The Globalization of Virtual Water Flows: Explaining Trade Patterns of a Scarce Resource

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Abstract

Although 80% of global water withdrawals are for agriculture, the burgeoning literature on virtual water has not reached a consensus on the applicability of the comparative advantage theory in water resources for food production and trade. Using panel data of bilateral virtual water trade flows, we first demonstrate that exporter-importer relative water endowments have a positive effect on food trade, suggesting that the driest countries use trade as a means to alleviate water scarcity. Second, we demonstrate that relative water productivity and food trade display an inverted u-shape, suggesting a threshold effect in demand in developed countries and a disregard for water resources relative to the lack of other inputs (capital, technology, qualified labor) in relatively water scarce countries.

JEL classification: F14, O13, P28, Q17, Q25, Q27

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1 Introduction

The claim that the wars of the future will likely occur over freshwater have resonated in various policy circles. Given that water is crucial for basic survival, irreplaceable, transcends international borders, and often scarce, it follows that states will take up arms to defend access to a shared river. Yet scholarly research has largely debunked this claim, touting the notable absence of interstate violence over shared water as an indication of what the future may hold (Wolf, 1998 and 2003).

Several conjectures have been offered to explain the absence of water wars. Some authors have stressed the cooperation-inducing nature of scarce water finding that decreased water availability actually motivates the formation of international water treaties (Dinar 2009; Tir and Ackerman 2009). Other scholars have pointed to the role of so-called second-order resources or institutional capacity (such as water augmentation technologies and know-how) as a means of dealing with physical water scarcity (Ohlsson 1999; Turton and Ohlsson 2000). A third explanation, and the focus of this investigation, pertains to the role of trade in water-intense food products or embedded water (Allan 1993, 1997). Popularly known as "virtual water," the concept suggests that agricultural and non-agricultural commodities require water, and by importing such products countries are spared the economic and political stress of mobilizing the needed allocation of water to produce the product indigenously (Allan 2001 and 2002).

To date, the topic of virtual water has received a great deal of attention in the extant literature. Two competing arguments have been advanced. The first considers water endowments, and in particular exporter-importer relative water endowments, as the main motivation for trade in water-embedded food products suggesting that virtual water flows from relatively water rich countries to water poor countries. The alternative explanation places the focus on exporter-importer relative water productivity, suggesting that virtual water flows from countries using water relatively more efficiently in comparison to those using water less efficiently. Methodologically, both explanations have been analyzed and explored in the context of national and regional case studies (Yang and Zehnder 2002; De Fraiture et al. 2004; Kumar and Singh 2005; Verma et al. 2005; Ma et al. 2006; Novo et al. 2009; Mekonnen and Hoekstra 2014) and, in some isolated cases, cross-national empirical investigations albeit with product or time restrictions (Hoekstra and Hung 2002 and 2005; Hoekstra and Chapagain 2007; Fracasso 2014).

Despite the merits of the two above arguments, the literature has still not reached any type of consensus. This paper sets out to make two main contributions to the existing literature. First, we consider the determinants of virtual water flows by empirically assessing the two competing explanations. By examining these two arguments side-by-side we are able to ascertain the strength of each explanation as it relates to understanding virtual water flows and food trade. Our second contribution is methodological given that we undertake a cross-national empirical study using panel data, as opposed to a case-study approach or cross-sectional data approach, which spans more than a decade of trade relations between countries. Using a gravity model approach with two high dimensional effects, as established in Head and Mayer (2013), our results demonstrate that food bilateral trade flows are positively correlated with exporter-importer water endowment asymmetries, revealing that the driest countries indeed resort to food trade to alleviate water scarcity as originally conceived by Allan (1991) and act according to their comparative advantage. We also find that relative water footprint asymmetries at the product level also matter but with strong non-linear effects. As expected, food flows from relatively more productive to less productive countries, thus saving water globally. However, past a certain threshold, high water productive countries import products from relatively low water productive nations thus challenging the validity of comparative advantage as far as water productivity is concerned. Our data also show that between 1994 and 2007, food trade from more to less water productive countries resulted in saving $4750km^3$ of water which represents around 25% of the total $18700km^3$ of water that was traded during that period. We also find that in terms of water savings, cereal trade is currently the most efficient in the distribution of goods from relatively more to less water productive countries.

Below we begin with a theoretical discussion of the two competing explanations pertaining to virtual water flows. We then discuss additional independent and control variables important for understanding trade in water embedded products. After operationalizing our variables and explaining our identification strategy, we discuss the results and conclude with some lessons as well as policy implications.

2 Explaining Virtual Water Flows: Water Endowments versus Water Productivity

The term virtual water was coined in 1993 by Tony Allan to draw attention to the notion that serious local water shortages could be effectively ameliorated by global economic processes. The Middle East and North Africa, or MENA, was used as an example of a region embodying significant food imports. While some scholars had contended that the high food imports was a sign of the region's dismal failure in feeding its own people, others argued that food imports actually provided an opportunity for the region's economies to solve their serious and deteriorating water scarcity. In other words, the political and economic impacts brought about by water scarcity (such as a possible armed conflict over scarce water resources) was moderated by the region's ability to reach out to other watersheds in the world, through international trade in virtual water or water embedded in imported agricultural products (Hakimian 2002). This claim also corresponded to the more general neo-liberal argument proposed by the international trade literature, suggesting that the probability of war is lower for countries that trade more while also enhancing cooperative political relations (Mansfield and Pollins 2003; Martin, Mayer, Thoenig, 2007).

The general virtual water contention stems from Ricardo's comparative advantage (1817) and the ensuing Heschker-Ohlin-Samuelson model (1941) on factor endowment in international trade: countries will export products that use their abundant and cheap factor of production and import products that use the countries' scarce factors. To date, a variety of studies have examined the endowment contention. In some cases, the argument has been confirmed yet in other cases ambiguous, nuanced, or even contradictory results were identified. Yang and Zehnder (2002), for example, found that while the relation between water endowments and virtual water trade patterns seemed to follow the rules of comparative advantage for cereal trade in certain southern Mediterranean countries, such patterns were confined to a restricted sample of countries. Yang et al. (2003) found that a clear negative correlation between water endowments and cereal imports existed only beneath a certain threshold (less than 2000 m^3 of water per capita per year for a specific country)[1].

[1] According to the Falkenmark indicator (1989), a country is considered under water stress if its water availability is less than 1700 m^3 per capita per year. This figure includes daily water requirement (drinking water, sanitation, bathing and food preparation) and embedded water in food, textile, energy, etc.

Finally, the literature also revealed that certain countries actually had counter-intuitive production and trade strategies related to their water endowments as in the famous cases of water-poor Northern China exporting food to better-endowed Southern China (Ma 2004, Ma et al. 2006, Guan and Hubacek 2007, Liu and Zeng 2012) and flood-prone Eastern India importing food from drier states of the country (Verma et al., 2008). In many cases, the issue of food security/self-sufficiency appeared as a main driver for agricultural subsidization, extensive irrigation schemes in dry areas and massive food imports even when water was relatively abundant. Most recently, and employing a large-n methodology, Fracasso (2014) finds that national water endowments as well as pressures on natural resources indeed determine virtual water flows between countries. While the study is limited to a single year, the results are robust across the estimation models.

The diversity in results pertaining to the endowment contention suggests that water availability may not be a sufficient policy criterion for explaining international trade in water embedded products (Wichelns, 2010). Scholars further contended that endowments likely played a minor role compared to other variables such as climate and land (Verma et al. 2005, Kumar and Singh 2005) as well as labor, capital, politics, economics, history, and culture (Turton 2000, El Fadel and Maroun 2003, Warner 2003, Novo et al. 2009, Hoekstra 2010, and many others). These results led some to conclude that although virtual water is conceptually based on the Heckscher-Ohlin framework, the model performed poorly (Ansink 2010).

As an alternative to the water endowment contention, studies have also suggested that a major indicator of food production and export strategies was the amount of water required to produce a unit of crop or livestock, namely water footprint. The water footprint as exemplified in the Water Footprint Network (WFP) introduced by Hoekstra and Hung (2002) and further elaborated by Chapagain and Hoekstra (2004) is a complex variable that varies within countries and across regions, driven by exogenous climatic and soil conditions, as well as a large range of endogenous factors such as economic strength (Turton, 2000), government subsidies, technology, capital, labor and food security policies (Wichelns, 2010, De Fraiture et al., 2004; Novo et al., 2009).

Water Footprint figures provide relevant information on the structure of food markets and have been widely used in quantitative studies at the global, national, sectoral and product levels. For instance, Hoekstra and Hung (2002) first quantified volumes of all virtual water trade flows between 1995-1999 showing that 13% of water used for crop production in the world was not used for domestic consumption but was virtually exported. At the national level, Chapagain and Orr (2008) computed that 62% of the United Kingdoms virtual water was accounted for by exports, highlighting the countrys dependency on food imports. At the sectoral level, Chapagain et al (2006), showed that 84% of the water footprint of cotton in Europe is located outside Europe, specifically impacting water resources from scarce regions in India and Uzbekistan. Comparing countries' performance in water footprints, De Fraiture (2004) also demonstrated that India produces 0.39 kg of wheat for every m^3 of water used compared to 0.72 in the US. Still, India is among the largest exporters of wheat, thus implying that water is being lost through trade. The water footprint argument thus reveals much about our dependency towards resources, and even more, whether it is a local or foreign water-dependency.

Comparing water footprint figures also sheds light on differences in the productivity of water use across regions and countries. However these figures remain difficult to interpret because of the diversity of inputs and local conditions. Water resources are also often overlooked as essential inputs, which means that high levels of water productivity may or may not be sustainable.[2] In general, using water productivity figures requires to consider the larger political and historical context. For instance groundwater depletion and low water productivity in India cannot be observed separately from food security policies and the Green Revolution (Singh, 2006). Water scarcity in Kenya has been argued to be less restrictive than lack of other expensive inputs such as capital and technology making Kenya a highly water-productive nation at the cost of its own resources (Ong and Swallow, 2003). On the other hand, capital-abundant nations like Israel or Singapore have massively invested in water-saving technologies and achieved high levels of water productivity. The interpretation of our results will thus take these factors into consideration.

3 Data

Although the extant literature has examined the water endowment and productivity arguments separately and largely from a qualitative or limited (fo-

[2]Water productivity is easier to achieve under rain-fed conditions but knowledge and technology can dramatically improve water efficiency and offset to a certain extent the impact of a drier climate. On the other hand, the absence of capital investment and knowledge in farming and climate uncertainties can easily foster sub-optimal use of water.

cusing on specific regions) quantitative fashion, the two arguments have not been subject to systematic, country-pair and cross-national scrutiny. In addition, no empirical cross-national study has been conducted on a cross-sector or time series level. This paper empirically sets out to fill the lacuna in the literature and shed further light on this debate.

3.1 Bilateral trade flows

This paper considers annual bilateral trade flows between 1994 and 2007 at the product level in tons as the dependent variable. Trade flows are taken from the BACI dataset, as developed in the CEPII report by Gaulier and Zignago (2010). They provide data at the highest level of product disaggregation, 6 digits Harmonized System (HS) code from 1994 to 2007. The original data is sourced from the COMTRADE database of the UN Statistical Division and were harmonized for more than 200 countries since 1994. The BACI dataset is particularly suitable for this investigation because it deals with missing data by employing a reconciliation methodology[3]. Missing values of bilateral trade for a specific product can occur if one or both of the countries fail to report their trade flows. BACI utilizes the double information available on each trade flow to provide a unique "reconciled" value for each flow reported by at least one of the partners. The only missing values are those of two non-reporting countries[4]. Our dataset also distinguishes directions of trade: observations consist in reported trade flows of a particular product p from exporter i to importer j at year t.

3.2 Relative water endowments and footprints

To test our two arguments we quantify and compare the impact of relative water-land endowments and water productivity on food trade. These indicators are both measured as a ratio to identify how asymmetries in endowments and productivities between exporting and importing countries shape their food

[3]Reconciliation provides an explanation for the discrepancy between the import and export statistics of trading partners by identifying conceptual reasons for them and explaining differences in data collection and processing. See United Nations (2004). Similar to COMTRADE, BACI does not report zero values of trade because of computational issues. It also does not report zero values for products no longer, but previously, traded between two countries, raising the issue of selection bias. Furthermore, a missing observation is considered a zero when at least one of the trading partners reports its trade to the UN. If both partners are not reporting, the missing observation is considered a true missing value.

[4]See Gaulier and Zignago (2010) for more detailed explanations

trade strategies.

In order to capture the effect of resource endowment asymmetries, we include the ratio of actual renewable water resources per ha of land for our country pairs, following the reasoning that when access to arable land increases, the ability for a country to use its water resource and raise livestock or produce crops increases (Kumar and Singh, 2004). Actual renewable water resources per year are taken from the FAO Aquastat dataset and arable land data is provided by the World Bank indicators[5]. Total renewable water resources are the sum of Internal Renewable Water Resource (IRWR)[6] and External Renewable Water Resource (ERWR)[7]. Although the IRWR is roughly fixed across time, the ERWR can vary with time. Total water resources per capita thus decrease over time because of population increase and political or climatic events changing the ERWR.

We include a squared term to account for non-linear effects of resource asymmetries on virtual water trade and to identify whether excessive asymmetries might affect bilateral trade of food products. Indeed, Yang et al. (2002), De Fraiture et al (2004) and Wichelns (2010) claim that the significance of water scarcity over food trade is strongest for water poor countries. In the result tables, the variables will be displayed as $RatioWaterLand$ and $RatioWaterLand^2$.

We hypothesize that virtual water exports will be positively correlated with water per land asymmetries, supporting the literature which has demonstrated that a country's ability to produce is largely determined by the amount of arable land it has access to and water availability (Kumar and Singh 2004).

Water productivity figures are taken from Mekonnen and Hoekstra (2011) and Chapagain and Hoekstra (2003) for crops and livestock respectively[8].

[5] Visit http://www.fao.org/nr/water/aquastat/dbase/index.stm and http://data.worldbank.org/indicator

[6] Long-term annual flow of rivers and recharge of aquifers generated from endogenous precipitation

[7] Resources not generated in the country, including inflows from upstream countries, border lakes and/or rivers; takes into account the quantity of flow reserved by the upstream or downstream country through formal or informal agreements

[8] These studies on water footprint, as well as others (Chapagain et al. 2006a; Yang and Zehnder, 2007), have made a point of distinguishing between blue, green and grey water. In this paper, we do not make the distinction between water types for two reasons: one pertains to the issues around the economic interpretation of green versus blue water; the other relates to computational issues. Blue water is volume of surface and groundwater consumed or

Mekonnen and Hoekstra (2011) provide national water footprint figures for 146 crops disaggregated at the 6-digit HS level, averaged over the period 1996 to 2005. We use their data for 146 crops - which correspond to 102 different sub-categories (HS4) of 18 major crops (HS2) - and 144 livestock products (HS6). Appendix A provides a detailed description of the crops and livestock products we cover in this analysis.

We control for relative values of water footprint for a specific crop/livestock product p traded between the exporter i and the importer j. We also include the squared term of productivity ratios for the same reasons as above. In the regression tables, they will be displayed as $RatioWFP$ and $RatioWFP^2$.

Water footprint figures are available for about 77% of trade flows provided by BACI, hence we restrict our analysis to the trade flows for which we have this information. We hypothesize that the exporter-importer ratio of water footprint for a specific product should be negatively correlated with virtual water exports, thus supporting the fact that countries make use of their relative comparative advantage in water resources. Following our reasoning, as the exporter-importer water footprint ratio decreases, the exporting nation uses relatively less water to produce a unit of the good than what the importer would have consumed, had it produced the good itself.

3.3 Gravity and control data

We include a set of control variables associated with gravity models for trade as well as additional variables that impact the extent of food trade. In all, these variables proxy for the countries geographic proximity, cultural affinity, and political relations as well as demographic and economic conditions.

Gravity Variables

We utilize control variables inherent to gravity models for trade (Tinbergen 1962). Referred to as multilateral resistance terms they include the distance

evaporated as a result of the production of a good. Green water is rainwater that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetatio. Grey water is the volume of freshwater required to assimilate the load of pollutants based on existing water quality standards. The relevance of dividing empirical estimates of virtual water flows into blue, green and grey components has been questioned (Wichelns, 2010) because the methodology is not based on a conceptual framework able to guide policies. It has been suggested that the opportunity cost of green water is smaller than that of blue water (Yang et al., 2006; Aldaya et al. 2008, 2010) while Wichelns argues this interpretation can be overturned according to local country characteristics.

between trade partners, contiguity of the states, language and common colonizer (Anderson and van Wincoop, 2003). We hypothesize that as the distance between trade partners diminishes and/or when trade partners are immediate neighbors sharing a border, the level of trade will increase. States sharing a common language and common colonizer should also evince increased trade. Data for these variables is taken from Head, Mayer and Ries (2010).

Recent research has demonstrated that overall trade relations are also an important component of a trade gravity model (Carrere 2006). In particular, regional trade agreements (RTAs) have been shown to promote peaceful relations between states as well as increased inter-state trade (Mansfield and Pollins 2003; Carrere 2006). We account for the states membership in a RTA (using a dummy variable) utilizing data in Head et al (2010).

Demographic and Economic Controls

A growing population is one of the main drivers of increased water withdrawals as well as food imports (Rosegrant and Ringler, 2000; Liu et al., 2008; Ercin and Hoekstra, 2014). Taking population data from the Penn World Table (PWT) 7.0,[9] we include the relative rate of exporter-importer population increase from one year to another allowing us to compare the level of strain on each trading partner.

We hypothesize that countries with a high rate of population growth will need to either increase food production should they have the means to do so or decrease exports/increase imports to satisfy national demand. This would mean a negative correlation between the ratio of population rate of increase and virtual water exports.

The economic power of a country also plays an important role in a country's ability to engage in virtual water trade. Turton (2000) explains that the very difference between countries that use virtual water as a rationale coping strategy and those who resort to food aid is the ability to pay, thus increasing the economic leverage offered by a developed industrial-based economy over a developing, predominantly agriculture-based one. Hoekstra (2010) discusses the ability of rich countries to invest capital into water-efficient technologies, hence increasing a countries own comparative advantage in producing water-intensive goods. Furthermore, food trade is subject to particularly high trade

[9] It is provided by Alan Heston, Robert Summers and Bettina Aten, Penn World Table Version 7.0, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, May 2011.

costs which end up excluding certain developing countries (Hoekstra and Hung, 2002; Reimer, 2012). Following Dinar et al. (2011), we measure asymmetries of wealth by considering the ratio of GDP per capita, taken from the World Penn Table as well (gdp per capita is derived from growth rates at 2005 constant prices). Since the wealthiest countries in the world are also among the largest exporters of virtual water, we hypothesize that virtual water exports will increase along with the ratio of wealth between the exporting and the importing country. However, we also recognize that very poor countries may not be able to participate in the global virtual water trade. Hence we measure for both a linear and quadratic relationship.

We also control for asymmetries in food price levels since access to, and trade, in food is mainly constrained by incomes and food prices. We utilize a food price index, provided by the FAO, and calculate a ratio measured as food purchasing power parity (FoodPPP) divided by the general PPP. This ratio of domestic food price index captures the importance of food in the overall consumption basket and we expect that the indicator will be higher for least developed countries. These nations are not self-sufficient in domestic food production and are financially constrained when considering food imports, suggesting that this variable should be negatively correlated with virtual water exports.

3.4 Summary Statistics

Table 1 provides summary statistics for the variables of interest. The dependent variable, virtual water exports, is at the dyadic-year-product level. The explanatory variables are all country-pair and year specific, apart from contiguity, common colonizer, common language and distance which are fixed over time. Our study covers 179 countries, 2113 products from 25 different trade sectors. All of the countries have at least 1 million inhabitants so as to reduce the effect of specific local conditions of small countries on the analysis (see Yang et al. 2003).

We observe that exporting countries display a smaller average water-land endowment in comparison to importing nations, but with a smaller standard deviation. Indeed, part of the importing countries in this study tend to feature extreme values water-per-ha-of-land endowments, further away from the mean. Importing countries that display low values of water-per-ha-of-land values vindicate the water endowment argument as they resort to trade to compensate the lack of resources . Maximum values represent either small-medium coun-

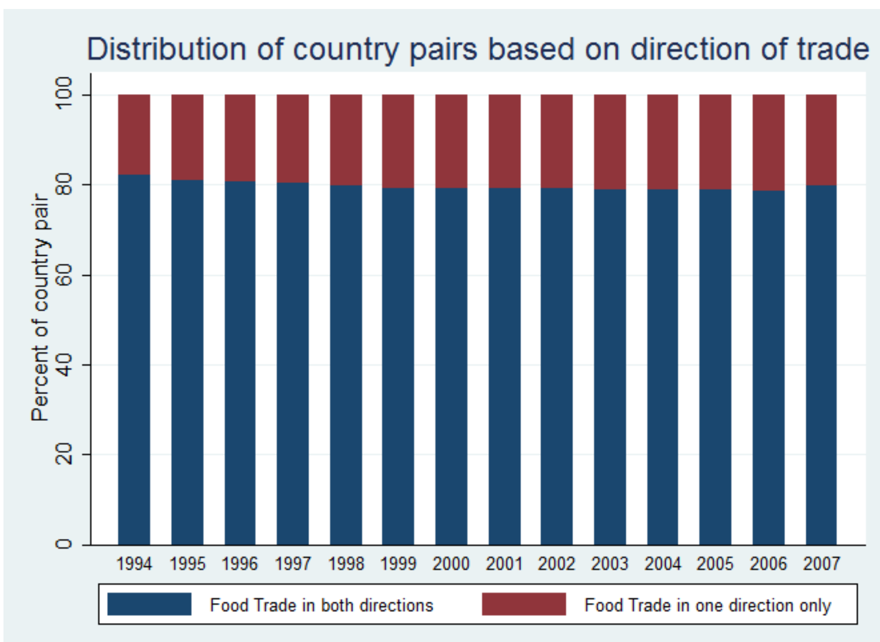
Table 1: Summary statistics

Variable	Mean	Std. Dev.	Min.	Max.
Food Exports_ijt	6437174.135	128079557.556	0	76820332544
WaterLand_i	72150.648	172025.846	345.168	4150259
WaterLand_j	90143.380	225446.173	345.168	4150259
RatioWaterLand	5.773	31.908	0	6287.918
WFP_i	7784.384	23328.793	5.808	1575091
WFP_j	9211.91	30484.489	4	1575091
ratioWFP	1.232	2.179	0.002	253.764
GDPcap_i	20114.824	14363.151	160.797	100110.977
GDPcap_j	18554.37	14711.632	160.797	100110.977
ratioGDPcap	4.127	10.821	0.003	337.555
Food_Price_Index_i	1.345	0.302	0.75	4.33
Food_Price_Index_j	1.406	0.336	0.75	4.33
Ratio_Price_index	1.008	0.314	0.231	4.33
PopEvol_i	1.004	1.26	-3.782	19.105
PopEvol_j	1.119	1.646	-3.782	19.105
RatioPopEvol	3.583	52.083	-2380.994	4204.476
Contiguity_ij	0.132	0.339	0	1
Common Colonizer_ij	0.045	0.207	0	1
Common Language_ij	0.197	0.398	0	1
Distance	5203.31	4369.028	114.637	19650.135
RTA	0.301	0.459	0	1

Note: exporting country i, importing country j, year t , RTA = Regional Trade Agreement tries (Singapore, Papua New Guinea, Liberia) that entirely rely on imports, or important producing countries (Chile, Malaysia, Norway, Columbia) with high demand effects. Exporting countries feature a lower water footprint average, meaning a higher average water productivity, in favor of the comparative advantage argument. Exporting nations are also wealthier on average.

Figure 1 shows the distribution of country pairs according to the direction of trade. Roughly 80% of country pairs, as established by the BACI data, trade food and account for over 85% of virtual water exports every year. Out of the country pairs that trade in both directions, 16% actually trade the same product; when this is the case, both trade flows still appear as two discrete observations between the partners, once for each direction.

Figure 1: Distribution of country pairs according to direction of trade



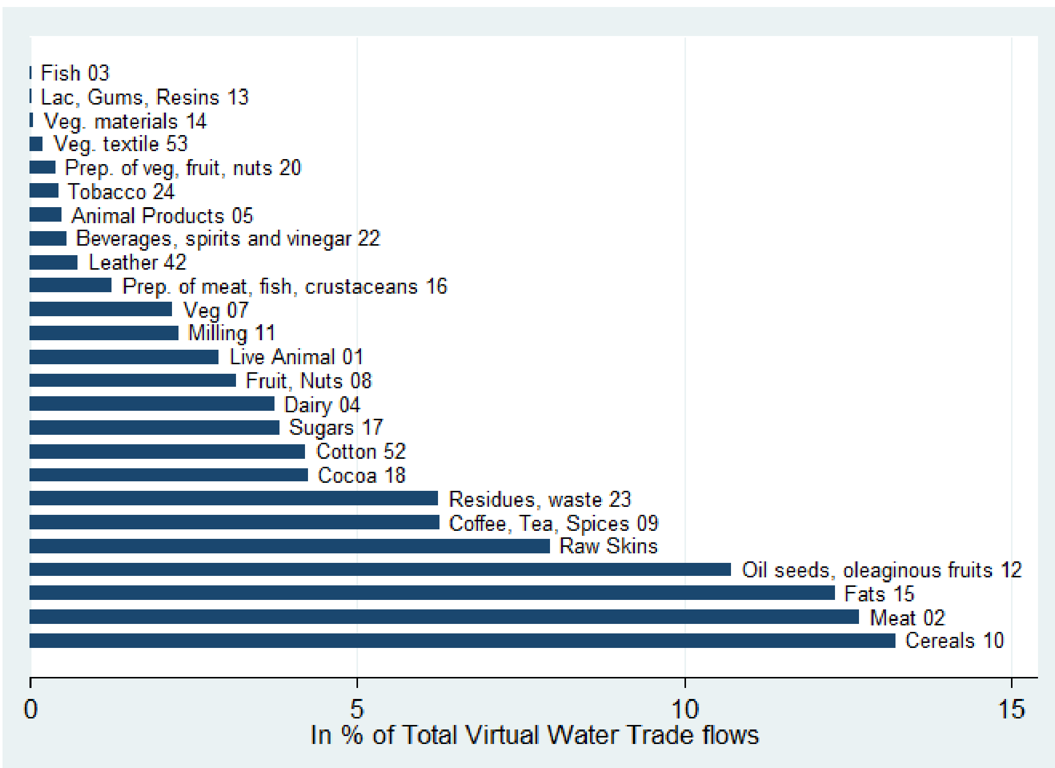
Sectoral Statistics

Food sectors are not equally accountable for water withdrawal around the world. Figure 2 shows the distribution of trade flows between 1994 and 2007 according to sector. Products from the Cereal (HS10), Meat (HS02), Fats

(HS15) and Oil Seeds (HS12) sectors are the most traded between 1994 and 2007 and represent just a little less than 50% of all bilateral virtual water trade flows.

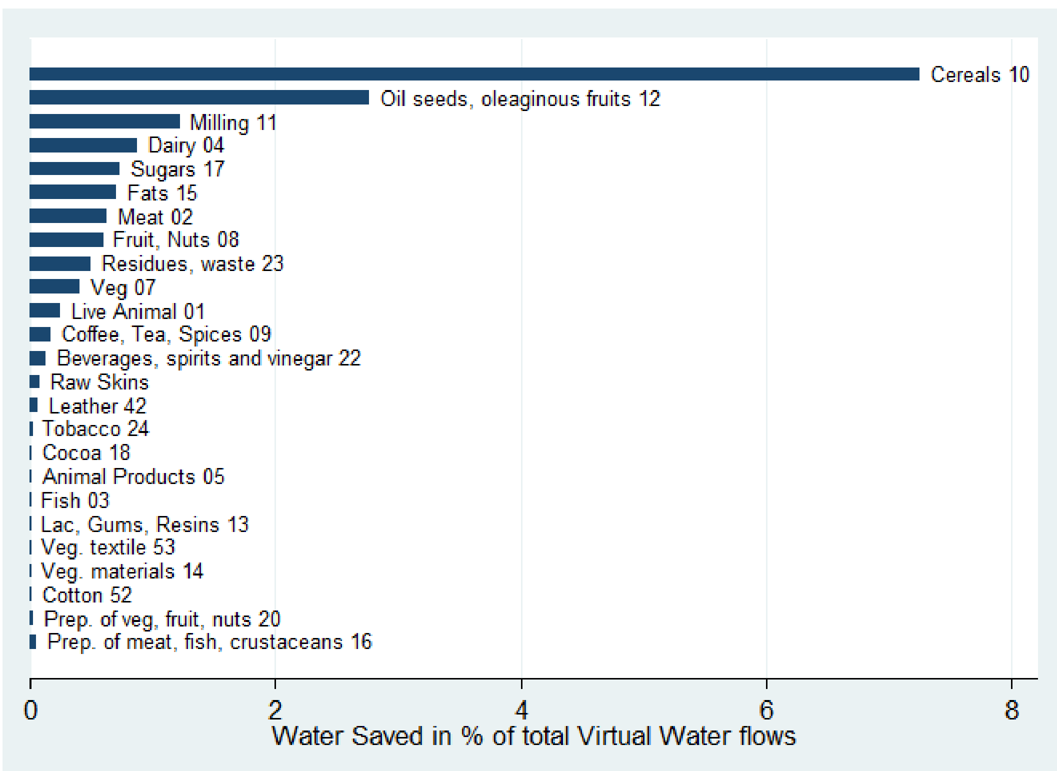
Given the availability of water footprint data in $m^3.ton^{-1}$ for both the exporter and the importer as well as quantities in tons, we are able to compute the counterfactual amount of water that would have been used if the importer had produced locally rather than import. The difference between the real and the counterfactual water footprint gives us the amount of water saved or additionally consumed through trade. Figure 8 shows the distribution of global water savings as a percentage of total water traded between 1994 and 2007, and according to sector.

Figure 2: Share of Trade Flows according to food sector between 1994 and 2007



We can see that, on average, between 1994 and 2007, the sector for which inter-state trade saved the most water globally is cereals, relieving water withdrawals for slightly more than 7% of the total amount of virtual water trade. This result is similar to De Fraiture et al. (2004), who find that in 1995 global crop water use in cereal production would have been higher by 6% had it not been for international trade. Out of 18700 km^3 of embedded water being traded between 1994 and 2007, cereal importers have saved around 1350 km^3 of water that would have otherwise been depleted. The second sector for which trade has contributed to water savings is "Oil seeds and oleaginous fruits", for which the amount of water saved corresponds to an average of 2.7% relative to total virtual water traded between 1994 and 2007.

Figure 3: How Sectors contribute to saving water through international trade between 1994-2007



4 Econometric Methodology

We perform our analysis of bilateral virtual water flows at the product-dyad-year level and so our gravity model needs to address several issues.

Our dyads will display strong heterogeneity, exacerbated by unobserved factors (such as culture and and other types of qualitative exxchanges) that will affect the level of trade and be correlated with the explanatory variables. Therefore the econometric analysis needs to account for unobservable country-pair effects and potential heteroskedaticity. We control for country heterogeneity by using a gravity model with two time-varying effects (Head and Mayer, 2013) at the exporter-product-year level and the importer-product-year level. Our time-varying country-product effects will control for all omitted variables that are cross-sectionally specific, such as variations in national economic indicators, political shocks, relations with other countries (excluding the trading partner), etc. Our explanatory variables on the other hand will be strictly bilateral and cover time-varying and constant characteristics.

We estimate country's i export volume of trade to country j as:

$$lnQ_{ijpt} = \alpha_{ipt} + \alpha_{jpt} + \beta_{ijpt} Z_{ijpt} + \epsilon_{ijpt} \quad (1)$$

where i is the exporter country, j the importer country, p is the traded product at year $t \in$ [1994;2007]. Q_{ijpt} is the volume of exports from country i to j for product p at year t, expressed in tons. The intercept has two parts: α_{ipt} which is specific to product p, year t in country i and α_{jpt} which is specific to product p, year t in country j. The error term ϵ_{ijpt} is assumed to be normally distributed with zero mean and constant variance for all observations. It is also assumed that the errors are pairwise uncorrelated.

We assume here that the slope coefficients are constant across country pairs and over time. The 1 x k row vector Z_{ijpt} comprises all of our explanatory bilateral variables which are the following:

$$RatioWaterLand_{ijt} = \frac{WaterpLand_{it}}{WaterpLand_{jt}} \quad (2)$$

for year t, exporting country i and importing country j.

$$RatioWFP_{ijp} = \frac{WFP_{ip}}{WFP_{jp}} \quad (3)$$

for product p exported from country i to country j.

We also control for non-linear effects of asymmetries in population growth by including the squared term of this ratio. These variables will be displayed as $RatioPopEvol$ and $RatioPopEvol^2$ where:

$$RatioPopEvol = \frac{pop_{it} - pop_{it-1}}{pop_{it-1}} / \frac{pop_{jt} - pop_{jt-1}}{pop_{jt-1}} \tag{4}$$

The ratio of GDP per capita is modeled as $ratioGDPcap$ and $ratioGDPcap^2$ where:

$$ratioGDPcap = \frac{GDPcap_{it}}{GDPcap_{jt}} \tag{5}$$

Food purchasing power parity (FoodPPP) divided by the general PPP:

$$RatioPriceindex = \frac{FoodPPP_{it}}{PPP_{it}} / \frac{FoodPPP_{jt}}{PPP_{jt}} \tag{6}$$

Patterns of trade make up another important control. Countries are likely to trade a product p in year t if they were already trading it the previous year. By including a dummy variable that indicates whether product p was traded the year before, we capture characteristics of trade that generally reflect on trade patterns that are not necessarily related to comparative advantage in water-land endowments or water productivity. The dummy is defined in the following way:

$$Crop(t-1)_{ijpt} = \begin{cases} = 1 & \text{if product p was traded in t-1 between i and j} \\ 0 & \text{if not} \end{cases} \tag{7}$$

We expect the coefficient on this dummy to be strongly significant and positive.

We use the reg2hdfe command to estimate our linear regression model with two high dimensional fixed effects provided by Guimaraes and Portugal (2010).

5 Results

Table 2 displays results for OLS analysis with quadratic terms, with the second regression being clustered at the exporter-year-sector level. The clustered analysis covers 1,548,173 observations, over 26587 groups[10].

[10] We ran the regressions with many different clusters and got similar results for all coefficients, apart from the quadratic term of the ratio of food price indexes which lost its significancy. We also performed the regression without the quadratic terms to observe the linear effects of our variables on food exports (see Appendix for regression table) and obtained similar results.

Table 2: Linear regression with two high dimensional fixed effects

	(1)		(2)	
	y		y	
$RatioWaterLand$	-0.00337***	(0.000331)	0.00137***	(0.000338)
$RatioWaterLand^2$	0.00000168***	(0.000000229)	-0.000000790*	(0.000000322)
$ratioWFP$	-0.230***	(0.0173)	-0.0548***	(0.00652)
$ratioWFP^2$	0.00174***	(0.000268)	0.000384***	(0.0000707)
$ratioGDPcap$			0.0117***	(0.00263)
$ratioGDPcap^2$			-0.000108***	(0.0000269)
RatioPriceindex			-1.269*	(0.637)
RatioPriceindex2			0.0179	(0.129)
Bil4			0.0114	(0.0246)
CropDummy			1.100***	(0.0111)
$RatioPopEvol$			-0.000254***	(0.0000218)
$RatioPopEvol^2$			2.85e-08***	(3.83e-09)
contig			0.938***	(0.0184)
comcol			0.234***	(0.0358)
comlang_off			0.225***	(0.0152)
lndist			-0.810***	(0.0113)
rta			0.260***	(0.0200)
N	1945345		1547241	
F				
df_m				
df_r	573740		476169	

Standard errors in parentheses

Source is here

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Water-land relative endowments

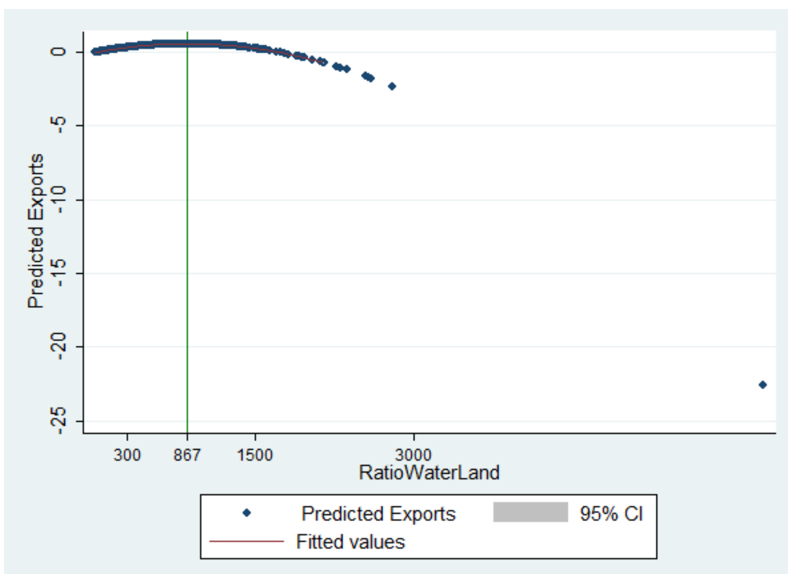
The results for clustered regressions display a weak non-linear relationship between exporter-importer water-land ratio and food exports: the linear and quadratic term are significant at the 1% level.

Figure 3 plots the predicted values of predicted exports according to the ratio of water-land endowments. For small values of $\Delta RatioWaterLand$, the effect on exports can be computed as follows:

$$log(Q_{ijt}) \approx 0.00137 * RatioWaterLand - 0.00000079 * RatioWaterLand^2) \quad (8)$$

$$\Delta log(Q_{ijt}) \approx 100 * (0.00137 - 0.00000158 * RatioWaterLand)\Delta RatioWaterLand \quad (9)$$

Figure 4: Non-linearity of water per land asymmetries on predicted exports between 1994 and 2007



Our regression results show that a one standard deviation from 10 to 41.908 in the exporter-importer water-land ratio leads to a 4.2% increase in food exports. The slope is relatively weak and decreases as water-land asymmetries increase[11]. This suggests that keeping other factors constant, countries are

[11]We also performed the regressions without the quadratic term, and results are shown in appendix C shows the result table when performing regressions without the quadratic

using their relative comparative advantage in water until a point where the water-land asymmetry becomes so high that the trend inverses. The left side of the curve is in line with Allan's theory of virtual water, suggesting that water-land resources do play a role albeit slightly given our weak coefficients - in shaping countries food production and trade strategies.

The result does not mean that relatively water scarce countries do not export to relatively water rich nations, but simply that overall food trade flows in the right direction, strictly from a water-land resource point of view. This trend is validated for country-pairs displaying below-8 exporter-importer water-land ratios, which is about 99% of our sample, for which the exporter-importer water-land ratio is beneath 80. Beyond 80 and up to 500 are country-pairs for which the exporter is among the top 10 water-land rich nations in the world (USA, Brazil, Canada, China, Columbia, etc.), thus displaying a very high water-land asymmetry relative to the importing nations.

The threshold of 867 is extremely high and in fact concerns all trade flows to Saudi Arabia, the second driest country in terms of water-land resources (with an average of 650 m^3 of water per ha of land per year) behind Libya (380 m^3 of water per ha of land per year). Beyond that threshold, the large water-land asymmetries between exporters and Saudi Arabia are negatively correlated with exports. This means that Saudi Arabia's imports are highly diversified and come from countries such as Brazil, Canada, Chile, Congo, Ecuador, Malaysia, Peru, New Zealand or Singapore. Among these exporters, Ecuador, Malaysia, Congo, Chile and New Zealand are the richest countries in water per capita and in water per land, hence the exceptionally high water-per-land ratio[12]. The highest water-land ratios are actually between New Zealand and Libya and Singapore and Libya, with ratios of over 2000[13]. Because of trade diversification, trade among countries with high endowment asymmetries makes up for a very small fraction of total virtual water trade, explaining the declining trend in virtual water exports.

terms. The coefficient for the RatioWaterLand variable is very significant and positive: a one standard deviation increase in water endowment asymmetries increases exports by 2%.

[12]The case of Singapore stands out, as it is among the poorest countries in water per capita but among the richest in water per hectare of land. Furthermore, Singapore's exports are built up by the fact that the nation re-exports around 70% of its food imports, mainly dairy products, frozen poultry and poultry parts.

[13]The outlier value of over 6000 is between Papua New Guinea and Saudi Arabi, which account for only one observation in our dataset, for one trade flow in 1995.

In terms of quantitative effects, the coefficient on RatioWaterLand takes on a weak value because our dependent variable is at the product level, which is the most disaggregated. This is further discussed below, when we perform the regressions at the sectoral level.

Figure 5: Distribution of VW exports based on country-pair asymmetry of water endowment per ha of land

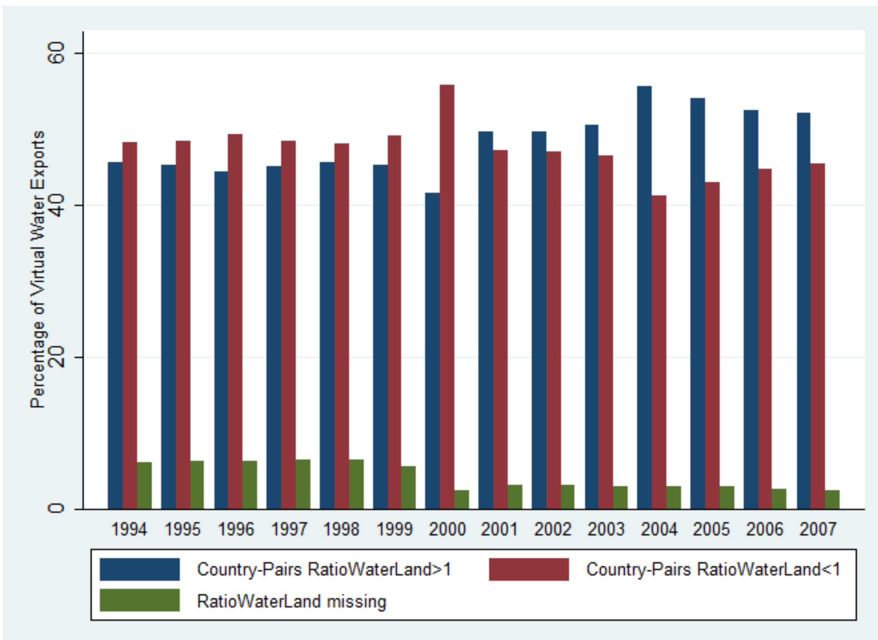


Figure 4 also shows that food flows are almost equally divided between countries with water-per-land ratios above and below one (45% of virtual water trade occurs between country-pairs with water-per-land ratio below one). This is because 80% of our country-pairs trade in both directions and are represented at least twice as depicted in figure 3[14]. These figures show that relatively less-endowed countries are as likely as their better-endowed counterparts to be exporting virtual water.

Both these results are important: first, they suggest that relatively less-endowed countries are exporters as much as their relatively better-endowed

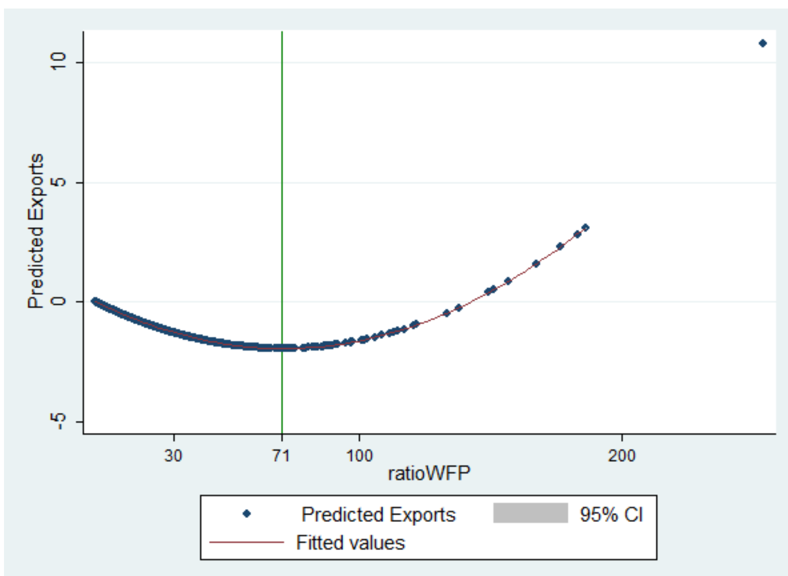
[14]There will be one observation for each product that country-pairs trade, unidirectionally; country-pairs will appear more than one time if they trade more than one product.

trading partners. Second, they also show that water-rich nations are exporting higher volumes of virtual water, thus arguing in favor of a positive effect of water endowments on food and virtual water exports.

Relative Water Footprints

We now turn to the analysis of the coefficients of relative water footprints at the product level. Water footprint is the inverse of water productivity - meaning that the higher the exporter-importer ratio of water footprint for a specific product, the more water the exporting country uses to produce a unit of the product and so the less water productive. Figure 5 plots the predicted values of food exports according to exporter-importer water footprints ratio.

Figure 6: Non-linearity of water footprints on predicted values of exports



Our data shows that the water footprint ratio at the product level has a strongly significant non-linear effect on exports both in the non-clustered and clustered models. The variable is fixed for each country-pair and product across years and the effects can be seen through the equation:

$$log(Q_{ijt}) \approx (-0.0548 * RatioWFP + 0.000384 * RatioWFP^2)$$

and so:

$$\Delta log(Q_{ijt}) \approx 100 * (-0.058 + 0.000768 * RatioWFP)\Delta RatioWFP$$

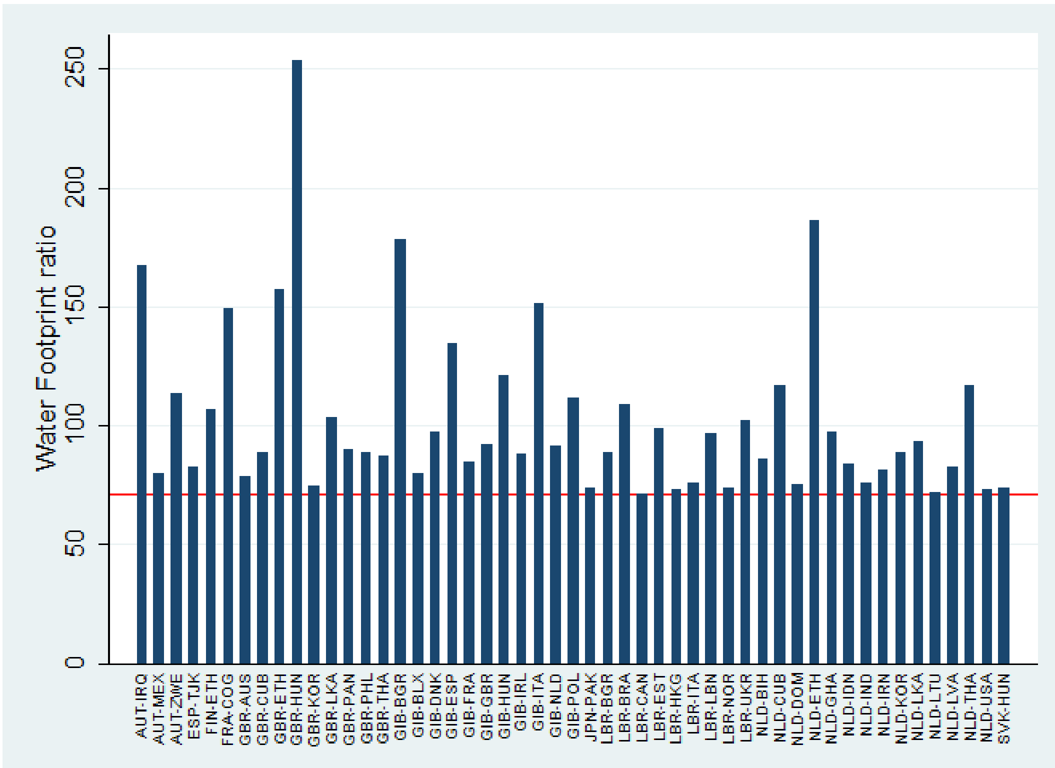
The quadratic function is decreasing in water footprint asymmetries until the threshold value of 71, after which it increases. On the left side of 71, a one standard deviation increase in water footprint asymmetries from 10 to 12.179 will decrease exports of the product by 10% which is a very strong decreasing effect. The slope decreases along with asymmetries: a one standard deviation change from 30 to 32.179 decreases virtual water exports by 6%. On the right side of the curve, a one standard deviation increase in water footprint ratios from 100 increases exports by 5%.

We hypothesized that a country exports a product only if he is relatively more water efficient $ratioWFP = \frac{WFP_{ip}}{WFP_{jp}} < 1$. As a matter of fact, about 40% of trade flows are between countries with a water footprint ratio lower than 1 (meaning the exporter has a higher water productivity)) and the rest are roughly divided between missing water footprints and water footprint ratios higher than 1 (30% and 30%, respectively). If we consider only the existing data on water footprints, then 57% of trade flows are between countries with a water footprint ratio lower than 1. This in fact means that (keeping relative water endowment and other relative economic and social factors constant), our hypothesis is validated for more than half of our sample. To the extent, we can claim that food production and trade behave according to the comparative advantage argument, as far as water productivity is concerned.

The non-linearity of the water footprint ratio, however, suggests that as the exporter-importer water productivity gap increases, the trend is inversed: virtual water flows from relatively less to more water efficient countries. This is counter-intuitive in terms of comparative advantage as suggested in the existing literature. Several explanations are in order. The threshold value of 69 is quite high and only 309 trade flows are reported to be above it, representing only 0.014% of the sample. This is negligible, yet the quantities of exports are sufficiently high for our coefficients to stay significant and change signs. In addition, we mentioned that decision-making within agriculture results from many different factors pertaining to labor, capital, technology and so on, meaning that countries with relatively low productivity for certain products may still decide to produce them. Furthermore, because there are few country-pairs on the right side of the curve, we can easily distinguish them and better understand this result.

Figure 6 shows the country-pairs with the highest levels of exporter-importer water footprints ratio. We found that the 309 country-pairs actually concerned

Figure 7: Country-pairs with highest Water Footprint ratios



a small number of importing nations, yet a higher number of exporters, so we labeled the x-axis in the importer-exporter format (although the y-axis is still to be read as exporter-importer water footprint ratio). There are five main nations which import products for which they are over 71 times more water productive than their exporting counterpart: Austria, Great-Britain, Gibraltar, Liberia and the Netherlands. Apart from Liberia, these countries are OECD members who are also known to be exporters of virtual water. Despite their relative abundance in water resources, there are different explanations as to why they are importing from relatively less water-efficient countries. The Netherlands and Austria lack available land. As such, their amount of water per ha of land is relatively higher than other countries, but their total levels of food production are significantly lower than the rest of Europe. Great-Britain has historically favored industries over agriculture since the 19th century, hence the need to resort to imports to satisfy demand. Moreover, western diets and rising populations are increasing demand for crops and livestock and the need to resort to imports.

Furthermore, these countries are not only importing from water abundant, developed countries but also from developing nations, suggesting the importance of export, or cash crop production for the latter. Through the mechanisms of contract farming (Key and Runsten, 1990), farmers in developing countries are incentivized by international agribusiness firms to switch from subsistence crops, locally sold and consumed, to crops specifically destined for exports. Firms thus benefit from cheaper labor and land and can easily satisfy western demand for food goods; yet in developing countries water management practices are often sub-optimal, in particular for irrigated crops, leading relatively less water-efficient countries to export to relatively more water productive nations. Although not the focus of this paper, the complex issue of water pricing is also part of the explanation for the inadequate use of water relative to the theory of comparative advantage. Indeed, the absence of any water scarcity rent leads food markets to perceive water resources equivalently, regardless from their location in the world and regional scarcity (Wichelns, 2010).

Liberia, on the other hand, is among the ten least developed countries in the world and imports over 90% of its staple food as it benefits from international food aid programs. But because of the country's former intensive production in cash crops such as rubber, palm oil, coffee and cocoa, it still displays stronger water efficiency than certain western countries for certain products (specifically for sectors HS20 - Preparations of vegetables, fruits and nuts and HS40 - Raw Hides, Skins and Leather). As such, the counter-intuitive relationship between imports and relatively higher water productivity in Liberia partly stems from a previous domination of export crops in the country.

Time-varying and fixed control variables

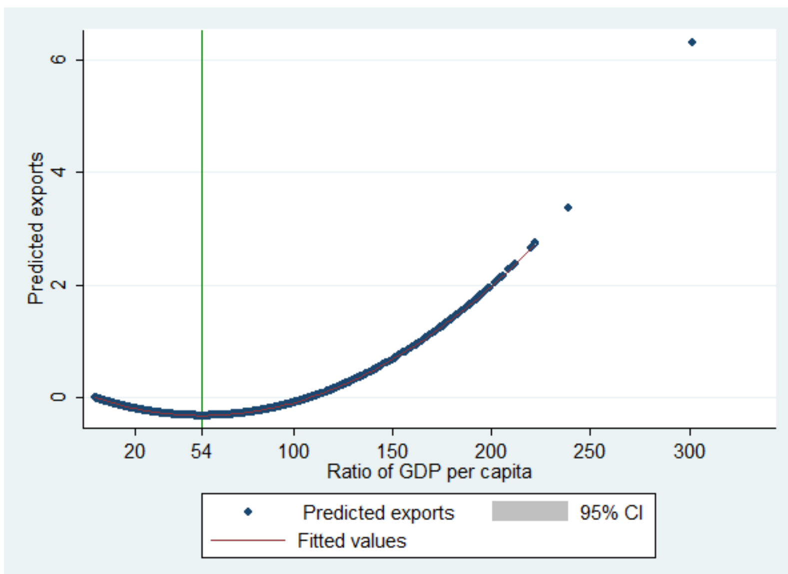
Our time-varying control variables include ratios of wealth and food price indices. Our fixed controls include the exporter-importer ratio of population increase between 1994 and 2007 as well as customary international trade dummy variables for contiguity, common colonizer, common language, distance and the existence of Regional Trade Agreements (which remain constant for our time span of 13 years).

Relative wealth

GDP per capita is considered as a measure of wealth (Dinar and Dinar,

2011) which is bound to be correlated with the ability to invest in agricultural production and engage in trade. Wealthy nations are generally large exporters and importers of food - but remain net exporters of virtual water, whereas relatively poorer nations are often net virtual water importers (Hoekstra and Hung, 2002)[15]. Our results show that asymmetries of wealth have a non-linear effect on food exports, with an inverted u-shape with a high distribution of observations on the right of the threshold value 55. Figure 8 shows the distribution of predicted exports according to values of GDP per capita ratios.

Figure 8: Non-linearity of wealth asymmetries on predicted values of food exports



On the left side of the curve, food exports increase along with wealth asymmetries. On this part of the curve, a change in wealth asymmetry from 10 to 20 (meaning the exporting countrys GDP per cap is 20 times that of the importing nation) induces an increase in virtual water exports of approximately 8.6%, a very strong effect. The slope then decreases around the value of 54 and then becomes increasingly negative according to:

$$log(VWexp) \approx 0.0117 * RatioGDPcap - 0.000108 * RatioGDPcap^2$$

[15]This does not exclude that patterns of exports and imports in developing countries tend to vary from year to year.

and so:

$$\Delta log(VWexp) \approx 100 * (0.0117 + 0.000216 * RatioGDPcap)\Delta RatioGDPcap$$

What our results suggest is that exports do flow from relatively wealthier to poorer countries, but only up to a point. Above an asymmetry of 54, food exports from wealthy to very poor countries will decrease. Summary statistics show that 50% of country-pairs have GDP per capita ratios below 1 and 90% below 10. Country-pairs with above 10 and beyond asymmetries in GDP per capita generally involve wealthy or emerging nations as exporters and among the poorest nations as importers, mostly from the African continent. Above the threshold of 55, exports decrease because countries are financially excluded from food trade country pairs above the value of 100 include Ethiopia, Liberia, Malawi and Zimbabwe as importers. This is also in line with De Fraiture et al. (2003) who find that most food trade occurs between rich countries – we find that 90% of food trade occurs between countries whose wealth asymmetry does not go beyond a ratio value of 10.

Relative population growth

According to our results, the exporter-importer ratio of population increase has a slightly non-linear impact on predicted food exports, with a strong negative effect on the linear term. The regression plotted in Figure 9 is as follows:

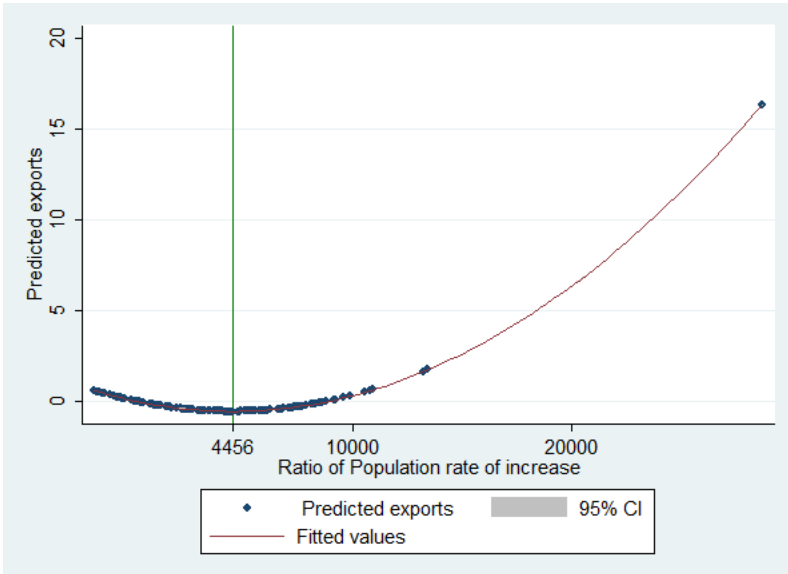
$$log(VWexp) \approx -0.000254 * PopInc + 0.0000000285 * PopInc^2$$

and so:

$$\Delta log(VWexp) \approx 100.(-0.000254 + 0.000000057 * PopInc)\Delta PopInc$$

Ercin and Hoekstra (2014) identify population growth as a main driver of change in water scarcity. The need to feed a growing population exerts pressure on water resources and food production processes and thus modifies trading patterns. Developing countries, in particular in the African continent, are more vulnerable to this threat: Africas population is expected to double from 1.1 to 2.4 billion by 2050 (Population Reference Bureau) while the population of more developed regions is expected to increase minimally, from 1.25 to 1.28 billion by 2100 (United Nations Population Fund). Water management and infrastructures for agriculture are still lagging behind in many developing countries, making them unfit to rapidly react to an increase in population and food demand. They can resort to increase imports to satisfy national demand, while developed nations with enhanced investment capacities may have the

Figure 9: Predicted Virtual Water exports according to ratio of population rate of increase



ability to increase production, decrease exports and/or increase imports. The strong negative coefficient confirms that relatively higher (lower) population growth pressure will translate into less (more) exports.[16].

Relative Food Purchasing Power Parity

Measures of food price indices help capture the importance of food in the overall consumption basket and take the highest values for the least developed countries. One can expect these high values to stem from insufficient local production, difficult access to a diversified basket of consumption goods and high vulnerability to international price shocks. Our regression shows that the coefficient on the exporter-importer food price purchasing power ratio variable is linear and negative at the 10% significance level, meaning that countries with relatively high food price indices resort to imports.

Gravity controls: contiguity, common colonizer, common language, dis-

[16]The very high ratios of population rate of increase (above 4000) are all attributable to trade flows towards the Czech Republic, whose rate of natural population growth was negative from 1994 to 2005.

tance and RTAs

The gravity controls behave according to expectations in the extant literature on international trade. Indeed, contiguity, common colonizer and common language are all highly significant and positively correlated with food exports.

If the exporting and importing countries are contiguous, exports of food products almost double as they increase by 93.5%. Having been colonized by the same nation will also increases food trade (in our analysis by 25%), which is in line with the results of Head, Mayer and Ries (2010). Sharing a common language increases virtual water exports by 23.2%. As predicted by international trade theories, a 1% increase in distance between the exporting and importing countries decreases virtual water exports by 0.8%. The positive effect of Regional Trade Agreements on food trade flows is also supported by the literature (Martin, Mayer and Thoenig, 2012).

Effect of bilateral and persistent trade of a product
ENLEVER??

Our results show that reconducting trade of a same product from year to year and trading in both directions are strongly and positively correlated with virtual water exports. These variables are utilized to capture any country-pair effects and provide more robustness to our results.

6 Sectoral Analysis

Our model considers panel data of food exports from 1994 to 2007 at the product level, regardless of the sectors. Sub-sampling for sectors is interesting from an operational point of view: countries often specialize vertically, within a sector, because of the many advantages it brings (transaction costs, know-how, seasonal crops, etc.). Sectors are generally historically determined by local conditions and know-how, and thus provide indications as to local management and water practices. For instance, paddy rice requires different types of infrastructures and landscapes then wheat. Turning to a sectoral analysis will allow to capture heterogeneity within the overall economy of food production, and observe comparative advantage and positive production spillovers within the same category of products. The analysis is conducted by sub-sampling our data according to HS2 categories of products, further described in Appendix A.

The model used is the same as the one used previously: the dependent variable is at the product, country-pair and year level but the number of observations per sample is reduced to the number of trade flows belonging to the same sector. Table 3 displays the results of the coefficients for our two main variables of interest, asymmetry in water endowments and in water footprints. The coefficients with a level of significance of at least 10% are in bold.

The results show important inter-sectoral differences in the way they relate to exporter-importer water-land endowments and productivity asymmetries. Trade flows for 12 out of 25 sectors are significantly correlated to water-land asymmetries, while 13 display significant correlation to water footprint differences. In addition, even when we find a significant non-linear relationship with our variables of interest, the squared term is almost always very weak. It is interesting to interpret these results in light of Figures 2 and 3 (% share of sectors in total trade and how sectors contribute to saving water through international trade) because of the underlying hypothesis:

- As seen in Figure 2, the most traded goods are those from the cereal, meat, fat and oil seed sectors. These are among the most water-consuming sectors and we should thus expect these sectors to have a higher sensitivity to available water resources.

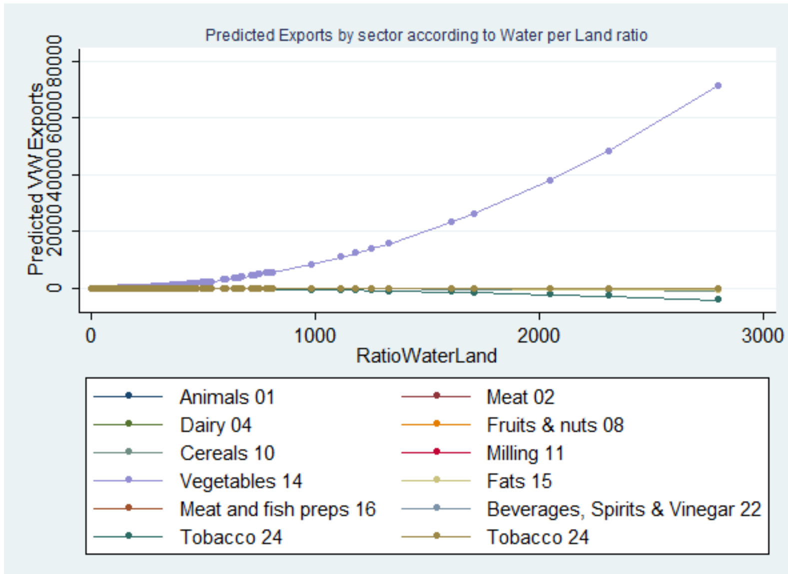
- The most water saving sectors (again cereals, oil seeds and milling) are the ones for which the amount of embedded water exported is lower than what would have been used if the importing country had produced the good locally. As the gap between water efficiency increases, so does the amount of water saved. We should thus expect food exports, for these specific sectors, to be significantly correlated with water footprint asymmetries.

Among the top six traded sectors which represent over 5% of total virtual water trade between 1994 and 2007, around half display significant coefficients for the water endowment asymmetry variable. These sectors are: Cereals (HS2 10), Food residues and waste (HS2 23) and Fats (HS2 15). Fats display a strong positive linear relationship while cereals and food residues and waste display non-linear coefficients, suggesting that food exports behave accordingly with water-land asymmetries up to a certain threshold. On the other hand, virtual water trade flows in the Meat (HS2 02), Oil seeds (HS2 12) and Coffee, Tea and Spices (HS2 09) sectors diverge from those prescribed by our expectations for water productivity. Figure 12 shows predicted exports by sectors according to water endowment asymmetries. The figure only shows the sectors for which the coefficients in table 3 are significant. We can see that the two sharpest slopes are indeed for the Cereal and Food waste sectors while other sectors have a very flat slope as their sensitivity to water per land asymmetry is very weak.

Table 3: Linear regression with two high dimensional fixed effects - Sector analysis

	Variables				
Sectors	Intercept	RatioWL	$(RatioWL)^2$	RatioWFP	$(RatioWFP)^2$
Live Animal 1	10	**0.00296****	**-0.00000204***	-0.141	0.0209
Meat 2	-18	**0.00133***	-0.000000905	0.0190	0.0218
Fish 3	8.5	-0.00180	0.0000165	-0.0952	-0.00334
Dairy 4	17	**0.00177****	**-0.00000114***	**-0.554*****	**0.0275*****
Animal Prod. 5	11	-0.000408	0.00000228*	1.084	-0.219*
Vegetables 7	17	0.00374	-0.0000144	**-0.0467*****	**0.000320*****
Fruits, Nuts 8	8	**-0.00263***	0.00000260	**-0.0555****	0.000483
Coffee, Tea, Spices 9	12	0.0158	-0.000124	**0.0716***	**-0.000997****
Cereals 10	16	**0.0209*****	**-0.000101*****	**-0.224****	0.00716
Milling 11	5	**0.00999***	-0.0000281	**-0.131***	**0.00330***
Oil Seeds 12	7	-0.00195	0.0000198*	-0.0513	0.00329**
Lac, Gums, Resins 13	-19	-0.000924	0.00927*	-0.223	0.193
Veg. Materials 14	16.5	**-0.446***	**0.00927***	0.333	0.0163
Fats 15	4	**0.0279****	-0.0000716	**-0.354*****	**0.00659***
Prep. of meat, fish 16	8	**0.00332*****	-0.00000200	**0.235*****	-0.00747
Sugars 17	13	0.00120	-0.00000628	0.477	-0.0191
Cocoa 18	-19	0.0688	-0.00216	11.89	-1.898
Prep. of Veg. 20	4	0.000464	0.000000193	-0.0260	0.000440
Beverages 22	6.5	**0.00344****	**-0.0000167*****	-0.0658	0.00355
Food Waste 23	16	**0.06*****	**-0.000534*****	**-3.999*****	**0.405*****
Tobacco 24	4	**0.00877*****	**-0.0000171*****	**-0.154***	0.00646
Raw Skins 41	6	0.000143	9.18e-08	**1.085*****	**-0.108*****
Leather 42	5	-0.000470	0.000000535	**3.032*****	**-0.226*****
Cotton 52	7.5	0.0188	-0.0000429	**-0.867***	0.106**
Other Veg. Text. 53	13	-0.00899	-0.00000867	0.199	-0.0140*

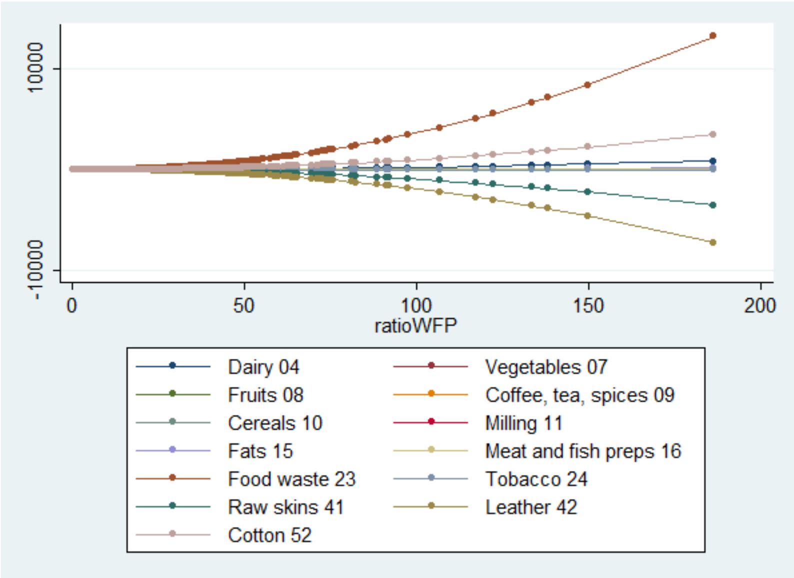
Figure 10: Predicted food exports by sector according to Water per Land ratio



We interpret these differences as resulting from the existence, or the absence, of complimentary production factors to water resources and the persistence of traditional and colonial heritage. Livestock and grazing have traditionally been part of rural activity around the world even in relatively water poor countries while coffee, tea and spice production was largely implemented in former colonies (Columbia and Vietnam for instance) because of favorable climatic conditions. Oil seed production is much more spread out around the world which also explains the absence of a strong correlation between food exports and resource endowment asymmetries. Food residues and Fats require the appropriate processing infrastructures mostly found in developed and relatively water abundant countries. The cereal sector, although an important part of agriculture in many developing and relatively water scarce countries, is largely monopolized by three water rich producers, the USA, Brazil and Argentina. Accounting for over 50% of cereal production in 2007, they are bound to increase the importance of water-land asymmetries within our sample.

Regarding our second variable of interest, even if the quadratic effects are moderately strong, sectors seem to be much more sensitive to water footprint asymmetries. This is shown in figure 13, which displays the predicted food exports by sector according to water footprint asymmetries. The figure only shows the sectors for which the coefficients in table 3 are significant.

Figure 11: Predicted food exports by sector according to Water Footprint ratios



We should expect virtual water exports to be significantly, and negatively, correlated with water footprint asymmetries within the most water-saving sectors. Indeed, water is being saved when an exporter is relatively more water efficient than the importer. As this ratio decreases, more water is saved, hence the likelihood of exports increasing to the extent that countries care about the depletion of their water resources.

This hypothesis is validated for 13 out of 25 sectors, including three among the top four water saving sectors; cereals, milling and dairy. Again, these are sectors for which production is highly dominated by a small number of water rich and water-efficient countries exporting to relatively less water productive nations.

The sectoral analysis is thus interesting because it demonstrates how asymmetries of power translate into agricultural production and trade strategies. For most traded sectors in the world (cereals, meat, fruits, coffee), dominated by a few producing nations, virtual water and food trade offsets the unequal distribution of water resources and inefficient water practices around the world. Regarding the other sectors, production is more spread out geographically, suggesting that the water constraint is supplanted by other types of economic constraints such as technology, capital or qualified labor.

7 Conclusion

Food trade has been argued to be important for understanding why conflict over scarce water resources has not taken place as often as some scholars and practitioners have predicted. Consequently, we investigate the main motivation for virtual water trade by comparing two distinct arguments. The first suggests that countries adopt food production and trade strategies according to their water resource availability. The second argument suggests that trade strategies are determined by the efficiency of water use. Our model includes additional control variables important for understanding trade and food production.

Our results demonstrate that most countries do resort to food trade to alleviate water paucity, although nations described by very high water scarcity persist in being excluded from global food trade. This finding empirically validates earlier theories about virtual water trade and food (Allan, 1991). Our results also validate more recent explanations of virtual water those regarding water productivity. We find that countries that are more productive water users export water intense products to less water productive countries. Yet this relationship is valid only up to a point. We also find a strong non-linear relationship between exporter-importer water footprint ratios and food exports. In other words, relatively less water efficient and less water-endowed nations are exporting to relatively more water-efficient and water-rich countries. While we do not consider the possible social benefits brought upon by such policies, concerns regarding efficiency, the equitable redistribution of cash crops and secure access to food among locals are of relevance.

Our empirical cross-national methodology allows us to identify the nuances of bilateral food trade. Both endowment and productivity seem to motivate trade in water intensive products as less water endowed and productive states import from more water endowed and productive states. This finding is at the heart of understanding why states have averted violent conflict over scarce water resources. That said, our results also suggest that even water poor countries export water intense products. The same can be said for states that are unproductive in their water use. Increasing knowledge about virtual water flows, endowments and productivity should help countries implement more efficient use of their water resources for agricultural, industrial and individual consumption. More recently, Ercin and Hoekstra (2014) constructed four scenarios of water footprint for 2050, arguing that reducing humanity's water footprint is possible, provided that we modify our consumption patterns and through reallocation of food production across regions, according to local comparative advantages. Since most agricultural sectors across the globe are highly subsidized, it seems unfeasible that governments may wish to stop producing basic crops despite low water productivity. Nevertheless, such information can be valuable in order to foster innovation and technology use to increase crop yield and decrease water footprint. It can also help farmers get a better sense of which crops to cultivate.

One of the main challenges remains that of data collection for enhanced computations of water footprint values. Water footprint measurements mainly constitute a mixture of climatic and soil characteristics data (e.g. soil, land, evapotranspiration, temperature, etc.). But productivity is also endogenous to the economic, political and historical strengths of a country and these factors cannot be overlooked when building and implementing sustainable water management policies.

Appendices

A World Customs Organization - HS Nomenclature 2012

- HS01 - Live animals
- HS02 - Meat and edible meat offal
- HS03 - Fish and crustaceans, molluscs and other aquatic invertebrates
- HS04 - Dairy products; birds' eggs; natural honey; edible products of animal origin, not elsewhere specified or included
- HS05 - Products of animal origin, not elsewhere specified or included
- HS07 - Edible vegetables and certain roots and tubers
- HS08 - Edible fruit and nuts; peel of citrus fruit or melons
- HS09 - Coffee, tea, mat and spices
- HS10 - Cereals
- HS11 - Products of the milling industry; malt; starches; inulin; wheat gluten
- HS12 - Oil seeds and oleaginous fruits; miscellaneous grains, seeds and fruit; industrial or medicinal plants; straw and fodder
- HS13 - Lac; gums, resins and other vegetable saps and extracts
- HS14 - Vegetable plaiting materials; vegetable products not elsewhere specified or included
- HS15 - Animal or vegetable fats and oils and their cleavage products; prepared edible fats; animal or vegetable waxes
- HS16 - Preparations of meat, of fish or of crustaceans, molluscs or other aquatic invertebrates
- HS17 - Sugars and sugar confectionery
- HS18 - Cocoa and cocoa preparations
- HS20 - Preparations of vegetables, fruit, nuts or other parts of plants
- HS22 - Beverages, spirits and vinegar
- HS23 - Residues and waste from the food industries; prepared animal fodder
- HS24 - Tobacco and manufactured tobacco substitutes
- HS41 - Raw hides, skins and leather
- HS42 - Articles of leather; saddlery and harness; travel goods, handbags and similar containers; articles of animal gut (other than silk-worm gut)

- HS44 - Wood and articles of wood; wood charcoal
- HS52 - Cotton
- HS53 - Other vegetable textile fibres; paper yarn and woven fabrics of paper yarn

Table 4: Linear regression with two high dimensional fixed effects and no quadratic terms

	(1)		(2)	
	y		y	
RatioWaterLand	-0.00151***	(0.000180)	0.000722***	(0.000155)
ratioWFP	-0.0967***	(0.00560)	-0.0257***	(0.00320)
ratioGDPcap			0.00285	(0.00149)
RatioPriceindex			-1.341***	(0.141)
Bil4			-0.0173	(0.0243)
CropDummy			1.077***	(0.0107)
PopInc			-0.000247***	(0.0000213)
PopInc2			2.96e-08***	(3.79e-09)
contig			0.942***	(0.0159)
comcol			0.252***	(0.0363)
comlang_off			0.283***	(0.0152)
lndist			-0.834***	(0.0112)
rta			0.266***	(0.0200)
N	2007653		1704754	
df_r	578280		487260	

Standard errors in parentheses

Source is here

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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