The water productivity of internationally traded agricultural products

Angela Cheptea, UMR SMART, INRA, Rennes, France
angela.cheptea@inra.fr

Catherine Laroche-Dupraz, UMR SMART, Agrocampus-Ouest, Rennes, France
catherine.laroche@agrocampus-ouest.fr

Selected Paper prepared for presentation at the 2018 Agricultural & Applied Economics Association Annual Meeting, Washington, D.C., August 5-August 7

1. Introduction

The concept of *virtual water*, introduced in the early 1990s, refers to the volume of water used to produce a good or service. It reveals aspects related to production, consumption, and trade in goods overlooked by economic (monetary) indicators. Accordingly, the concept of virtual water was rapidly identified as a potential indicator for guiding policy-makers on issues related to water use, water scarcity, and water management in a world where many countries face important water shortages (Antonelli and Sartori, 2014).

Extensive recent works conducted by agronomists and geographers have quantified the amount of water needed for the production of main agricultural products in different countries of the world (Mekonnen and Hoekstra, 2011a, 2016). The amount of virtual water – the *water footprint* – is measured in terms of in cubic meters of water used per kg of produced good (m^3/kg). These works separate the *green water*, that corresponds to the rainfall necessary for the production of the good, from the *blue water*, that corresponds to the irrigation water brought in surplus on farming plots. Mekonnen and Hoekstra (2011a, 2011b, 2016) computed the water footprint in terms of both green water and blue water for different agricultural products in different countries and regions of the world. Their database provides the average annual water footprint values over the 1996-2005 period for 207 countries and territories and 353 agricultural products.

The concept of virtual water is closely associated with international trade. Exporting an agricultural product can be interpreted as exporting the water footprint embedded in that product. Adopting this perspective led to the emergence of the concept of *virtual water trade.* According to Hoekstra et al. (2011), the virtual water trade flow between two geographical entities corresponds to the volume of virtual water that is being transferred as a result of product trade. Following this definition, virtual water trade can be easily computed by combining data on water footprints with data on international trade in agricultural products expressed in physical quantities. For the exporting country, the virtual water trade is the water volume used to produce the exported good, multiplied by the exported quantity. For the importing country, the virtual water trade represents the water volume saved by choosing to import the good instead of producing it domestically. The transition from real water to virtual water is linked to the international trade flow of a good from the exporting country to the importing country. Antonelli and Sartori (2014), Debaere (2014) and Gilmont (2015) computed the overall profile of countries as net exporters or importers in terms of virtual water. These studies reveal inconsistencies between virtual water trade and available water resources in net exporting countries, in contradiction with theories of international trade. This questions the efficiency of water management not only at country level, but also on a global scale.

For instance, Gilmont (2015) focuses on the agricultural imports of North African and Middle East countries and concludes that increasing the imports of certain food products and concentrating domestic production on crops well adapted to the aridity of their climate would permit these countries to optimize the use of their limited water resources. Virtual water is used here to analyze countries' strategies in terms of adjusting (structuring) their imports to their water endowments and food security objectives.

On the other hand, standard international trade models incorporate traditional factors of production such as capital, labor and land, but do not take into account the countries' water endowments. A commonly invoked argument in the literature is that the markets for water are thin or lacking (Antonelli and Satori 2014, Debaere, 2014). Therefore, the economic value of the water used in agricultural production is rarely addressed in the literature. An exception to this trend is the recent work by Afkhami et al. (2018), who combine the water (matched with arable land) and capital (both human and physical) in a Heckscher-Ohlin model and show that water-scarce developing countries may specialize in water-intensive crops because they lack capital to specialize in non-agricultural sectors.

In the present paper, we focus on the agricultural sector and investigate how countries valuate virtual water through the exports of agricultural products. More specifically, we question whether the choice of crops irrigated in a country depends on the expected revenue from exporting these crops. By answering this question we provide elements for the broader issue of the link between the use of water resources in agriculture and the market value of produced agricultural goods.

To answers to this question, we use a classical theoretical international trade setting. Water is an essential factor for the production of exported agricultural goods, but not the only production factor: water is combined with labor, seeds, inputs (fertilizers, pesticides, energy, etc.), on arable land. However, our analysis focuses on the water factor alone. We test the extent to which the use of this production factor (water) is the result of a trade-off based on the revenues generated by its use to produce different agricultural commodities, relying on international and inter-product comparisons.

2. The economic productivity of blue water

To examine how the water used for agricultural production can be valuated, exploited via international trade, one can introduce water as a production factor in a classical trade model based on factor endowments (Heckscher-Ohlin). This model suggests that countries with large water endowments should specialize in water-intensive agricultural products, while countries facing water scarcity should specialize in products adapted to arid climates and import water-intensive commodities. However, previous studies provide many examples of countries that deviate from this line of reasoning (Antonelli and Sartori, 2014; Debaere, 2014; Gilmont, 2015). Thus, the water-scarce Jordan and Morocco are major exporters of tomatoes, a water-intensive agricultural product. Similarly, cotton – another water-intensive agricultural commodity – accounts for a large share of the exports revenues of arid Central Asian countries. All these specializations arise due to an intensive use irrigation. Since irrigation is costly, countries should privilege irrigating crops with a higher expected revenue, i.e. agricultural goods that can be sold at a higher price on international markets. An empirical confirmation of this statement would indicate that producers internalize the irrigation cost. On the contrary, the rejection of a positive link between the decision to irrigate and the export price of agricultural goods would point to the fact that agricultural producers consider irrigation as a complementary public good.

Since water is an indispensable production factor in agriculture, farmers are more likely to choose to produce water-intensive commodities in water-abundant rather than in water-scarce regions. However, at the local level, producers cannot choose the areas that will benefit from a higher rainfall. Rainwater falls naturally; it is a natural resource that cannot be purchased, acquired. The same is not true for irrigation water, which requires the use of adapted equipment and, therefore, has a cost for the producer (farmer). Hence, it is safe to assume that producers who invested in irrigation equipment and infrastructure face a trade-off regarding which crops to irrigate, and that their decision is based on the opportunity cost of irrigating one crop rather than another, which depends on the expected revenues from selling each crop in the market.

We define the water productivity (*WP*) the quantity of crop expressed in kilograms that can be produced with one cubic meter of water. Water productivity is expressed in kg/m3. The water productivity of a crop is equal to the inverse of its water footprint (*WF*), i.e. the inverse of the amount of virtual water associated to that crop: $WP = 1 / WF$. We seek to characterize, explain the productivity of irrigation (blue) water, i.e. the amount of water intentionally used by producers to irrigate the property.

For a given agricultural commodity, the productivity of blue water most likely increases with the abundance of rainwater. Indeed, an agricultural commodity naturally requires less irrigation in a water-abundant country than in a water-scarce country. Therefore, we expect the blue water productivity of an agricultural good to be positively correlated with the country's rainfall. At the same time, water-intensive crops need to more irrigation than crops adapted to arid regions. The green water footprint is a good indicator of how water-intensive is a crop. Accordingly, the blue water productivity of an agricultural good should be positively correlated with the green water productivity of that good. Other factors influence as well the productivity of blue water. The quality of the irrigation system, the qualification of producers that use irrigation, and water losses (due to leakage, spills or contamination) affect the efficiency of irrigation. The current paper tests the hypothesis that on top of these physical aspects, irrigation also depends on the economic behavior of producers of internationally traded agricultural goods. We assume that producers with irrigation equipment choose which crops to irrigate based on the revenues from exporting these crops. More specifically, we test how the productivity of blue (irrigation) water depends on the price at which producers can sell their irrigated crops in the international market.

Theoretically, the maximization of profits obtained from exporting an agricultural good k at unit price p_k consists in maximizing export revenues less variable costs. We consider agricultural goods as processed blue water products. In other words, we assume all other production factors as constant (as numeraire) and focus solely on the choice of which agricultural goods to irrigate. Profit maximization leads to the first order condition according to which the marginal cost of using an additional unit (1 m^3) of blue water should be equal to the marginal productivity of this water unit (in terms of kg of the produced agricultural good). We then define the economic productivity of blue (irrigation) water of a good, *BlueWPEcon*, as the monetary valuation of this good's blue water productivity at the export price: $BlueWPEcon_k = p_k \times BlueWP_k. = p_k / BlueWF_k$. Accordingly, *BlueWPEcon* is expressed in US dollars of exports per m^3 of irrigation water. The economic productivity of irrigation water of a crop increases with the export price of the irrigated crop and decreases with its blue water footprint.

$BlueWPEcon_k$ broadly corresponds to the willingness-to-pay of agricultural producers for one cubic meter of irrigation water in order to produce good *k*. If the market for irrigation water were efficient, the economic productivity of water should converge across crops produced within the same country, and across countries with a similar level of rainfall producing the same crop. If, on the contrary, this variable strongly diverges between the different crops produced in a country, or internationally between countries producing the same crop, one can conclude that the costs of using irrigation water are disconnected from the expected revenues associated with the use of irrigation, and are driven by other factors.

3. Data for the empirical analysis

In this paper, we focus on irrigation water (blue water) because it results from a prior decision taken by farmers to build and maintain an irrigation infrastructure, to choose which the products to irrigate and how much. On the opposite, farmers have no say on the amount of rainfall (green water) used by their crops. Since most countries in the world irrigate some crops, our focus on irrigation water does not hamper the generalization of the results we obtain.

We use the water footprint data computed by Mekonnen and Hoekstra (2011a, 2016), and available at http://waterfootprint.org/en/resources/waterstat/. This database provides information on the average annual blue and green water footprints for 353 agricultural products in 207 countries and territories, over the 1996-2005 period. Blue water footprints provide information on how intensively each agricultural product is irrigated in each country (in terms of m^3 of irrigation water per kg of product). Although farmers might also decide how extensively to irrigate each product (the size of irrigated farming plots),[1] irrigation requires an adapted infrastructure that cannot be rapidly extended or relocated. We consider countries' irrigation infrastructures, and accordingly the size of irrigated farming plots, as constant. This is a reasonable assumption for a data panel spanning across only ten years. Under these conditions, farmers decide only which products to farm on irrigated plots.

[1] To our knowledge, there is no database collecting statistical data on the size of irrigated farming plots by product and country.

We use the export price (unit value) as a proxy for the market value of that product. We prefer this value to the domestic price for two reasons. First, unlike domestic prices that can be strongly distorted by agricultural policies (e.g. subsidies, quotas) or the size of demand, export prices reflect more accurately the market value of a product. Second, export prices can be computed at same level product disaggregation as water footprint data (6-digit of the HS classification). Domestic prices are usually collected at a different (more broader) level of product definition. We use the BACI trade database and compute the export unit value as the ratio between the monetary value of exports and the amount of traded products in physical units (tons). Since BACI trade data are in FOB terms, export unit values are not inflated by trade costs (e.g. products are shipped to more remote markets, require special transportation and storage facilities due to a high perishability, face high import tariffs). We observe a high variation of unit values across destinations, for a given exporting country and good. To obtain country-specific unit values for each product, we take the median unit value across destinations.

Water footprint data does not vary across time: these data are provided only as annual averages computed over the 1996-2005. We match water footprint data with export unit values within the same period. To reduce the correlation between present and past unit values and insignificant changes in export prices, we consider data at five-year intervals, i.e. covering only years 1997, 2001, and 2005.

We acknowledge that processed agricultural goods exported by a country can be obtained from domestic or imported unprocessed goods (e.g. pasta from wheat). This information is generally unavailable in trade data. Water footprints are computed assuming that solely domestic inputs where used in the production process. To reconcile this difference between the two data bases, we restrict our sample to unprocessed goods. We end up with a data panel covering 183 countries and 159 products (6-digit HS codes).

Additional control variables that may affect the economic productivity of irrigation water are obtained from the World Development Indicators database of the World Bank. The average value of annual precipitations (in mm) reflects the country's level of water abundancy. Water-scarce countries are identified by a lower level of precipitations. The share of agriculture in a country's total water use (in %) indicates the level of water pressure faced by the country's agricultural sector. Finally, we use the per capita GDP (in current USD) as a proxy for the cost of irrigation equipment (initial investment and maintenance). Data on the share of water resources used in agriculture and annual precipitations are missing for a large number of years (different years for different countries), but depict insignificant variations across time. We fill in the missing data with country-level averages computed on observed data.

Table 1 summarizes the descriptive statistics for variables in our data panel.

Table 1 Descriptive Statistics

Variable	Unit	Nb obs	Mean	Std. Dev.	Min	Max
Blue Water Footprint	m^3/kg	14,366	819.71	3,721.85	0	150,204
Green Water Footprint	m^3/kg	14,366	2,765.08	6,662.30	4	257,913
Export price (unit value)	USD/ton	14,323	203.18	9,983.86	.0027	1,121,092
World average export price	USD/ton	14,366	144.65	686.97	.2279	1,4295.34
Water use in agriculture	%	12,324	59.81	29.64	.2081	99.59
Precipitation (rainfall)	mm	14,363	972.72	683.44	51	3240
Per capita GDP	USD	14,270	8,619.53	11,693.51	117.41	66,775.38

4. Main estimation results

In this section we use empirical data to answer the following question: Does the price at which products can be sold in the international market influence countries' decision regarding which product(s) to irrigate?

We estimate the following empirical model, where the blue water footprint for agricultural good k in country i is explained by the export price of this product:

$$BlueWF_{ik} = f(p_{ikt}; P_{kt}; GreenWF_{ik}) \quad (1)$$

We distinguish between the country-specific export price of product k, p_{ikt}, and its average price on international markets, P_{kt}, and control for how water-intensive is good k in country i , that is reflected in the green water footprint, $GreenWF_{ik}$. Subscript t denotes annual dimension of the data.

Results from estimating equation (1) are reported in column (1) of Table 2. We find a positive and significant coefficient for the global price of the irrigated product and a small negative coefficient for the country-specific export price. These results indicate that countries base their decision to irrigate on the price at which products can be sold on the global market, but they fail to channel products to the markets paying the highest price. These findings are consistent with general assumption of international trade models. Producers base their decisions on anticipated prices, reflected by global prices in our model, without knowing the actual price at which they will be able to sell their products on international markets, i.e. the country-specific export price in our model.

The decision on which crops to irrigate may be driven by country- or product-specific controls that were omitted by our model. To check whether these factors may bias our results, we estimate equation (1) with product and country fixed effects, used separately and jointly. We report obtained results in columns (2) to (4) of Table 2. All estimated effects remain statistically significant and change only slightly in magnitude. The robustness of our results is not affected even when we use time-varying country and product effects (see Table A1 of the Appendix). In this case, some of the explanatory variables drop due to collinearity with fixed effects.

To understand how irrigation depends on different country-specific characteristics, we estimate a version of equation (1) augmented with additional country-specific controls. The fair correlation of these control variables and with the explanatory variables of equation (1) permits to include them separately or simultaneously (see Table A2 of the Appendix). Table 3 displays the estimation results. The magnitude of coefficients is directly linked to the measurement unit of each variable and, therefore, does not indicate a higher or lower impact on irrigation. We resume below our findings.

Countries that channel a larger share of their water resources to agriculture irrigate more intensively. These countries rely more heavily on agricultural resources and try to increase the productivity of their crops through irrigation. Water-abundant countries (with higher levels of annual precipitations) irrigate less. This confirms our expectation that irrigation is less necessary in areas with natural water abundancy. We also find that richer countries (with a higher per capita GDP) irrigate more. This result confirms that irrigation is a costly activity and not all countries can afford to build and maintain an extensive irrigation system. This result is not driven by the fact the water intensity of irrigated crops, captured by the green water footprint. Note that adding these controls does not affect the significance and magnitude of export price effects. The per capita GDP can also be regarded as a proxy for the average price of goods exported by a country. Indeed, richer countries tend to export more expensive goods, embedding higher technologies, higher quality inputs, and more highly remunerated labor. The export price effects remain unchanged in specifications with per capita GDP. Therefore, we also conclude that export price effects identified in Tables 2 and 3 do not reflect countries' specializations in more expensive or less expensive products. We also found that countries that irrigate a larger share of their agricultural lands also irrigate more intensively, but this result is less robust.[2]

Table 2: The decision to irrigate and the export price

	Explained variable : Blue (irrigated) Water Footprint			
	(1)	(2)	(3)	(4)
Export Price	-0.0062**	-0.0060**	-0.0062**	-0.0059**
	(0.0027)	(0.0025)	(0.0025)	(0.0024)
World Average Export Price	0.2937***	0.3077***	0.3288***	0.3095***
	(0.0399)	(0.0433)	(0.0366)	(0.0408)
Green Water Footprint	0.2790***	0.3219***	0.3308***	0.3633***
	(0.0040)	(0.0053)	(0.0041)	(0.0052)
Number of observations	14,232	14,232	14,232	14,231
Fixed efects	-	product	country	product country
R^2	0.252	0.365	0.383	0.471
F-test	1608.849	1252.956	2229.541	1622.614

Notes: Standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5%, 10%.

[2] Results from these estimations can be provided upon request.

Table 3: The decision to irrigate and the export price, additional controls

	Explained variable : Blue (irrigated) Water Footprint							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Export price	-0.0060**	-0.0066**	-0.0047*	-0.0060**	-0.0052**	-0.0065**	-0.0047*	-0.0052**
	(0.0025)	(0.0027)	(0.0025)	(0.0025)	(0.0026)	(0.0027)	(0.0025)	(0.0026)
World average export price	0.3077***	0.3228***	0.3048***	0.3069***	0.3208***	0.3244***	0.3043***	0.3227***
	(0.0443)	(0.0483)	(0.0436)	(0.0444)	(0.0476)	(0.0484)	(0.0437)	(0.0476)
Green Water Footprint	0.3219***	0.3400***	0.3291***	0.3266***	0.3519***	0.3484***	0.3334***	0.3597***
	(0.0053)	(0.0058)	(0.0053)	(0.0053)	(0.0058)	(0.0058)	(0.0053)	(0.0058)
Share of agriculture in country's water use		13.9615***			11.6036***	17.6957***		15.4003***
		(1.0306)			(1.0218)	(1.1474)		(1.1369)
Precipitation (rainfall)			-0.8298***		-0.9116***		-0.8122***	-0.8896***
			(0.0386)		(0.0466)		(0.0386)	(0.0466)
Per capita GDP				0.0023		0.0202***	0.0025	0.0202***
				(0.0022)		(0.0027)	(0.0022)	(0.0026)
Number of observations	14,323	12,289	14,320	14,227	12,289	12,193	14,224	12,193
R^2	0.365	0.392	0.386	0.369	0.410	0.399	0.389	0.416
F-test	1252.956	918.324	1047.551	961.800	834.418	765.836	850.706	718.184

Notes: All estimations include product-specific fixed effects. Standard errors in parentheses. ***, ** and * indicate statistical significance at 1%, 5%, and 10%.

The small negative effect of the country-specific export price in Tables 2 and 4 comes from observations corresponding to export prices that highly exceed the world average price. When for each product, we exclude observations corresponding to the lowest 2.5% and highest 2.5% of country-specific export prices, the effect of this variable becomes strongly positive and the effect of the world average price loses in significance. [3]

5. Strong and weak price effects

In this section we investigate the link between irrigation and export price for specific groups of products. Figure 1 illustrates the correlation between blue (irrigation) water footprints and export unit values in the United States, for unprocessed crops for which the country is a net exporter. The strong positive correlation between these variables is driven to large degree by nuts, products that are highly irrigated and heavily exported. The decision of American nut producers to intensively irrigate appears to be directly linked to the high export price of nuts on international markets. The case of almonds is particularly interesting. Almonds stand out with the highest irrigation rate (4,000 m3 per kg), the United States being the main exporter of almonds (accounting for 88% of world exports in 2017 according to USDA, 2017). However, the irrigation of almonds and other nuts induces a high constraint for the irrigation of other cultivated crops and generates major water-scarcities at the regional level. Tensions on the use of irrigation were particularly high in California, a state affected by successive severe drought over the last decade. Differently, for cereals the correlation between irrigation and export price is very small, and reflected in Figure 1 by an almost vertical line. Cereals are irrigated despite their relatively low export price per ton with respect to other crops. This observation is consistent with the assumption that the production of cereals is induced primarily by domestic demand, and only excess production is sold on international markets and is subject to export speculations. Indeed, cereals are the main product group subject to export restrictions worldwide, mainly for securing domestic supply and food security reasons (Mendez-Parra et al., 2016). The link between the blue water footprint and the export price level is less obvious in the case of other crops.

Next, we test two additional hypotheses regarding the link between export price and countries irrigation behavior:

(i) The link should be stronger when countries are net exporters.

(ii) The link should be weaker for commodities essential for meeting domestic food security objectives, such as cereals.

Hypothesis (i) relies on the following reasoning. Producers of crops for which domestic production does not meet domestic demand (for which the country appears as a net importer) base their production decisions mainly on domestic market evolutions and are less attracted by export opportunities, which involve complex international transactions. On the contrary, producers of crops for which domestic production exceeds domestic demand are more sensitive

[3] Results from these estimations can be provided upon request.

to the evolution of global demand and more prepared to engage into export operations. To test hypothesis (i), we check how price effects identified in Tables 2 and 3 change when we limit the sample to observations where countries are net exporters (Table 4). We find that the positive global price effect doubles, while the negative country-specific price effect become less significant.[4] We interpret this as a confirmation of our hypothesis (i).

To test hypothesis (ii), we estimate model (1) for the cereals (Table 5). Cereals are farmed by a large number of countries with very different climate and water endowments, and are largely traded internationally. Moreover, cereals constitute staple food worldwide. Most countries cultivate cereals to ensure their domestic food security. In the case of cereals, food security challenges the objective related to their economic valuation via international trade. In addition, the global markets for cereals are highly integrated, with the bulk of international transactions relying on reference prices published daily for the main cereal products. Compared to other crops, cereals are easily stored and transported. Due to their lower perishability, producers can afford to postpone export if the market price is judged to low. There are fifteen cereals in our data panel. We find non-significant price effects when we estimate the model on these products. This validates our hypothesis (ii).

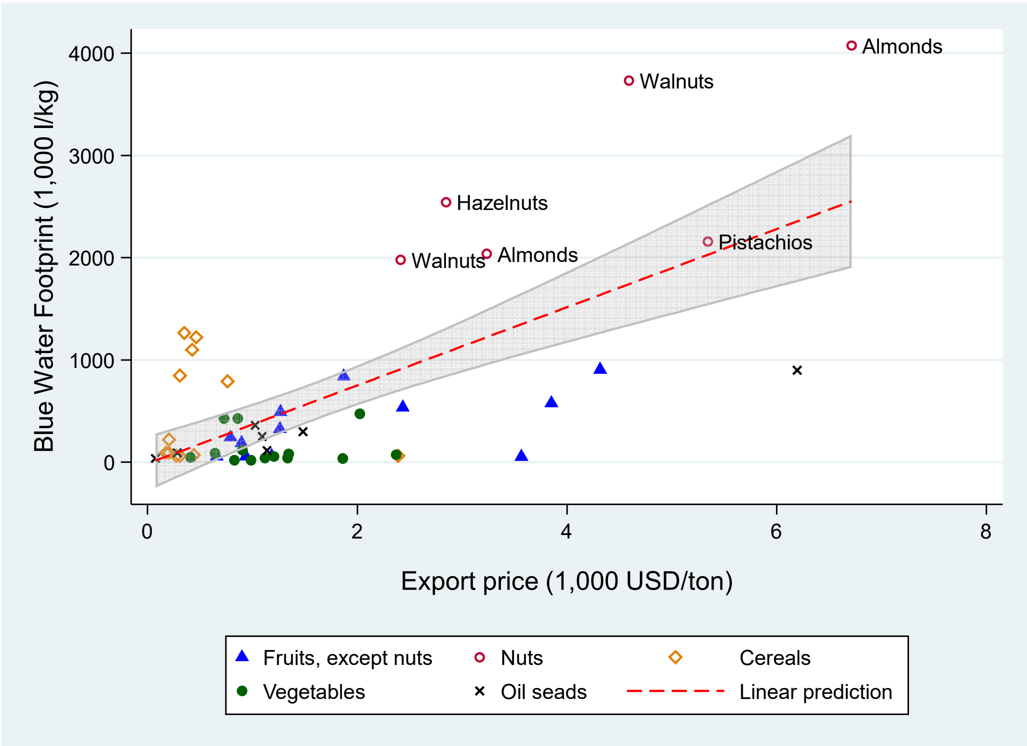

Figure 1: Blue (irrigation) water footprints vs. export prices in the U.S.

Notes: median export price in 2005, blue water footprints annual averages over 1996-2005, all products within HS chapters 7-12 for which the country was a net exporter.

[4] The variable trade balance has a statistically non-significant effect. These results are not reported in the paper, but can be provided upon request.

Table 4: The decision to irrigate and the export price: net exports

	Explained variable : Blue (irrigated) Water Footprint			
	(1)	(2)	(3)	(4)
Export Price	-0.0171***	-0.0041	-0.0196***	-0.0114*
	(0.0078)	(0.0072)	(0.0069)	(0.0064)
World Average Export Price	0.6194***	0.6103***	0.6400***	0.5852***
	(0.0560)	(0.0631)	(0.0492)	(0.0560)
Green Water Footprint	0.2849***	0.3480***	0.3588***	0.4042***
	(0.0045)	(0.0058)	(0.0045)	(0.0057)
Number of observations	8,033	8,033	8,033	8,026
Fixed efects	-	product	country	product country
R^2	0.345	0.482	0.510	0.601
F-test	1411.625	1237.721	2226.459	1694.173

Notes: Standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5%, 10%.

Table 5: The decision to irrigate and the export price: cereals

	Explained variable : Blue (irrigated) Water Footprint			
	(1)	(2)	(3)	(4)
Export Price	-0.0079	-0.0109	0.0021	0.0002
	(0.0107)	(0.0102)	(0.0080)	(0.0068)
World Average Export Price	-0.0170	-0.0074	-0.0235	0.0043
	(0.0327)	(0.0366)	(0.0233)	(0.0229)
Green Water Footprint	0.1122***	0.1019***	0.1398***	0.2035***
	(0.0152)	(0.0153)	(0.0162)	(0.0160)
Number of observations	1,923	1,923	1,923	1,913
Fixed efects	-	product	country	product country
R^2	0.028	0.113	0.557	0.686
F-test	18.592	15.224	25.122	54.172

Notes: Standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5%, 10%.

6. Conclusion

We build on previous works on water footprints and virtual water trade to evaluate the average economic productivity in value of water in the agri-food sector. We integrate the issue of virtual water into an international trade model where agricultural products are processed products of traditional production factors (land, labor, capital) and water. We investigate whether the use of irrigation water in farming is linked to the economic value of produced agricultural goods.

We test this relation empirically using data on 159 irrigated crops exported by 183 countries. We find that countries irrigation behavior is strongly linked to the global price of crops. This indicates that agricultural producers internalize the price of irrigation water when choosing which crops to irrigate. Results remain unchanged when we add time invariant or time-varying product- and country-specific controls and fixed effects. The export price effect is stronger when countries are net exporters of irrigated crops and weaker for internationally traded crops for which there are globally used reference prices and constitute a pillar of most countries' domestic food security, such as cereals.

Our analysis relies on average annual water footprints from Mekonnen and Hoekstra (2011a, 2016) computed over a decade. This limits the validity of our results with respect to time variations. Ideally, we would need to use annual water footprints and explain countries' irrigation decisions by export prices observed in the past (with a one year lag). This calls for an extension of the present analysis using fully time-varying data.

As an additional extension of the current analysis, we can test the validity of our arguments by zooming on a specific crop, and exploring data variation across the different regions of the same country. Indeed, Mekonnen and Hoekstra (2011a, 2016) report blue and green water footprints at the sub-national level for a large number of crops. We need to match these data with corresponding regional data on trade, climate, rainfall and water use from different sources and available only for small number of countries.

Bibliography

Afkhami, M., T. Bassetti, H. Ghoddusi and F. Pavesi (2018) Virtual Water Trade: The Implications of Capital Scarcity. Working Paper 2018-3, Department of Economics, University of Verona, https://ssrn.com/abstract=3166874.

Antonelli, M. and M. Sartori (2014), Unfolding the potential of the Virtual Water concept. What is still under debate? MPRA Paper No. 60501.

Debaere, P. (2014) The Global Economics of Water: Is Water a Source of Comparative Advantage? *American Journal of Agricultural Economics*, 6(2), 32-48.

Gilmont M. (2015), Water resource decoupling in the MENA through food trade as a mechanism for circumventing national water scarcity, *Food Security*, 7, 1113-1131.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011) – "The Water Footprint Assessment Manual: Setting the Global Standard", Earthscan, London, UK.

Mekonnen, M. M. and Hoekstra, A.Y. (2011a) The green, blue and grey water footprint of crops and derived crop products, *Hydrology and Earth System Sciences*, 15(5): 1577-1600

Mekonnen, M.M. and Hoekstra, A.Y. (2011b) National water footprint accounts: the green, blue and grey water footprint of production and consumption, Value of Water Research Report Series No. 50, UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M. M. and Hoekstra A. Y. (2016), Four billion people facing severe water scarcity, *ScienceAdvances,* 2, http://advances.sciencemag.org/.

United States Department of Agriculture (USDA), Foreign Agricultural Service (2017) Tree Nuts: World Markets and Trade, https://apps.fas.usda.gov/psdonline/circulars/TreeNuts.pdf

Mendez-Parra, M., Schubert and S. R., Brutschin, E. (2016) Export taxes and other restrictions on raw materials and their limitation through free trade agreements: Impact on developing countries, Study for the European Parliament, Directorate-General for External Policies. http://www.europarl.europa.eu/RegData/etudes/STUD/2016/534997/EXPO_STU(2016)534997_EN.pdf.

Appendix

Table A1: Irrigation and the export price with time-varying controls

	Explained variable : Blue (irrigated) Water Footprint			
	(1)	(2)	(3)	(4)
Export Price	-0.0062**	-0.0070**	-0.0063**	-0.0070**
	(0.0027)	(0.0026)	(0.0026)	(0.0024)
World Average Export Price	0.3026***		0.3317***	
	(0.0402)		(0.0373)	
Green Water Footprint	0.2790***	0.3225***	0.3321***	0.3664***
	(0.0040)	(0.0053)	(0.0041)	(0.0053)
Number of observations	14,232	14,232	14,232	14,284
Fixed efects	year	product×year	country×year	product×year country×year
R^2	0.252	0.373	0.390	0.484
F-test	1610.012	1832.960	2205.129	1576.857

Notes: Standard errors in parentheses. ***, **, * indicate statistical significance at 1%, 5%, 10%.

Table A2: Correlation coefficients

	Variable	1	2	3	4	5	6	7
1	Blue Water Footprint	1.0000						
2	Green Water Footprint	0.5190	1.0000					
3	Export price (unit value)	-0.0012	0.0116	1.0000				
4	World average export price	0.0589	0.0109	0.1866	1.0000			
5	Water use in agriculture	0.1291	0.0446	0.0090	-0.0031	1.0000		
6	Precipitation (rainfall)	-0.1016	0.1212	0.0248	0.0089	-0.0604	1.0000	
7	Per capita GDP	0.0558	-0.1199	-0.0111	-0.0167	-0.4845	0.0149	1.0000