Working Paper Series
Department of Economics
University of Verona

Virtual Water Trade: The Implications of Capital Scarcity

Mohamad Afkhami, Thomas Bassetti, Hamed Ghoddusi, Filippo Pavesi

WP Number: 3 May 2018

ISSN: 2036-2919 (paper), 2036-4679 (online)

Virtual Water Trade: The Implications of Capital Scarcity

Mohamad Afkhami [1],Thomas Bassetti [2], Hamed Ghoddusi [3], Filippo Pavesi [4]

Abstract

The original idea behind the virtual water (VW) concept is that water-abundant countries will become producers of water-intensive goods and consequently net exporters of water, and this will alleviate the initial unequal distribution of hydric resources. We criticize this optimistic view by introducing empirical evidence that is consistent with the Heckscher-Ohlin model of international trade. We find that, though virtual water exports are increasing in the combined availability of water and arable land when comparing countries with a similar level of available water-land resources, those with higher (lower) levels of physical-human capital tend to be net importers (exporters) of water. This result relies on the intuition that high levels of capital accumulation lead water to become a relatively scarce factor in developed countries. Thus, while more developed countries shift away from agriculture, less developed countries that lack sufficient capital do not have this option and end up using water resources even if they are not abundant. Such a trade pattern could create immediate economic benefits for less developed countries, but also exerts pressure on their water resources. Therefore, prioritizing economic development in countries that have limited water availability, may be crucial to avoid excessive usage and depletion of global water resources.

Keywords: Virtual Water, International Trade, Global Water Trade, Economic Development, Heckscher-Ohlin

JEL classification: F14, F18, O13, Q25, Q27, Q56

1. Introduction

The concept of *Virtual Water* (VW) was first coined by the geographer John Allan in the early 1990s in response to the popular belief that water shortage will be a major cause of

[1]Stevens Institute of Technology. Address: School of Business, Stevens Institute of Technology, 1 Castle Point on Hudson, Hoboken, NJ 07030, USA. : mafkhami@stevens.edu

[2]University of Padua, Department of Economics and Management "Marco Fanno", Via del Santo 33, 35123 Padova, Italy. thomas.bassetti@unipd.it

[3]Stevens Institute of Technology. Address: School of Business, Stevens Institute of Technology, 1 Castle Point on Hudson, Hoboken, NJ 07030, USA. hghoddus@stevens.edu, web:www.ghoddusi.com

[4]University of Verona, Via Cantarane 24, 37129, Verona, Italy. filippo.pavesi@univr.it

future wars (see Allan, 1998; and Allan, 2003). The major promise of VW is that countries that have limited availability of fresh water resources can offset their internal shortage of water by importing water-intensive goods from water-abundant countries (Hoekstra and Chapagain, 2011). The term is very well advertised and has been widely used in policy and scientific discussions and is one of the cornerstones of global water discourse.

The predictions of VW look appealing and optimistic. If all countries follow what the mainstream VW discourse suggests, then the *ex-post* (after trade) distribution of water consumption across different countries should be smoother than the *ex-ante* (before trade) distribution of water endowments.

While we appreciate the fundamental insights of the virtual water trade paradigm, we take a critical stance in relation to some of its predictions. Using a Hecksher-Ohlin (HO) type framework, our empirical analysis clearly indicates that virtual water trade, at least in its original form, may not achieve the promised goal of alleviating problems related to limited availability of water resources in certain areas of world. Moreover, VW trade may not necessarily result in a more equal ex-post distribution of water across different countries. We show that those countries that have greater endowments of both arable land and water resources may not necessarily have a comparative advantage in producing water-intensive goods if they also have high levels of capital. The relative abundance of capital makes these countries *water scarce* and causes them to become potential "importers" of water.

We are not the first to critically examine the concept of virtual water. Several papers have done this in the past, and we build our contribution on the insights offered by previous researchers. Yang and Zehnder (2007) acknowledge that the virtual water literature has raised awareness regarding global water scarcity but has failed to stimulate practical policy implications. Using the standard HO model of trade, other papers have provided critical discussions of the role of virtual water.

The two closely-related papers to our work are Ansink (2010) and Reimer (2012). Ansink

(2010) refutes the major claim of the virtual water paradigm by illustrating cases in which the HO model does not necessarily imply a more equal distribution of water resources. Reimer (2012), however, defends the validity of the HO model by showing that it is actually consistent with a more even *relative* redistribution of water resources. We build on the discussion by illustrating how Ansink's claim remains, since the relevant dimension when assessing the validity of the virtual water promise is the impact of trade on the *absolute* distribution of water resources.

Other papers including Wichelns (2010) have also discussed and pointed out the shortcomings of the virtual water paradigm in explaining the stylized facts, and therefore in failing to provide solid foundations for policy making. As an example of a more empirical study, Kumar and Singh (2005) use cross-country data from 151 countries showing that pure water endowments do not fare well in explaining much of the virtual water trade. There also exists a rich strand of literature that assesses global and regional virtual water trade flows using empirical data. Some examples include Oki et al. (2003), Dietzenbacher and Velázquez (2007), Guan and Hubacek (2007), Feng et al. (2012), and Bae and Dall'Erba (2018). Gawel and Bernsen (2011) and Antonelli and Sartori (2015) provide the most recent review of the academic and policy debate surrounding the notion of virtual water.

Sayan (2003) tests the validity of the Heckscher-Ohlin model using data from 11 MENA countries. Debaere (2014) is one the few papers that study the role of water abundance in determining countries' exports of water intensive goods. The paper affirms that water abundance is a source of comparative advantage; however, it also demonstrates that water has a weaker power in explaining trade patterns compared to the classic production factors (labor and capital). Although we use the same dataset employed in Debaere (2014), we adopt a partially different approach. First of all, in line with the existing literature based on the HO theory, we use a measure of net-exports as a dependent variable; whereas considering only exports, Debaere (2014) tests a quasi Heckscher-Ohlin model (see Romalis, 2004). This allows us to take into account the presence of intra-industry trade. Second, we reduce the input space going from four separate factors to two composite factors. Indeed, as argued by Leamer and Bowen (1981), Aw (1983), and Forstner (1985), when there are more than two factors of production, usual regression procedures provide inappropriate tests of the factor proportions theory.

International trade models other than HO have also been used to explain VW flows. Fracasso (2014) estimates a trade gravity model and finds that bilateral flows are affected by water endowments and pressure on water resources in addition to the classic determinants of the gravity model. Utilizing the same model, and examining VW flows across the Mediterranean basin, Fracasso et al. (2016) verify that larger water endowments do not necessarily result in more VW exports. Seekell et al. (2011) use trade data to argue that VW flows are directed by global economic structures and trade relations rather than by the relative scarcity of water within nations. They also argue that VW trade is unlikely to mitigate water inequality as the water used in agriculture (the dominant water need of countries) cannot be completely compensated by VW transfers. In a study with a similar approach and conclusion, Suweis et al. (2011) find that 4% of international trade connections account for 80% of virtual water transfers. Putting weight on abundance, Lenzen et al. (2013) include the scarcity of water resources at the country level to analyze global water trade and draw a new structure of global virtual water networks under this assumption.

Our contribution can be summarized as follows. First, by using a hierarchical, multi-scale decomposition technique called *treelet* algorithm, we show how a model with four separate factors of production can be reduced to a model with two composite factors without losing relevant information. This methodology allows us to exploit the disperse correlation structure of country- and industry-level data and solve the econometric problems related to estimates of the HO model. Second, we highlight that the HO model is not inconsistent with the fact that trade may indeed lead to a less equal distribution of water resources. In particular, we show that countries that have a relative abundance of water (and arable land) versus capital (human and physical) will tend to be net exporters in sectors that display a relative intensity of these factors (i.e., agriculture versus manufacturing/services). Finally, we show that the main difference between the exporters and importers of virtual water is not their endowment of natural resources, but their capital endowment. This implies that there exists a threshold level of capital above which a country is a net-importer of VW, and below which it turns out to be a net-exporter of water resources. These findings have significant policy implications in relation to economic development. Indeed, our theoretical and empirical analysis suggest that the production and export of water-intensive goods in less developed countries is a natural consequence of free trade.

The rest of the article is organized as follows. Section 2 provides a brief background of the importance of global water trade and presents some stylized facts. Section 3 introduces the theoretical framework, and the empirical analysis follows in section 4. Section 5 concludes the article and proposes topics for future research.

2. Background and Motivating Facts

The trade of virtual water becomes important in a world in which there is a significant unevenness in the initial distribution of water resources.[5] Stylized facts based on World Bank data highlight that the inequality of water distribution is indeed a relevant issue and appears to have increased over time. Figure 1 illustrates four measures of global endowments of fresh water resources over time. In each plot the single bars represent *cross-country* statistics of per-capita water endowments for a particular year. The figure therefore highlights the

[5] Another source of comparative advantage may be related to differences in relative productivity across countries (gains from from trade due to specialization), which we abstract from in our analysis. We make it clear that our analysis is focused on the pattern of embedded water trade between countries. We take no stance regarding the relation between economic development and the efficiency of the agricultural production and distribution process.

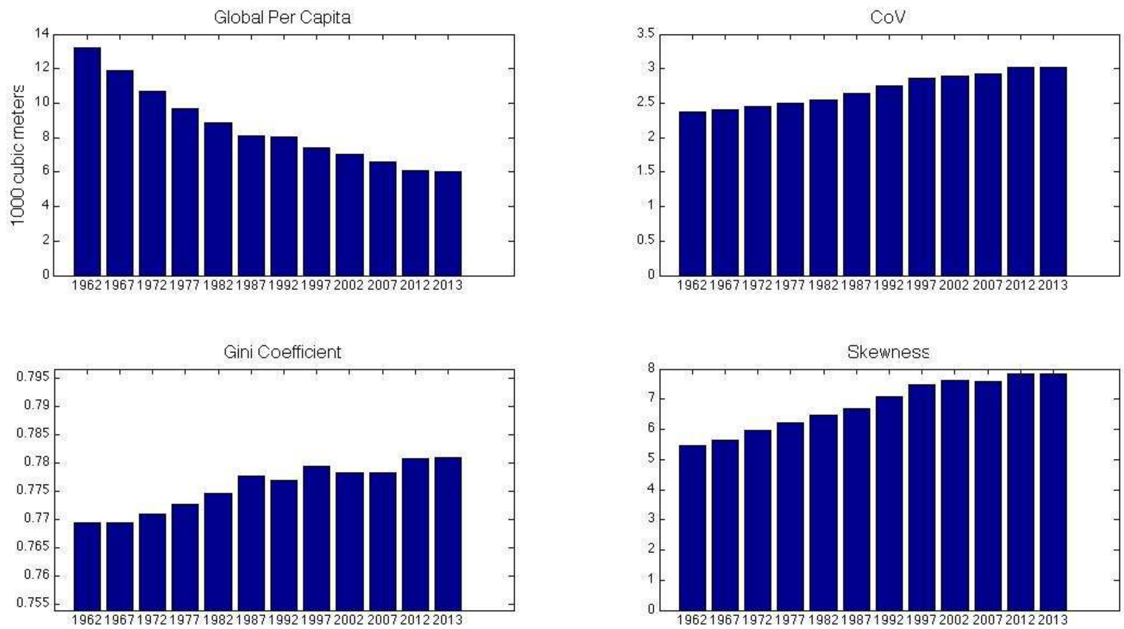

Figure 1: Dynamics of Fresh Water Distribution Over Time. The upper left panel shows the trend of global per capital endowment of fresh water. The upper right shows the coefficient of variation (CoV) for the per capita distribution of fresh water among more than 200 countries. The lower left panel is the Gini coefficient and the lower right panel is the skewness of per capita distribution of water. Source of data: World Bank

dynamics of four cross-country statistical measures over time. The top left panel shows the per-capita endowment of water at the global level. As expected, population growth and climate change have resulted in a secular decline of per-capita water endowments. The first conclusion that can be drawn by observing this trend is that water is becoming a scarcer resource over time. The other three panels of Figure 1 show the distribution of water across different countries over time. The top right panel shows the coefficient of variation (CoV) of the per capita distribution of water, the lower left panel is the Gini coefficient, and the right lower panel is the skewness of the distribution. All three reported statistics suggest that water distribution has become more unequal and also skewed over time.

Unlike other natural resources, water has certain distinguishing features which make its global distribution particularly critical. Commodities such as crude oil, natural gas, timber, copper, coal, etc. can be produced in one location and economically transported to others

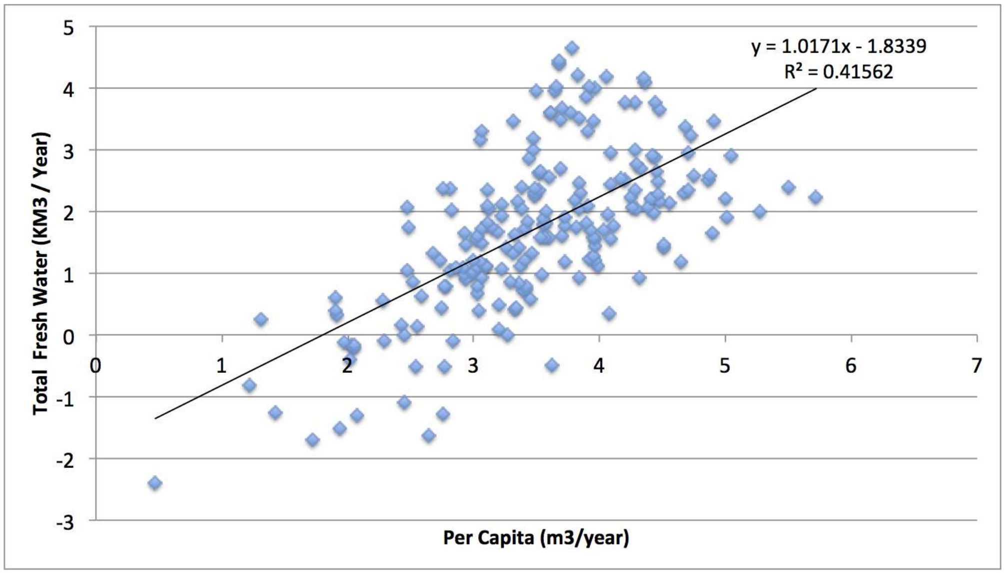

Figure 2: Relationship between Total and Per Capita Endowment of Fresh Water. Source of data: World Bank

for consumption and production purposes. Indeed, some rare earth materials are produced only in a few sites and are distributed globally. Water differs from these commodities in its non-transportability (given the current transport costs and market prices). Therefore, the spatial distribution of water resources is an extremely relevant issue.

Though water is not easily transportable across the globe, population can move between water scarce and water abundant countries. The free movement of population can potentially create a more equal per-capita endowment of water across countries. To scrutinize this conjecture, in Figure 2 we plot the relationship between total and per capita endowments of water across different countries. If the global population dynamics was such that a greater share of the population were concentrated in water-abundant regions, then the per-capita endowments should be close to each other and the best fit line should be vertical (i.e independent of the total water endowment of the country). However, as we see in Figure 2 the actual behavior does not follow this pattern, and there is a significant degree of variation in the distribution of water resources per capita across countries.

3. Theoretical Framework

We adopt a simple theoretical framework to illustrate our major points and examine the promise of VW. This framework follows the core logic of the HO model of international trade based on two goods, two countries, and two production factors. Using the standard notation of international trade models, the two countries, home and foreign (where we denote the latter with an asterisk (*)), are characterized by different endowments of water and capital. The water endowment (WL) includes both water (W) and arable land (L), while capital (KH) includes both physical (K) and human capital (H), which by assumption are internationally immobile. In order to concentrate on the relevant issues, we focus on the trade-off between water-land and capital per capita, assuming that all goods can be produced combining these two factors. Therefore, the prodcution of each of the the two commodities requires a combination of the different factors, however, Y_1 is a water-land intensive agriculture crop and Y_2, is a capital-intensive industrial product.

One of the main findings of the model is that, under the standard assumptions of homogeneity of preferences and technologies across countries, allowing for final goods to be traded between two countries will result in the equalization of production input prices across countries (i.e., factor price equalization), even absent any trade or mobility of production factors. If the two countries have a sufficiently similar ratio of factor endowments, they will produce in the so-called cone of production, in which both countries will use the same combination of resources; though, they may produce different quantities of each good. In other words, the HO model predicts that under this setup, the capital abundant country will produce more of the capital intensive good, whereas the water abundant country will focus on the water intensive good as ilustrated in Figure 3.

If the global trade of virtual water follows the predictions of the Heckscher-Ohlin model, the local scarcity of water resources should be equal in all countries. Relatively water abundant countries will therefore produce more water-land intensive goods and will become net

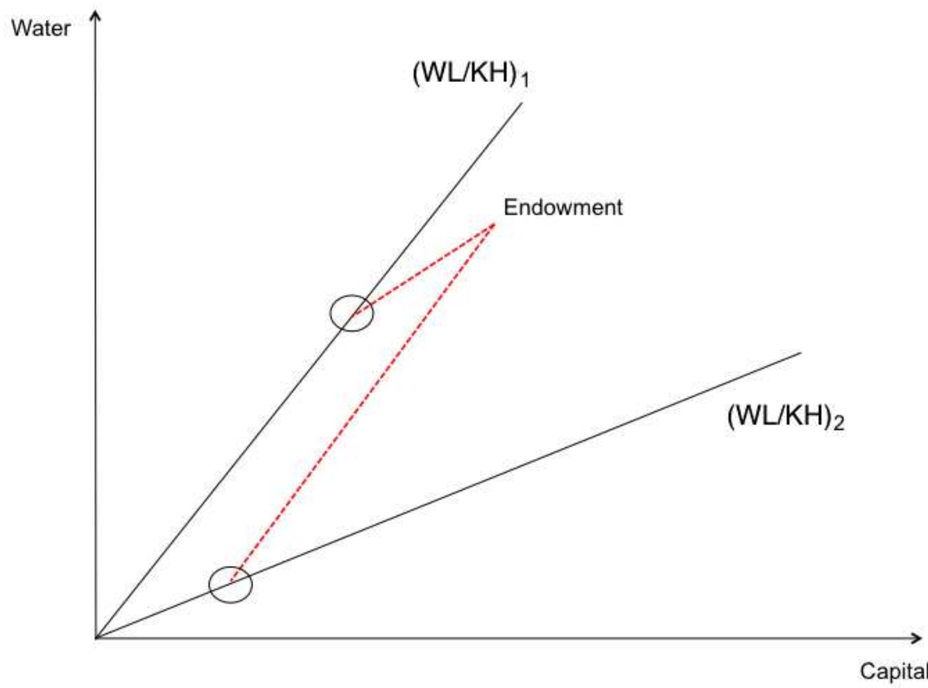

Figure 3: Cone of Diversification in the Heckscher-Ohlin Model. Countries produce both goods using the same production technology; however, since the endowment of production factors differ between two countries, each country will produce different quantities of final goods in order to fully use the endowment of two production factors.

exporters of virtual water. Relatively water scarce countries, on the other hand, will focus on producing a relatively larger quantity of capital-intensive goods and will become net importers of virtual water. However, in what follows we argue that comparative advantages are not sufficient to allow for trade to lead to a more equal redistribution of water resources as implied by the VW paradigm. In particular, when trade occurs between two countries, one of which has an absolute scarcity of all factors with respect to the other, it may not necessarily lead to a more equal distribution of water. For instance, consider the following two trade partners:

(a) An arid or semi-arid country (e.g., Mongolia, Afghanistan, etc.) that is also poor in other production factors (in particular capital). This country may have a very high ratio of water-land to capital. Therefore, following the predictions of the HO model it may become a net exporter of virtual water.

(b) A water abundant country (e.g., Australia, Canada) that also has large endowments of other production factors (e.g., capital or skilled labor). This country's resources may be channeled toward producing goods using those abundant resources. In practice a developed country with high productivity in the service and industrial sectors, may find it non-economic to produce agriculture products, despite having a significant endowment of water. This will result in a large volume of *unused water* in a water-abundant country, potentially putting pressure on water resources in a less-developed but more arid country.

In this case, the resulting equilibrium trade path delivers opposite predictions with respect to those implied by the virtual water paradigm. Both countries will gain from trade and the arid country may enjoy a high export value; however, the ex-post distribution of water resources in absolute terms may become even more unequal. In this sense, this result may provide a partial explanation for the stylized facts presented in the previous section. The main determinant of virtual water trade is the relative scarcity of water and land with respect to capital as factors of production. In particular, as our empirical analysis in the next sections indicates, if water abundant countries are also those that are more rich in capital, the optimistic promise of virtual water trade may remained unfulfilled.

To make this point clearer, we resort to the example made by Reimer (2012) in contesting the claim made by Ansink (2010), that there may not be a "levelling" of water around the world. If the pattern of global trade is such that countries that are relatively scarce in water with respect to capital are also those that are absolutely more abundant in water, then as correctly observed by Reimer these countries are also essentially "larger", since they are more abundant in both factors. Notice that since the HO model is a two country model, this implies that applying the model to settings that have the features described above is equivalent to assuming that global trade is mainly characterized by large countries trading with smaller countries. Thus, the question we are posing is not whether the VW promise is consistent with the HO model, but rather, whether on average, countries specializing in agricultural production are comparatively scarce in both capital and water, with respect to those specializing in manufacturing and services.

More formally assume that foreign is the larger country that is endowed with a greater amount of both factors, but has relative scarcity of water with respect to home. We represent the vector of factor endowments with V (V^*), gobal income with Y^g and the share of global income with s (s^*). Applying the standard assumptions of the HO model of identical homothetic preferences, and identical goods prices via trade, foreign's demand for goods is just the share of world output s^*Y^g. In order to obtain the factor content of consumption, which is the relevant variable to determine the net export of factors, we define A as the matrix of factor demands, where each row of the matrix represents the quantity of each factor needed to produce a given good. Considering the global endowment vector $V^g = V + V^*$, factor market clearing implies that $AY^g = V^g$. Therefore the factor content of consumption for home (foreign) is simply equal to sV^g (s^*V^g).

Now consider the same numerical example made by Reimer (2012), in which the two production factors are water-land (WL) and physical and human capital (KH):

$$V = \begin{bmatrix} WL = 20 \\ KH = 5 \end{bmatrix}, V^* = \begin{bmatrix} WL = 30 \\ KH = 45 \end{bmatrix}.$$

Assuming that $s = 20\%$ and $s^* = 80\%$, we obtain the following values for the factor content of consumption of each country:

$$sV^g = \begin{bmatrix} WL = 10 \\ KH = 10 \end{bmatrix}, s^*V^g = \begin{bmatrix} WL = 40 \\ KH = 40 \end{bmatrix}.$$

First notice, that the HO model implies that trade leads to a more even *local* distribution of factors, since now both countries consume a bundle of goods that contains a 1-to-1 proportion of factors. However consider the net exports of water-land and capital in each country:

$$\begin{aligned} nx^{wl} &= 20 - 10 = 10 \text{ and } nx^{wl*} = 30 - 40 = -10 \\ nx^{kh} &= 5 - 10 = -5 \text{ and } nx^{kh*} = 45 - 40 = 5 \end{aligned}$$

Notice that home which is absolutely scarce in both resources is now a net exporter of water (and importer of capital), since capital is the locally scarce factor. Indeed, the smaller country specializes in water intense goods in order to increase its consumption of capital intense goods. Thus countries that are already water scarce will tend to reduce their consumption of water leading to a less even distribution of water, and more even distribution of capital across countries. This example therefore illustrates that the HO model is not inconsistent with the result that trade may indeed lead to a less even distribution of water.

This allows us to state the following empirical predictions that we aim to verify in the next section:

The Role of Capital. If water abundant countries tend to have an even larger endowment of capital, the trade of virtual water will only have a minor role in equalizing the initial distribution of water resources.

Reverse Direction of Trade. The relatively water-abundant (scarce) countries may become net importers (exporters) of water.

4. Empirical Analysis

4.1. Sample and Variables

This study takes advantage of the cross-country dataset described in Debaere (2014). The primary sources of the initial dataset, together with a brief description of the variables entering the analysis, are provided in Appendix A (Table A1). We use data from Feenstra et al. (1997) to supplement the dataset with a measure of multilateral import. This additional variable is necessary to compute the net exports from each country in each industry. The final sample consists of 68 countries (developed and developing) and 194 industries. Due to missing values, we have a total number of observations equal to 11,187, although our regression analyses drop out 13 singleton observations. Table A2 in Appendix A shows the sample composition by country.

In line with the existing literature on the HO theory, our dependent variable is a measure of net exports (NX) (see, e.g., Deardorff, 2011; Forstner, 1985; Romalis, 2004; Nunn, 2007; Levchenko, 2007; and Debaere, 2014).[6] Because we consider a multilateral trade context instead of bilateral trade, we cannot ignore the existence of intra-industry trade, and therefore net exports undoubtedly represent the most appropriate dependent variable. In this way, we

[6] Since we want to estimate a linear regression model in which countries' endowments interact with sectors' factors intensities, the log-transformation of the difference between exports and imports would not necessarily be a linear function. Therefore, to avoid this problem, instead of using this difference as the dependent variable, we use the exports-imports ratio. This specification can be easily log-linearized and becomes $NX = ln(X) - ln(IM)$, where X is the export level, and IM is the import level. In this way, we can assume a traditional Cobb-Douglas function for both exports and imports.

control for the fact that, in a specific sector, a country might be simultaneously an exporter and an importer.

The set of independent variables can be divided into two groups. The first group consists of four different variables measuring the country's endowments of water, land, physical and human capital; whereas, the second group refers to four variables capturing the sectors' factor intensities. As a measure of water endowment (W), following Gleick and Cohen (2009), and Debaere (2014), we take the natural logarithm of country's available renewable fresh water per capita (cubic kilometers per capital). This variable measures the quantity of renewable water that can be used for human activities without threating environmental sustainability and is the sum the average annual surface runoff and the groundwater recharge (see Johnson et al., 2001; Gleick and Cohen, 2009; Debaere, 2014). As argued by Debaere (2014), this measure of water endowment is particularly appropriate if one is concerned about endogeneity issues, because it is not related to the current use of water. Moreover, the endowment of renewable fresh water per capita captures the opportunity cost of water much better than other measures based on water prices. Indeed, the markets for the production factors of the agricultural sector (in particular water) are either missing or are highly regulated or subsidized by the government. These institutional frictions and distorted price signals do not reflect water scarcity or firm-level production choices, which might significantly differ from those that would result in the presence of a competitive market clearing price. In contrast, the per capita endowment of water implicitly proxies the cost of water scarcity, since rationing and shortages are more likely when water is scarce.

Data on the endowment of land (L) comes from the World Development Indicators (World Bank) and is the natural logarithm of arable land in hectares per capita in 1997. The stock of physical capital K corresponds to the natural logarithm of the average capital stock per worker in 1992; whereas, the stock of human capital H is the natural logarithm of the ratio of workers completing high school to those not completing high school in 1992. The primary source for both stocks of capital is Antweiler and Trefler (2002).

Moving to the sectors' factor intensities, the measure of water intensity (w_b^d) is the relative ranking of US direct blue water intensities. Blue water refers to water from rivers, lakes, and groundwater that can be used in production activities. Although blue water is particularly important for households' consumption, the water used for the production of agricultural and industrial products can come from both blue and green water resources and may or may not have a grey water footprint, where green water represents the part of rainwater absorbed by soil and vegetation. This implies that world countries may significantly differ in terms of the nature of their virtual water import and export. Indeed, some water-stressed countries (e.g., Iran) may paradoxically become net exporters of blue water even if, overall, they are net importers of water. This happens because water-abundant countries are usually large exporters of green water and therefore, we may have that some net importers of water actually export blue water and import green water, experiencing additional pressure on their blue water resources. Therefore, it is important to test whether our conclusions hold even when we augment the model with indirect blue water intensities (w_b^{di}) and green water intensities (w_{gb}^d and w_{gb}^{di}). While direct water is the water directly used to produce a certain good, indirect water refers to the quantity of water embedded in intermediate inputs such as energy. The measure of indirect water intensity is based on Input-Output Tables. The primary source of this data is Blackhurst et al. (2010). Sector's land intensity (l) is the ratio of land use to total factor use as recorded by the Global Trade Analysis Project (GTAP). Finally, physical and human capital intensities (k and h, respectively) come from Bartlesman and Gray (1996). Debaere (2014) uses the skill and capital shares for agricultural sectors from GTAP to increase the number of industries for which physical and human capital intensities are available.

Table 1 presents the main descriptive statistics for collected data.

Table 1: Descriptive statistics (N=11,187)

Variable	Mean	SD	Min	p25	p50	p75	Max
Dependent variable							
NX	-2.605	3.757	-14.442	-5.066	-1.896	-0.403	13.816
Endowments							
W	2.016	1.705	-1.846	0.830	1.918	3.299	6.441
L	11.957	1.207	5.572	11.351	12.133	12.658	14.588
K	-4.711	1.312	-8.580	-5.576	-4.522	-3.724	-2.957
H	-1.667	1.120	-4.525	-2.140	-1.423	-1.006	0.925
Intensities							
w_b^d	0.038	0.144	0	0	0	0	0.854
w_b^{di}	0.052	0.152	0.001	0.002	0.004	0.013	0.863
w_{gb}^d	0.045	0.171	0.000	0.000	0.000	0.000	0.956
w_{gb}^{di}	0.065	0.192	0.001	0.002	0.004	0.014	0.960
l	0.026	0.067	0	0	0	0	0.28
k	0.784	0.510	0.212	0.453	0.651	0.946	3.568
h	0.376	0.141	0.092	0.295	0.365	0.447	0.853

Notes: This table reports the means, standard deviations, minimum values, three percentiles (25^{th}, 50^{th}, and 75^{th}) and maximum values of observed variables. All variables are in natural logs.

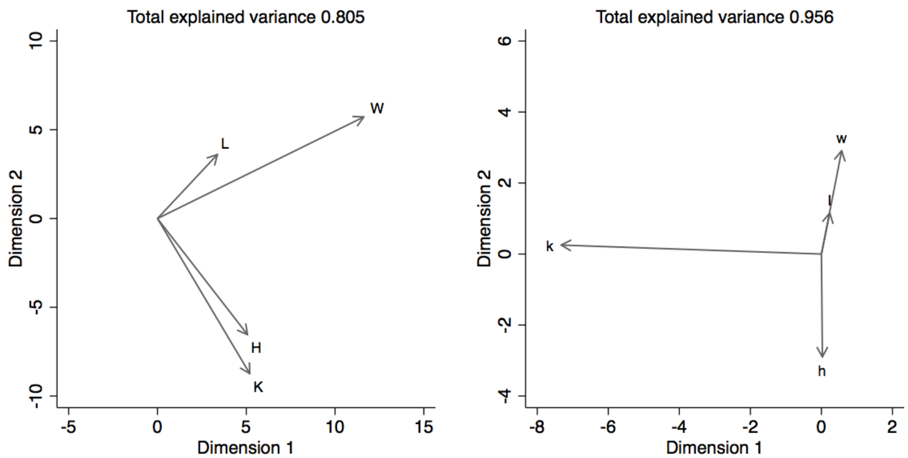

Figure 4: Biplot for endowments and intensity measures

4.2. Uncovering the Structure of the Data

There exist different ways to determine the underlying structure of a dataset. Figure 4 provides a biplot, that is, a graphical representation of the correlation structure of the explanatory variables (see Table A3 in Appendix A for the underlying correlation matrix). For the sake of readability, we omitted data points. The axes represent the first two singular vectors of the data matrix, while the cosine of the angle between arrows approximates the correlation between the variables. Notice that physical and human capital stocks exhibit a rather high correlation as well as water and arable land endowments. In contrast, the correlation between capital and natural resources is not so high. Regarding factors intensities, sectors characterized by a high intensity of water and land tend to be less intensive of capital, especially human capital.

Since the structure of our dataset might lead to inefficient estimates, we reduce the dimension of the initial dataset in order to improve the accuracy of the analysis. This approach is also justified by theoretical considerations. Indeed, the estimates of the HO model usually suffer from the limitations of the traditional setting: two factors, two goods, and two countries. As proved by Leamer and Bowen (1981), Aw (1983), and Forstner (1985), when there are more than two factors of production, most of the regression procedures used in the empirical literature provide inappropriate tests of the factor proportions theory. This happens because the HO model requires a positive-definite matrix of factors intensities. However, this condition is sufficient only in the two-factor case, while in case of multiple factors the cone of diversification becomes an iper-space and further econometric restrictions are necessary. In the robustness check section, we will show that our approach fits the data much better than a full four-factor model in which all factors of production enter the model separately.

Statisticians often carry out a principal component analysis (PCA) to tease apart highly correlated data. However, our correlation matrix is rather sparse to use a standard PCA in which a component is usually expected to load more than just two variables. Therefore, to deal with the sparcity of the correlation matrix, we group our variables using the "treelet" algorithm provided in Lee et al. (2008).[7] This technique is a sort of two-dimensional PCA in which the formation of groups is based on a series of Jacobi rotations to pairs of correlated variables. The final components are orthogonal and nested in a hierarchical tree combining pairs of variables. Unlike PCA, the algorithm exploits the local structure of the covariance matrix and is robust to multi-scale measures.

To extract the main components, the treelet algorithm requires specification of a cut-level for the associated clusters. We recursively determine the optimal cut-level using a cross-

[7]We also have checked the robustness of our conclusions using a PCA, and results are available upon request from the authors. However, although the value of the Kaiser-Meyer-Olkin (KMO) index is more relevant in a factor analysis than in a PCA, we found a value of KMO index of 0.572, which suggests that a PCA is marginally acceptable.

validation (CV) technique. In particular, we compute the sum of the variances associated with the three highest-variance components and set the cut-level when an increase in cut-level does not lead to a substantial increase in explained variance. Panel A of Figure 5 provides a graph of CV scores against different cut-levels, the optimal cut-level (which is 3) is represented as a "knee" in the CV score. As a robustness check, we repeated the analysis with four components, but the optimal cut-level remains 3.

As in PCA, the treelet technique can be used to uncover the latent structures of the data. Nonetheless, a treelet algorithm allows us to deal with sparse correlations. This new approach leads to a multiscale decomposition of variables into orthogonal components (factors) that reflect a hierarchical scheme. Panel B of Figure 5 displays the hierarchical tree behind our data and sorts the corresponding clusters according to the variances of the associated components. In line with Figure 4, our data can be summarized with three main components. A first component captures the strong correlation between physical and human capital. Indeed, the accumulation of physical capital also facilitates the accumulation of human capital (see, e.g., Acemoglu, 1996; and Galor and Moav, 2004). The second component confirms the fact that water-intensive goods, such as agricultural products, are also land-intensive goods (see, e.g., Merett, 2003; and Allan, 2003). This component is strongly associated with the distinction between agricultural and manufacturing sectors. The point biserial correlation coefficient is 0.843, and it is statistically significant at 1%, where agricultural sectors are characterized by a significantly higher value of wl (3.899) than manufacturing ones (-0.308). Finally, the last component deals with the positive association between the availability of water and the endowment of arable lands. After these three components, the fourth component would be a combination of the first and third components, whereas the fifth component would put together the endowments of resources and physical capital intensity. Human capital intensity is the most redundant variable.

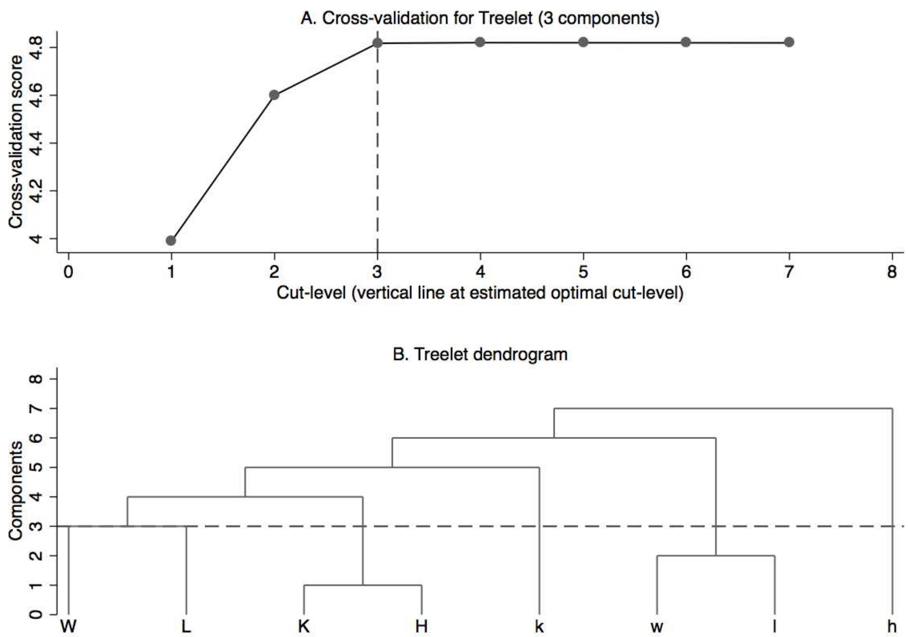

Figure 5: Treelet analysis

4.3. Methodology and Results

4.3.1. Virtual Water and HO Theory

Given the results of the treelet analysis provided in the previous section, we can now design a proper test for the factor proportion theory. In particular, by adopting the so-called "interactional approach" pioneered by Deardorff (2011), and Forstner (1985), we can test our theoretical predictions. This approach consists of regressing net exports on a set of country-level factors endowments and industry-level factors intensities.[8]

Formally, we estimate the following model:

$$NX_{sc} = \alpha_s + \beta_1 WL_c + \beta_2 KH_c + \gamma_1 WL_c * wl_s + \gamma_2 KH_c * wl_s + \varepsilon_{sc}, \tag{1}$$

[8]Other studies used this method to test a quasi-Heckscher-Ohlin model as well as a quasi-Rybczynski effect (see, e.g., Romalis, 2004; Nunn, 2007; Levchenko, 2007; and Debaere, 2014). Our article differs from these studies mainly because they use exports instead of net exports as the dependent variable. Nonetheless, when we test the VW hypothesis, we must take into account intra-industry trade. In this way, we control for the fact that, in a specific sector, a country might be simultaneously an exporter and an importer.

where α_s is a vector of sector fixed effects; NX_{sc} is the natural logarithm of the exports-to-imports ratio for country c in sector s; WL_c and KH_c are the endowments of resources for country c as indicated by the treelet analysis; wl_s is the water-land intensity of sector s resulting from the treelet analysis; elasticity coefficients are in small, greek letters and ε_{sc} is the disturbance term.[9] Since production technologies are certainly heterogeneous across industries, but they might be common across countries, we use a standard Hausman test to compare a model with both country and industry dummies with a model with only industry dummies. We have found that these two specifications do not differ significantly, and therefore we opted for the most parsimonious specification. Indeed, this specification has at least two important advantages: it is more efficient than a specification with two large sets of dummies and allows us to estimate also the direct effects of factors endowments on trade flows. As argued by Forstner (1985), on average, the OLS estimates of an interactional regression test of the HO hypothesis must be positive, and this must be true for both total and partial effects.

Table 2 shows the OLS estimates of Equation (1) using different definitions of water intensity to construct the water-land intensity component (wl_s). In Column 1, the water-land intensity is based on land and direct blue water intensity. Column 2 considers a measure of water-land intensity, taking into account both direct and indirect blue water intensity. In Columns 3 and 4, the water-land intensity measure is obtained by also considering green water intensities.All regressions include a full set of industry dummies; whereas, according to the Hausman tests reported at the end of the table, country dummies are unnecessary. Consistently with the inclusion of a full set of industry dummies, we clustered the standard errors at the industry level.

[9] Notice that the direct effects of factors intensities are completely absorbed by the vector of industry fixed effects. In the rest of the analysis, although we do not have a longitudinal dataset, we often refer to a full set of industry-specific dummies as "fixed effects."

All columns of Table 2 deliver the same results. In line with the HO Theorem, the coefficient of the interaction term between water-land endowment (WL) and water-land intensity (wl) is positive and statistically significant at 1 percent. This means that countries characterized by water-land abundancy export more in sectors characterized by a higher water-land intensity. In contrast, the interaction term between KH and wl shows that when the endowment of capital factors increases countries tend to be net importers of water-land intensive goods and net exporter in sectors characterized by a low water-land intensity (i.e., manufacturing industries not related to food processing). The direct effect of WL on net exports is negative and slightly significant; whereas the coefficient of KH is positive and highly significant. Hence, in sectors characterized by a water-land intensity close to zero, the endowment of capital factors is a key feature of net exporters.[10]

4.3.2. On the Re-distribution of Resources

Equation (1) allows us to frame our findings into a typical North-South model in which the more developed North produces manufactured goods, and the less developed South produces agricultural goods. As shown in Table 2, countries with a high endowment of water and land (WL) should export more in those sectors characterized by a high intensity of water and land (wl). In the same manner, countries with a high endowment of physical and human capital (KH) should export more industrial goods. Indeed, given (1), for any sector s, we can compute the threshold value of the relative endowment of resources that satisfies the following condition: $NX_{sc} = 0$, that is, $\frac{WL_c}{KH_c} = -\frac{\beta_2 + \gamma_2 wl_s}{\beta_1 + \gamma_1 wl_s}$.

On the basis of the coefficients estimated in Column 1 of Table 2, Figure 6 divides net exporters from net importers accordingly their relative endowment of water and land and sectoral intensities. Suppose North is relatively more abundant of capital than South, then

[10]We also estimated Equation (1) using a traditional PCA to reduce the space of factors. Results remain unchanged and are available upon request from the authors.

Table 2: Net Exports

	(1)	(2)	(3)	(4)
WL	-0.061*	-0.061*	-0.061*	-0.061*
	(0.036)	(0.036)	(0.036)	(0.036)
$WL * wl$	0.167***	0.177***	0.163***	0.170***
	(0.035)	(0.035)	(0.035)	(0.034)
KH	0.748***	0.747***	0.748***	0.747***
	(0.056)	(0.055)	(0.056)	(0.055)
$KH * wl$	-0.354***	-0.364***	-0.353***	-0.371***
	(0.086)	(0.082)	(0.083)	(0.074)
Sector dummies	Yes	Yes	Yes	Yes
N	11,174	11,174	11,174	11,174
Hausman (p-value)	0.945	0.986	0.923	0.895
F-statistic	82.896	85.154	83.586	89.110
RMSE	3.340	3.334	3.339	3.331
R^2	0.229	0.231	0.229	0.233

Note: This table contains the OLS estimates of Equation (1). In Column 1, we interact the water-land endowment with a water-land intensity based on direct-blue water intensity. Column 2 uses a water-land intensity component based on both direct and indirect blue water. In Columns 3 and 4, we re-estimate the models of Columns 1 and 2 also considering green water intensities. All estimates include a full set of sector dummies. We dropped 13 singleton observations. Clustered standard errors are in parentheses. Significance: *p<0.1, **p<0.05, ***p<0.01.

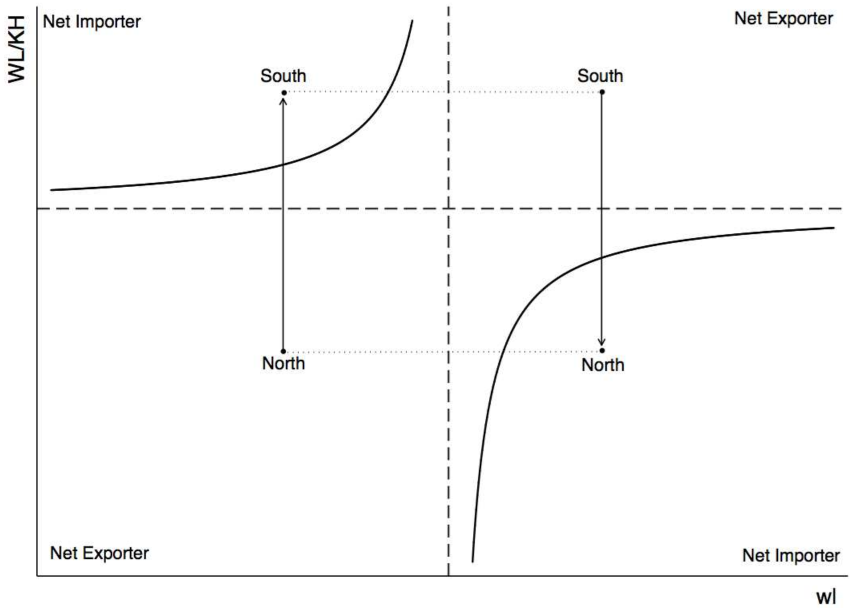

Figure 6: Net exports and Specialization (North-South model)

North will be a net exporter of manufacturing goods whereas South will be a net exporter of agricultural goods.

Figure 6 is perfectly consistent with HO Theorem. However, the fact that North is relatively more abundant of capital does not imply that its endowment of water and land is lower than South's endowment. Indeed, North can be more abundant of both natural and capital factors but relatively more abundant of capital. If this is the case, South will be a net exporter of water-land intensive goods and the distribution of hydric resources would be even more uneven after the international trade.

To address this important redistributive issue, we use the predicted values of net exports coming from Column 1 of Table 2 ($\widehat{NX}_{sc}$) and multiply this value by the blue-water intensity coefficient of sector s. This number is a measure of water traded by each country in each sector. Thus, by summing all water traded in each sector, we will obtain a measure indicating whether a country is a net exporter or a net importer of water. Figure 7 shows the relationship

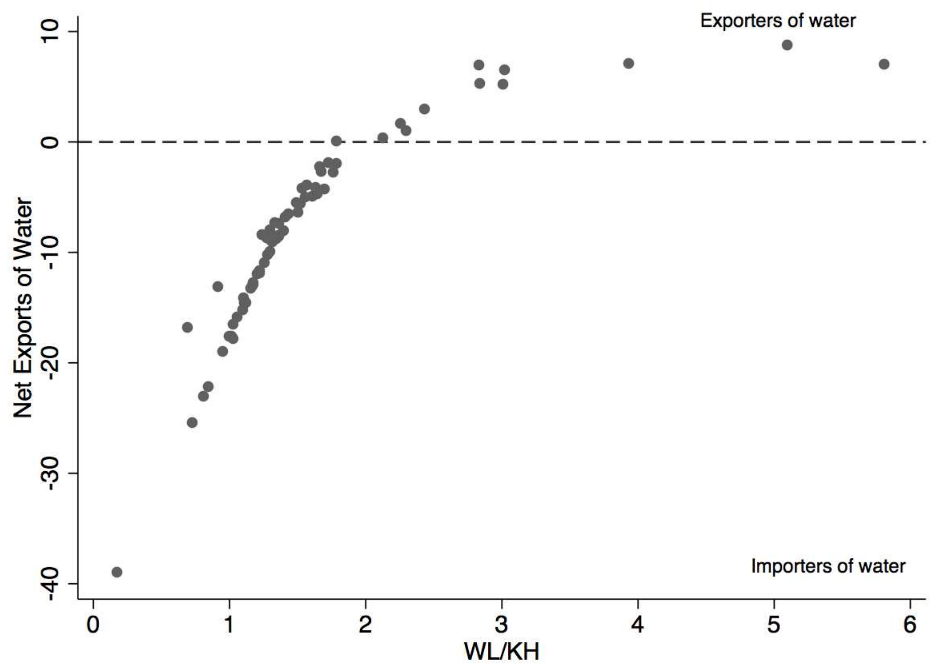

Figure 7: Relationship between WL/KH and (net) exports of water

between $\frac{WL_c}{KH_c}$ and the total amount of water traded by countries. As expected, there exists a threshold value (1.78) in the relative endowment of natural resources above which a country is a net exporter of water.

Figure 8 displays the distribution of WL and KH among countries. The dashed line represents the threshold value of WL/KH separating net exporters of water from net importers. As shown in Figure 8, the main difference between net exporters and net importers of water is not the endowment of natural resources but the endowment of physical and human capital. For instance, Canada or Australia have high endowments of all resources, but they are relatively more abundant of capital. Thus they are net importers of water. In contrast, Bangladesh or Ethiopia have low levels of all resources, but they are relatively more abundant of water and land than of physical and human capital. Therefore, Bangladesh and Ethiopia export water-intensive goods. In other words, international trade does not

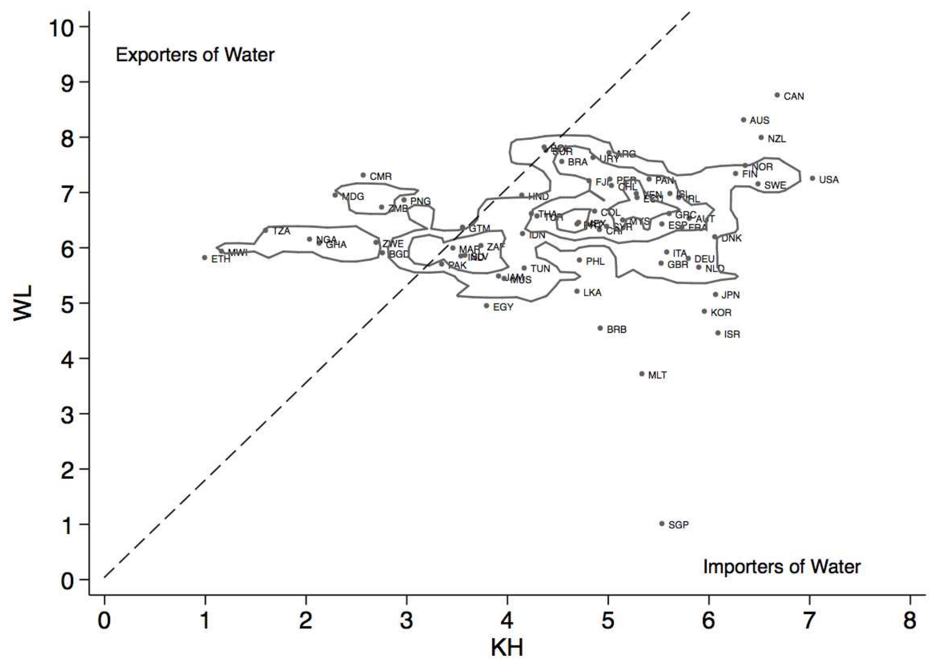

Figure 8: Distribution of WL and KH among countries

necessarily represent a way to re-equilibrate the distribution of water around the World.

To confirm the graphical evidence provided in Figure 8, Table 3 reports a t-test comparing the factors endowments of exporters and importers of water. According to this test, exporters of water are not more abundant of water and land than importers of water; in contrast, exporters of water are absolutely and relatively more abundant of capital factors than importers. These features of data are well captured by our components WL and KH. In line with HO theory, the ratio WL/KH is higher for exporters of water than for importers of water.

4.3.3. Robustness Checks

In this section, we address those issues potentially affecting our conclusions. First of all, the endowment of water is by definition a stock measure, but countries may also use as

Table 3: Exporters vs Importers of Water (t-test)

	Importers	Exporters	p-value
W	2.060	2.090	0.479
L	11.899	12.178	0.234
K	-4.327	-6.815	0.000
H	-1.327	-3.490	0.000
WL	6.317	6.493	0.315
KH	5.086	2.364	0.000
WL/KH	1.278	3.125	0.000

Notes: This table provides the results of a t-test in which we compared countries that are net exporters of water with countries that are net importers of water.

productive factor the water coming from precipitations, which is a flow variable. Therefore, following Debaere (2014), we replace the endowment of blue and green water with precipitation data. We expect the results to be consistent with the estimates provided in Table 2. Second, factor intensities derive from US technologies. We cannot exclude that, especially for agricultural sectors, the different availability of water affects the variety of goods produced and exported by each country. Debaere (2014) proposes to adjust the US water intensity with Mekonnen and Hoekstra (2011) data on the countries' intensity of green and blue water employed in agriculture.

Table 4 presents the new estimates. In Column 1, we replaced the water-land endowment (WL) with the natural logarithm of annual precipitations (per capita). In Column 2 of Table 4, wl is the result of the treelet algorithm in which water intensity takes into account Mekonnen and Hoekstra's data. Finally, in Column 3 we consider both measures at the same time.

Finally, we aim to test the reliability of our analysis based on the space reduction algorithm. To do this, we compare the division of countries into net exporters and net importers of water based on observed data with two model-based classifications: the one coming from

Table 4: Net exports

	(1)	(2)	(3)
WL	-0.454***	-0.061*	-0.454***
	(0.024)	(0.036)	(0.024)
$WL * wl$	0.071**	0.177***	0.069**
	(0.027)	(0.035)	(0.028)
KH	0.805***	0.747***	0.804***
	(0.056)	(0.055)	(0.055)
$KH * wl$	-0.346***	-0.364***	-0.355***
	(0.088)	(0.082)	(0.084)
Sector dummies	Yes	Yes	Yes
N	11,174	11,174	11,174
Hausman (p-value)	0.949	0.923	0.930
F-statistic	131.814	85.154	136.674
RMSE	3.229	3.334	3.225
R2	0.279	0.231	0.281

Notes: This table contains the robustness checks for our estimates. In Column 1, we replaced the water-land endowment with the natural log of annual precipitations (per-capita). Column 2 uses a water-land intensity component in which the US water intensity has been adjusted with Mekonnen and Hoekstra (2011) data. Columns 3 considers both changes together. All estimates include a full set of sector dummies. We dropped 13 singleton observations. Clustered standard errors are in parentheses. Significance: *p<0.1, **p<0.05, ***p<0.01.

Table 5: Correlation and tetrachoric correlation (estimated models vs observed data)

	Reduced model	Four-factor model
Pearson's correlation	0.528	0.336
Tetrachoric correlation	0.778	0.677
Standard Error	0.122	0.206
Two-sided test (H_0: independent)	0.000	0.025

Notes: This table compares the division of countries into net exporters and net importers of water based on observed data with two model-based classifications: the one coming from our reduced model and the one obtained by estimating a four-factor interactional model.

our analysis and the one obtained by estimating a four-factor interactional model. Table 5 shows the results of both a simple Pearson's correlation analysis and a tetrachoric correlation analysis for binary variables. Although a correlation analysis would lead to the same conclusions, a tetrachoric correlation provides more reliable results. In particular, it assumes a latent bivariate normal distribution for each pair of groups, and even if the means and variances of the latent classification are not identified, the correlation between them can be estimated from their joint distribution (see Edwards and Edwards, 1984). As shown in Table 5, compared to a four-factor model, our reduced model provides a classification of countries that is closer to the classification based on observational data. Indeed, our classification of countries in net exporters and net importers of water presents a higher correlation and a smaller standard error compared to the classification of countries deriving from a four-factor model.

5. Conclusion and Future Research

The promise of the virtual water narrative suggests that trade may lead to a more even global distribution of water resources. However, a simple application of the basic Hecksher-Ohlin model of international trade shows that if countries that are relatively water scarce, tend to be even poorer in terms of capital, then trade may not necessarily play such a positive role. Our empirical analysis provides evidence that this may be the case, illustrating that a significant determinant of water trade is the level of capital (both physical and human) in a given country. In particular, we find that regardless of its water resources, there is always a threshold level of capital above which a country is a net importer of virtual water.

Our work represents a further step in better understanding the role of water trade in addressing global water issues. However, the virtual water metaphor requires further empirical exploration, which has so far not been possible due to limitations in data availability. Indeed, future empirical studies relying on panel data are needed, in order to analyze the dynamic effects of the role of trade on the global redistribution of water resources.

Based on our results, one possible *conjecture* is that when less developed countries are also characterized by weak property rights, free trade may even result in over-exploitation of underground water resources. Trade may, therefore, generate export revenues (and possibly local employment) as well as increases in short-run welfare for the less developed countries; however, it may deplete water resources in an irreversible and unsustainable way, eventually leading to long-run welfare losses. A rigorous examination of the proposed conjecture and a detailed welfare analysis are beyond the scope of the current paper and may represent valuable topics for future research.

Acknowledgements

We thank participants in seminars and presentations at IIASA's Water group, Sharif University of Technology, and the 12th Annual Meeting of the International Water Resource Economics Consortium for their valuable comments and discussions. The usual disclaimers apply.

References

Acemoglu, D. (1996). A microfoundation for social increasing returns in human capital accumulation. *Quarterly Journal of Economics 111*(3), 779–804.

Allan, J. A. (1998). Virtual water: a strategic resource. *Ground water 36*(4), 545–547.

Allan, J. A. (2003). Virtual water-the water, food, and trade nexus: useful concept or misleading metaphor? *Water international 28*(1), 106–113.

Ansink, E. (2010). Refuting two claims about virtual water trade. *Ecological Economics 69*(10), 2027–2032.

Antonelli, M. and M. Sartori (2015). Unfolding the potential of the Virtual Water concept. what is still under debate? *Environmental Science & Policy 50*, 240–251.

Antweiler, W. and D. Trefler (2002). Increasing returns and all that: a view from trade. *American Economic Review 92*(1), 93–119.

Aw, B.-Y. (1983). The interpretation of cross-section regression tests of the Heckscher-Ohlin theorem with many goods and factors. *Journal of International Economics 14*(1-2), 163–167.

Bae, J. and S. Dall'Erba (2018). Crop Production, Export of Virtual Water and Water-saving Strategies in Arizona. *Ecological Economics 146*, 148–156.

Bartlesman, E. and W. B. Gray (1996). The nber manufacturing productivity database.

Blackhurst, B. M., C. Hendrickson, and J. S. I. Vidal (2010). Direct and indirect water withdrawals for US industrial sectors. *Environmental science & technology 44*(6), 2126–2130.

Deardorff, A. V. (2011). The general validity of the Heckscher-Ohlin theorem. In *Comparative Advantage, Growth, And The Gains From Trade And Globalization: A Festschrift in Honor of Alan V Deardorff*, pp. 91–103. World Scientific.

Debaere, P. (2014). The global economics of water: is water a source of comparative advantage? *American Economic Journal: Applied Economics 6*(2), 32–48.

Dietzenbacher, E. and E. Velázquez (2007). Analysing Andalusian virtual water trade in an input–output framework. *Regional studies 41*(2), 185–196.

Edwards, J. and A. Edwards (1984). Approximating the tetrachoric correlation coefficient.

Feenstra, R. C., R. E. Lipsey, and H. P. Bowen (1997). World trade flows, 1970-1992, with production and tariff data. Technical report, National Bureau of Economic Research.

Feng, K., Y. L. Siu, D. Guan, and K. Hubacek (2012). Assessing regional virtual water flows and water footprints in the Yellow River Basin, China: A consumption based approach. *Applied Geography 32*(2), 691–701.

Forstner, H. (1985). A note on the general validity of the Heckscher-Ohlin theorem. *The American Economic Review 75*(4), 844–849.

Fracasso, A. (2014). A gravity model of virtual water trade. *Ecological economics 108*, 215–228.

Fracasso, A., M. Sartori, and S. Schiavo (2016). Determinants of virtual water flows in the Mediterranean. *Science of the Total Environment 543*, 1054–1062.

Galor, O. and O. Moav (2004). From physical to human capital accumulation: Inequality and the process of development. *The Review of Economic Studies 71*(4), 1001–1026.

Gawel, E. and K. Bernsen (2011). What is wrong with virtual water trading? Technical report, UFZ-Diskussionspapiere.

Gleick, P. H. and M. J. Cohen (2009). The World's Water, 2008-2009: The Biennial Report on Freshwater Resources. Technical report, Island Press.

Guan, D. and K. Hubacek (2007). Assessment of regional trade and virtual water flows in China. *Ecological economics 61*(1), 159–170.

Hoekstra, A. Y. and A. K. Chapagain (2011). *Globalization of water: Sharing the planet's freshwater resources*. John Wiley & Sons.

Johnson, N., C. Revenga, and J. Echeverria (2001). Managing water for people and nature. *Science 292*(5519), 1071–1072.

Kumar, M. D. and O. P. Singh (2005). Virtual water in global food and water policy making: is there a need for rethinking? *Water Resources Management 19*(6), 759–789.

Leamer, E. E. and H. P. Bowen (1981). Cross-section tests of the Heckscher-Ohlin theorem: Comment. *The American Economic Review 71*(5), 1040–1043.

Lee, A. B., B. Nandler, and L. Wasserman (2008). Treelets-an adaptive multi-scale basis for sparse unordered data. discussions. *The Annals of applied statistics 2*(2), 435–500.

Lenzen, M., D. Moran, A. Bhaduri, K. Kanemoto, M. Bekchanov, A. Geschke, and B. Foran (2013). International trade of scarce water. *Ecological Economics 94*, 78–85.

Levchenko, A. A. (2007). Institutional quality and international trade. *The Review of Economic Studies 74*(3), 791–819.

Mekonnen, M. M. and A. Y. Hoekstra (2011). National water footprint accounts: the green, blue and grey water footprint of production and consumption. *Value of Water Research Report Series 50*, 1–50.

Merett, S. (2003). Virtual water and Occam's Razor. *Water International 28*(1), 103–105.

Nunn, N. (2007). Relationship-specificity, incomplete contracts, and the pattern of trade. *The Quarterly Journal of Economics 122*(2), 569–600.

Oki, T., M. Sato, A. Kawamura, M. Miyake, S. Kanae, and K. Musiake (2003). Virtual water trade to Japan and in the world. In *Hoekstra, AY 'Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade', Value of Water Research Report Series*, Volume 12.

Reimer, J. J. (2012). On the economics of virtual water trade. *Ecological Economics 75*, 135–139.

Romalis, J. (2004). Factor proportions and the structure of commodity trade. *American Economic Review 94*(1), 67–97.

Sayan, S. (2003). H–O for H2O: can the Heckscher–Ohlin framework explain the role of free trade in distributing scarce water resources around the Middle East? *Review of Middle East Economics and Finance 1*(3), 215–230.

Seekell, D., P. D'Odorico, and M. Pace (2011). Virtual water transfers unlikely to redress inequality in global water use. *Environmental Research Letters 6*(2), 024017.

Suweis, S., M. Konar, C. Dalin, N. Hanasaki, A. Rinaldo, and I. Rodriguez-Iturbe (2011). Structure and controls of the global virtual water trade network. *Geophysical Research Letters 38*(10).

Wichelns, D. (2010). Virtual water: A helpful perspective, but not a sufficient policy criterion. *Water Resources Management 24*(10), 2203–2219.

Yang, H. and A. Zehnder (2007). "Virtual Water": an unfolding concept in integrated water resources management. *Water Resources Research 43*(12).

Appendix A. Variables description and additional descriptive statistics

Table A1 contains a brief description of the variables used in our analysis. Additional details can be found in Debaere (2014).Table A2 reports for each country the number of sectors included in the sample.

Table A1: Variables Description

Variable	Description	Primary source
NX	Natural logarithm of net export in USD. When net export was negative, we used $NX = -ln(net\,import)$.	Feenstra, Lipsey, and Bowen (1997)
W	Natural logarithm of country's available renewable fresh water per capita ($km^3/million\,people$)	Gleick and Cohen (2009)
L	Natural logarithm of arable land in hectares per capita in 1997.	World Bank
K	Natural logarithm of average capital stock per worker in 1992.	Antweiler and Trefler (2002)
H	Natural logarithm of the ratio of workers completing high school to those not completing high school in 1992.	Antweiler and Trefler (2002)
w_b^d	Relative ranking of US blue water intensities (direct).	Blackhurst, Hendrickson, and Vidal (2010)
w_b^{di}	Relative ranking of US blue water intensities (direct and indirect).	Blackhurst, Hendrickson, and Vidal (2010)
w_{gb}^d	Relative ranking of US green and blue water intensities (direct).	Blackhurst, Hendrickson, and Vidal (2010)
w_{gb}^{di}	Relative ranking of US green and blue water intensities (direct and indirect).	Blackhurst, Hendrickson, and Vidal (2010)
l	Ratio of land use to total factor use for a sector.	Global Trade Analysis Project (GTAP)
k	Physical capital intensities.	Bartlesman and Gray (1996)
h	Human capital intensities.	Bartlesman and Gray (1996)

Notes: Sector codes have been converted from the original 4-digit SITC codes to the BEA 1997 IO industry classification. GTAP codes have been matched first with the 6-digit HS categories and then with the BEA 1997 IO.

Table A2: Sample composition

Country	Frequency	Proportion	Country	Frequency	Proportion
Argentina	172	1.54	Madagascar	142	1.27
Australia	173	1.55	Malawi	133	1.19
Austria	171	1.53	Malaysia	171	1.53
Bangladesh	161	1.44	Malta	158	1.41
Barbados	141	1.26	Mauritius	156	1.39
Bolivia	158	1.41	Mexico	172	1.54
Brazil	174	1.56	Morocco	168	1.5
Cameroon	153	1.37	Netherlands	172	1.54
Canada	172	1.54	New Zealand	172	1.54
Chile	170	1.52	Nigeria	165	1.47
Colombia	169	1.51	Norway	171	1.53
Costa Rica	162	1.45	Pakistan	164	1.47
Denmark	171	1.53	Panama	162	1.45
Ecuador	165	1.47	Papua N.Guin	146	1.31
Egypt	169	1.51	Peru	171	1.53
El Salvador	157	1.4	Philippines	172	1.54
Ethiopia	144	1.29	Portugal	172	1.54
Fiji	149	1.33	Singapore	170	1.52
Finland	172	1.54	South Africa	172	1.54
France	172	1.54	Spain	172	1.54
Germany	174	1.56	Sri Lanka	160	1.43
Ghana	162	1.45	Suriname	131	1.17
Greece	173	1.55	Sweden	174	1.56
Guatemala	163	1.46	Syria	155	1.39
Honduras	159	1.42	Tanzania	145	1.3
Iceland	159	1.42	Thailand	171	1.53
India	171	1.53	Tunisia	168	1.5
Indonesia	173	1.55	Turkey	173	1.55
Ireland	173	1.55	UK	172	1.54
Israel	168	1.5	USA	173	1.55
Italy	173	1.55	Uruguay	166	1.48
Jamaica	164	1.47	Venezuela	169	1.51
Japan	172	1.54	Zambia	150	1.34
Korea Rep.	172	1.54	Zimbabwe	168	1.5

This table shows the composition of our sample in terms of number of sectors and relative frequency by country.

Table A3 provides the pairwise correlation coefficients for our initial variables. As shown in this table, the endowments of physical and human capital present a very high correlation coefficient. Similarly, land and water intensity exhibit a rather high degree of correlation. For the sake of synthesis, we only report the correlation with our main water-intensity measure (i.e., the direct blue water intensity). However, results remain practically unchanged for all measures of water intensity.

Table A3: Correlation matrix (N=11,187)

	NX	W	L	K	H	w_b^d	l	k	h
NX	1								
W	-0.039***	1							
L	0.064***	**0.291*** **	1						
K	0.287***	0.138***	-0.041***	1					
H	0.230***	0.228***	0.054***	**0.832*** **	1				
w_b^d	0.094***	-0.002	0.004	0.004	0.002	1			
l	0.161***	-0.001	0.004	0.006	0.004	**0.688*** **	1		
k	-0.053***	-0.003	-0.001	0.008	0.009	-0.254***	-0.226***	1	
h	-0.119***	0.002	-0.003	-0.004	-0.002	**-0.408*** **	**-0.432*** **	-0.023**	1

Notes: Pairwise correlation coefficients. Significance: *p<0.1, **p<0.05, ***p<0.01.

The description of the principal components as well as the dependent variables capturing water-land trade flows are reported in Table A4.

Table A4: Descriptive statistics for principal components and generated dependent variables

Variable	Description	Mean	SD	Min	p25	p50	p75	Max
KH	Component of physical and human capital endowment	0	1.353	-3.658	-0.861	0.207	0.954	2.376
WL	Component of water and land endowment	0	1.136	-5.349	-0.506	0.071	0.767	2.406
wl_b^d	Component of water and land intensities (using direct blue water)	0	1.299	-0.457	-0.457	-0.457	-0.446	6.692
wl_b^{di}	Component of water and land intensities (using direct and indirect blue water)	0	1.307	-0.456	-0.456	-0.456	-0.447	6.444
wl_{gb}^d	Component of water and land intensities (using direct green and blue water)	0	1.279	-0.520	-0.498	-0.466	-0.260	8.166
wl_{gb}^{di}	Component of water and land intensities (using direct and indirect blue and green water)	0	1.328	-0.505	-0.502	-0.494	-0.446	5.972

Notes: This table describes our generated variables and shows their means, standard deviations, minimum values, three percentiles (25^{th}, 50^{th} and 75^{th}) and maximum values.