*(3.11)*
$\log WR_p$	-0.205***	-0.199***	-0.313***
	(-6.13)	*(-5.86)*	*(-5.89)*
rta	-0.513*	-0.545*	0.308
	(-2.27)	*(-2.45)*	*(1.11)*
_cons	14.23***	14.42***	6.819***
	(31.46)	*(31.64)*	*(10.05)*
Selection			
contig	2.206***	2.234***	1.147***
	(0.13)	*(0.14)*	*(0.218)*

comlang_off	0.525***	0.600***	0.315***
	(0.90)	*(0.94)*	*(0.08)*
colony	1.437***	1.463***	1.128***
	(0.19)	*(0.20)*	*(0.20)*
comleg	0.262***	0.272***	0.07
	(0.07)	*(0.07)*	*(0.05)*
logdistw	-0.527***	-0.554***	-0.389***
	(0.05)	*(0,05)*	*(0.08)*
_cons	0.458***	0.445***	0.905***
	(3.70)	*(3.63)*	*(6.12)*
Athrho			
_cons	-1.428***	-1.502***	-0.490***

	(-8.25)	*(-8.96)*	*(-5.25)*
Lnsigma			
_cons	1.620*** *(24.55)*	1.668*** *(27.01)*	1.447*** *(43.52)*
Inverse Mills Ratio	-4,5	-4,8	-1,93
Iteration	5	5	3
N	18001	18001	18034
Ind of Equation (Rho=0)	-0,89***	-0,91***	-0,45***
Wald test $\chi^2(9)$	1542,14***	1651.50***	429.48***

*Standard Deviations in Parentheses ; *p<0.05 **p<0.01 ***p<0.001 ; Marginal Effects reported for selection variables.*

Testing for Robust Results

In order to judge if the model is robust, we will do two more estimations. The first one is similar to the previous regressions as it just uses the Heckman *twostep* estimator, while the second estimation is of the more common log-linear form. In the latter, a unit is added to the dependent variable reducing the bias due to high zero distribution. The explained variable becomes : $\log(Xvw_{ij} + 1)$.

The Heckman twostep is very similar to the Heckman ML, and exists in order to solve for the converging problem that can be encountered with an ML. In table 4 estimation (5), we obtain the same results as those of estimation (2)[7]. However, it must be noted that it is impossible to read the standard deviations of the exclusion restrictions.

The log-linear estimation (6) is in OLS. The simplicity of the model enables us to control for multilateral resistance (Anderson & van Wincoop, 2003). It was solved for by the introduction of 'exporting' and 'importing' country fixed effects. The introduction of so many dummies can lead to colinearity problems and makes it impossible the use of unilateral control variables. We thus had to change the main interest variable (Water Resources Reporter and Partner) for a bilateral one. Therefore we created a variable representing the difference in water resources between both countries:

$$\mathrm{diffWR}_{rp} = \mathrm{WR}_{\mathrm{r}} - \mathrm{WR}_{\mathrm{p}}$$

An increase in this new variable implies higher water resources in the reporter country relatively to the partner country. Estimation (6) leads to robust results, with a positive differential variable (+0.002).

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[7] Cf. table 6 for disaggregated (blue/green) results of *twostep* estimator.

Table 2 : Robust Test Results

Variables	(5) *twostep*	(6) OLS
	logXvw	log(Xvw+1)
Outcome		
$\log GDPcap_{r}$	-0.729***	
	(-19.85)	
$\log GDPcap_{p}$	0.464***	
	(13.92)	
$arableland_{r}$	1.352***	
	(8.72)	
$arableland_{p}$	-0.690***	
	(-4.03)	
$\log POP_{r}$	-0.0767	
	(-1.52)	
$\log POP_{p}$	0.675***	
	(14.99)	
$\log WR_{r}$	0.819***	
	(18.57)	
$\log WR_{p}$	-0.218***	
	(-6.13)	
rta	0.605***	1.264***
	(3.47)	*(6.20)*
$DiffWR_{ij}$		0.002***
		(18.80)
contig		3.546***
		(11.83)
comlang_off		1.161***

		(8.31)
comleg		0.169*
		(1.98)
colony		1.993***
		(5.44)
logdistw		-1.742***
		(-21.80)
_cons	12.38***	12.99***
	(27.26)	*(16.26)*
Select		
contig	1.109***	
colony	0.929***	
comlang_off	0.316***	
comleg	0.075*	

logdistw	-0.208***	
_cons	0.577***	
	(-0,127)	
Inverse Mills Ratio	-1.590***	
	(-7.77)	
N	18001	17030
R^2		0.544
Wald test $\chi^2(9)$	1237.06***	

Standard Deviations in parenthesis ;
**p<0.05 **p<0.01*
****p<0.00;*
Estimation (6) with Fixed Effects;
Marginal Effects reported for selection variables.

Politicy Implications, Critic and Prolongation

A. Politicy Implications

International trade has a role to play in water preservation. Is it possible to balance this resource on a world scale by promoting virtual water flows? On the one hand, this depends on a developed country's, with absolute advantage in water, incitation to take advantage of its own resources, and thus, to reduce its net water import, rather than increasing it by specializing in capital intensive goods. On the other hand, bad price structure, such as agricultural subsidies (as seen in the USA and EU) is an obstacle to this objective. Wheat exports in the USA relies on irrigated agriculture, i.e. blue water, thus the support given by the government in this sector impairs sustainable development. We can understand the stake of an agriculture that relies on green water, it having a non exploited potential regarding better water productivity and sustainability. In this context, fragile tropical economies have a role to play in world trade, leading to a reduction of blue water extractions and promoting underground water protection. However, this would depend on numerous factors, such as water productivity, international treaties, market costs, the nature of economic objectives and national policies considerations. As of yet, there exists a disequilibrium between trade treaties and international water measures. No treaty has the power to reduce trade with harmful repercussions on local water systems. Equitable and efficient international rules must include a provision enabling consumers, through their government, to increase barriers towards products which have bad repercussions on the water systems, and indirectly the ecosystem (through ecological taxes for example). The WTO's report must indentify various mechanisms to ensure an equilibrium between trade and water: products transparence, an international price on water protocol and a System of Water Footprint Permit (Hoekstra A., 2010).

B. Critics and Prolongations

It must be noted that this study must not limit itself to nine agricultural commodities. We can not forget industrial product trade, which most likely puts forward questions regarding the capital factor or the evolution from the primary to secondary and tertiary sectors in developed countries. Due to the innovative aspect of this subject (in empirical terms), data is limited, implicating difficulty to show more than a simple correlation of water endowment impact on trade balances.

As demonstrated by the model, virtual flows don't lead to water saving in the case of a big country with an absolute advantage in water but a relative one in capital, such as Norway. This argument was criticized by Reimer (2012), for whom that big country will consume as much as this factor as the rest of the world, in relative terms, once borders are opened (cf. appendix). It could be interesting to expand this study to water saving in order to confirm if world flows can really resolve the rare resource's disequilibrium. To do so, a panel sample is necessary as to judge virtual water evolution and to test if countries with comparative advantage in capital (and absolute in water), respect trade theory by remaining net importers of the water service. This would confirm Ansink's (2010) theory and refute Reimer's (2012) model, proving that world water saving is not verified.

Moreover, it would be interesting to test subsidy role on water trade. Another point to study is on property rights. As suggested by Chichilnisky (1994), when they are not well defined, there exists an overexploitation of the resource. This hints to the fact that less strict countries have an advantage in relative costs. Water costs are generally badly included in national economies implicating severe distortions. If verified, this would put forward the need for world harmonization of exploitation and prices, for example through the WTO.

Finally, despite possible world water savings, international trade implies transportation costs and high greenhouse gas emissions. The question is therefore to know where the highest danger for the environment relies: over water exploitation or the increase of fossil energy consumption?

Conclusion

This paper puts into light virtual water flow stakes throughout the world, which are the indirect volumes of water necessary to the production of imported or exported goods and services of a given country. We have tested the impact of national water endowment on total virtual water bilateral exports, but also on disaggregated exports taking the form of blue and green virtual water.

Via a Heckman Model, we have concluded that the more a country is endowed in the water factor, the more he is inclined to export the virtual resource. The comparative advantage theory is verified. However, the absolute advantage one is refuted, as high GDP per capita is correlated with export reduction, implicating that developed countries specialize in capital intensive goods, independently to their wealth in real water. This last result suggests that virtual water flows aren't a balancing factor on world water, as a developed country won't necessarily share its resources (Ansink, 2010).

Once we disaggregate water flows, lower opportunity costs in green virtual water makes it more fit for export than blue water, even in a situation of high GDP per capita. Nevertheless, in terms of imports, a country well endowed in arable land or internal water will reduce its international blue water demand rather than its green one. This is explained by a higher dependence in partner countries in regards to green virtual water. Indeed, technology and research are less advances when it comes to increasing soil productivity -using green water for productive means- compared to those aiming at extracting blue water from its multiple sources (dams, irrigation etc.). A country is more aware of its wealth in blue water , he will therefore reduce these imports before reducing green virtual water ones. Demography also plays a role in this water dichotomy. An population increase of 1% reduces green virtual water exports of 0.9% while it increases blue ones of 0.62%. This difference can be explained by labor requirements in blue water exploitations (dam construction etc.). Demography thus plays a role in incentive to produce irrigated agricultural, while it can't impact natural soil moisture.

It can't be confirmed that water trade in its virtual form is practiced with the objective of saving world resources. The argument is more that traded flows lead to virtual water transfers. Through imports, countries save water, but this isn't their primary goal. Yang *et al.* (2003) demonstrated that under a certain aridity threshold, a relation can be established between cereal imports of a country and its renewable water resources per capita. International trade influences significantly water exploitation in most countries, by increasing or reducing domestic extraction. In this context, it seems important to build international trade treaties that go hand in hand with international treaties relative to sustainable water exploitation.

This study leads to many other possibilities. First, widening the analysis to panel data and to more goods, not only agricultural ones but also industrial one, taking into account different effects, most especially on developed countries. Moreover, deepening this work would open other approaches, such as estimation models judging directly of the possibility to reduce disparities between countries via virtual water flows. It would also be adequate to include variables that take into account climate choc. Another important point, is the place of agricultural subsidies administered by world powers: to what extent does it hurt competition and flexibility of world water trade? Another pertinent stake is property rights water costs (Chichilnisky, 1994). What is its impact in specialization choices and the repercussion on the environment. Finally, we can't forget the commodity transport effect on the environment via fossil energy exploitation and greenhouse gas emissions. As a result, we can question what is most preferable for a sustainable future: a local consumption increase in order to reduce harmful impact of transportation means, or, the promotion of global water rebalance thanks to virtual water trade limiting damages on renewable resources?

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Appendix

A. Graph Summary

B. Table Summary

C. Capital and Water Heckscher-Ohlin-Samuelson Model

This paper follows Ansink (2010) and Reimer (2012) reinterpretation of the HOS (Heckscher, 1919; Ohlin, 1933; Samuelson, 1949) model.

Theoretical context

- Two countries: H and F (with F denoted *)
- Goods $i \mid i = 1;2$
- c_i consumption of good *i*
- y_i production of good *i*
- p_i price of good *i*
- Two production factors: capital (K) and water (L) and their respective prices *r* and *w*
- a_{iL} units of water necessary to the production of good *i*
- a_{iK} units of capital necessary to the production of good *i*

Under the following conditions: pure and perfect competition of markets, identical homothetic preferences in both countries, free trade regarding goods, no transportation costs ensuring that prices of goods are identical in countries : $p_1 = p_1^*$ and $p_2 = p_2^*$.

Each firm determines L_i and K_i as to minimize the cost $wL_i + rK_i$ with constant returns to scale technology.

If conditional factor demand corresponds to a unit of production:

$$\frac{L_1}{y_1} = a_{1L}\ (w,r)\ \frac{L_2}{y_2} = a_{2L}\ \frac{(w,r)K_1}{y_1} = \frac{a_{1K}(w,r)K_2}{y_2} = a_{2K}\ (w,r).$$

Equilibrium Conditions

Equilibrium depends of the no profit condition and on the fact that produce of total production and of water amount necessary for the production of one unit of each good is equal to the total quantity of water factor in the country. Implying:

$$a_{iL}\,w + a_{iK}r = p_i,$$

$$a_{1L}y_1 + a_{2L}y_2 = L \text{ et } a_{1K}y_1 + a_{2K}y_2 = K.$$

Theoretical Implications

If country H has a comparative advantage in water: $\frac{L}{K} > \frac{L^*}{K^*}$,

And that good i=1 is intensive in water : $\frac{a_{1L}}{a_{1K}} > \frac{a_{2L}}{a_{2K}}$,

H produces more of good 1 than he consumes : $\frac{y_1}{y_2} > \frac{c_1}{c_2}$ and vice versa in country F. Then H (F) will import good 2 (1) and export good 1 (2).

D. Reimer (2012)'s model on relative factor consumption

Suppose V^w, world factor endowment with a hypothesis that the foreign country (denoted *) has an absolute advantage in water and a relative one in capital. If its demand is only its share of revenue in world's net output: s^*Y^w and with the technical matrix A, the factor content in consumption is : $s^*AY^w = s^*V^w$.

The important point is that the water content in consumption of the foreign country, after opening of borders, is a fraction of world endowment in capital and water factors, necessarily more intensive in water. After, borders open, the big foreign country (with an absolute advantage in water) goes from weak water consumption (V^*), to a consumption equal to the found proportions in the rest of the world (s^*Y^w).

Consider autarky initial endowment :

$$V = \begin{array}{ccc} L & = & 20 \\ K & = & 5 \end{array} \qquad \text{and} \qquad V^* = \begin{array}{ccc} L^* & = & 30 \\ K^* & = & 45 \end{array}$$

The domestic country has a comparative advantage in water, while the foreign country has a relative one in capital (yet absolute in water).

Once borders open, each country consumes a fraction of the world factor endowment vectors:

$$\mathrm{V}^{\mathrm{w}} = \boldsymbol{v} + \mathrm{V}^{*} = \begin{matrix} 50 \\ 50 \end{matrix}$$

This results suggests that, even if the foreign country has an absolute advantage in water, its factor consumption profile becomes similar to the domestic country. Water consumption therefore balances itself out throughout the world.

E. Abbreviations

EU :	European Union
FAO	Food and Agriculture Organization
GDP:	Growth Domestic Product
GWP :	Global Water Partnership
HOS :	Heckscher-Ohlin-Samuelson
IMR :	Inverse Mills Ratio
ML :	Maximum Likelihood
OLS :	Ordinary Least Squares
PPML :	Poisson Pseudo-Maximum Likelihood
USA :	United States of America
WDI :	World Development Indicators
WFN :	Water Footprint Network
WR :	Water Resources
WTO :	World Trade Organisation
Km^3 :	Cube Kilometers
Gm^3 :	Cube Gigameters
m^3 :	Cube Meters

F. Other Tables

Table 3 : OLS Regressions

Variables	(1) logXvw
logWR_r	
	0.820***
	(17.69)
logWR_p	
	0.208***
	(-5.77)
logGDP_r	
	0.718***
	(-19.34)
logGDP_P	
	0.496***
	(14.57)
Arableland_r	
	1.377***

	(8.87)
Arableland_p	
	0.687***
	(-4.01)
logpop_r	
	0.659***
	(11.07)
logpop_p	
	0.187***
	(3.36)
rta	
	0.304
	(1.55)
contig	
	1.326***
	(5.70)

comlang_off	-0.0109
	(-0.07)
colony	-0.233
	(-0.85)
comleg	0.359**
	(2.95)
logdistw	0.323***
	(-3.85)
_cons	12.39***
	(16.34)
N	3944
R^2	0.25

Breusch-Pagan $\chi^2(1)$	4.49*

*t statistics in parentheses ; *p<0.05 **p<0.01 ***p<0.001*

Table 4 : Robust Estimations (*disaggregated*)

Variables	(7) logXvw_green	(8) logXvw_blue
Outcome		
$\log GDPcap_r$	-0.770***	-0.0788
	(-20.48)	*(-1.48)*
$\log GDPcap_p$	0.462***	0.264***
	(13.53)	*(5.26)*
$arableland_r$	1.282***	1.971***
	(8.07)	*(9.23)*
$arableland_p$	-0.667***	-1.056***
	(-3.80)	*(-4.14)*
$\log Pop_r$	-0.146**	0.614***
	(-2.82)	*(7.71)*
$\log Pop_r$	0.662***	0.629***
	(14.37)	*(9.12)*
$\log WR_r$	0.898***	0.216***
	(19.89)	*(3.32)*
$\log WR_p$	-0.211***	-0.317***
	(-5.78)	*(-5.81)*
rta		
	0.708***	0.425
	(3.97)	*(1.72)*
_cons		
	12.27***	6.662***
	(26.46)	*(10.04)*
Select		
contig		
	1.052***	1.014***
comlang_off		
	0.299***	0.292***

colony	0.881***	1.057***
comleg	0.071*	0.046
logdistw	-0.198***	-0.343***
_cons	0.577***	0.906***
	(4.54)	*(6.48)*
Inverse Mills Ratio	-1.508***	-1.704***
	(-7.24)	*(-6.17)*
N	18001	18001
Wald Chi2(9)	1248.61***	445.42***

*t statistics in parentheses ; *p<0.05 **p<0.01 ***p<0.001*

Marginal Effects reported for selection variables

G. Sample

Table 5: Variable Description

Name	Description	Source	Specificity
Xvw	Total Virtual Water Exports	*Comtrade* ; Mekonnen, M.M. and Hoekstra, A.Y. (2010)	mean 1996-2005
Xvw_green	Green Virtual Water Exports	*Comtrade* ; Mekonnen, M.M. and Hoekstra, A.Y. (2010)	mean 1996-2006
Xvw_Blue	Blue Virtual Water Exports	*Comtrade* ; Mekonnen, M.M. and Hoekstra, A.Y. (2010)	mean 1996-2007
WR	Total Renewable Water Resources	Aquastat (FAO)	mean 1996-2008
pop	Population	World Bank's World Development Indicators	mean 1996-2009
GDPcap	GDP per Capita	World Bank's World Development Indicators	mean 1996-2010
distw	Distance between two countries	Cepii Distance Database	Constant variable in time
rta	Trade Treaties	Baier and Bergstrand (2007), WTO and Frankel (1997)	dummy
contig	Contiguity between two countries	Cepii Distance Database	dummy
comlang_off	Common Official Language	Cepii Distance Database	dummy
colony	Colonization History		dummy
comleg	Common Legal Origins	Andrei Shleifer, http://post.economics.harvard.edu/faculty/shleifer/Data/qgov_web.xls	dummy
arableland	Arable Land per Capita	Aquastat (FAO)	mean 1996-2010

Table 6 : Sample Countries

Country	ISO 3166-1	Country	ISO 3166-1	Country	ISO 3166-1
Albania	ALB	Ghana	GHA	Panama	PAN
Angola	AGO	Greece	GRC	Paraguay	PRY
Argentina	ARG	Guatemala	GTM	Peru	PER
Armenia	ARM	Guinea	GIN	Philippines	PHL
Australia	AUS	Guinea-Bissau	GNB	Poland	POL
Austria	AUT	Guyana	GUY	Portugal	PRT
Azerbaijan	AZE	Honduras	HND	Qatar	QAT
Bangladesh	BGD	Hungary	HUN	Romania	ROM
Belarus	BLR	Iceland	ISL	Russian Federation	RUS
Belgium	BEL	India	IND	Rwanda	RWA
Benin	BEN	Indonesia	IDN	Saudi Arabia	SAU
Bolivia	BOL	Iran, Islamic Rep.	IRN	Senegal	SEN
Bosnia and Herzegovina	BIH	Iraq	IRQ	Sierra Leone	SLE
Botswana	BWA	Ireland	IRL	Slovak Republic	SVK
Brazil	BRA	Israel	ISR	Slovenia	SVN
Bulgaria	BGR	Italy	ITA	Spain	ESP
Burkina Faso	BFA	Jamaica	JAM	Sri Lanka	LKA
Burundi	BDI	Japan	JPN	Sudan	SDN
Cameroon	CMR	Jordan	JOR	Suriname	SUR
Canada	CAN	Kazakhstan	KAZ	Swaziland	SWZ
Cape Verde	CPV	Kenya	KEN	Sweden	SWE
Central African Republic	CAF	Kiribati	KIR	Switzerland	CHE
Chad	TCD	Korea, Rep.	KOR	Syrian Arab Republic	SYR
Chile	CHL	Kyrgyz Republic	KGZ	Tajikistan	TJK
China	CHN	Lao PDR	LAO	Tanzania	TZA
Colombia	COL	Latvia	LVA	Thailand	THA
Congo, Rep.	COG	Lebanon	LBN	Togo	TGO
Costa Rica	CRI	Lesotho	LSO	Tunisia	TUN
Cote d'Ivoire	CIV	Liberia	LBR	Turkey	TUR
Croatia	HRV	Libya	LBY	Turkmenistan	TKM
Czech Republic	CZE	Lithuania	LTU	Uganda	UGA
Denmark	DNK	Malaysia	MYS	Ukraine	UKR
Djibouti	DJI	Mali	MLI	United Kingdom	GBR
Ecuador	ECU	Mauritania	MRT	United States	USA
Egypt, Arab Rep.	EGY	Mexico	MEX	Uruguay	URY
El Salvador	SLV	Moldova	MDA	Uzbekistan	UZB
Equatorial Guinea	GNQ	Mongolia	MNG	Venezuela, RB	VEN
Eritrea	ERI	Morocco	MAR	Vietnam	VNM
Estonia	EST	Mozambique	MOZ	Yemen, Rep.	YEM
Ethiopia	ETH	Namibia	NAM	Zambia	ZMB
Finland	FIN	Nepal	NPL	Zimbabwe	ZWE
France	FRA	Netherlands	NLD		
Gabon	GAB	New Zealand	NZL		
Gambia, The	GMB	Nigeria	NGA		
Georgia	GEO	Norway	NOR		
Germany	DEU	Oman	OMN		