CHAPTER 8

Economic aspects of virtual water trade: Lessons from the Spanish case

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ABSTRACT: Virtual water is the volume of water that is used in the production process of a commodity (Allan, 2003). Agricultural trade is by far the largest vehicle to move water virtually around the world. The effects of water scarcity in many countries and regions can be reduced through open farm trade and specialization. Many world countries are now suffering water shortages and expect worsening conditions in the future due to climate change, economic development and food demand increases. We first review a number of key facts about world water scarcity and reflect on the role of virtual water trade. Observing that most countries import and export water embedded in the exchanged products, we review the example of our evaluation of water *trade* in Spain for the period 1997–2006. We differentiate between the green (soil water) and blue (surface water and/or groundwater) components of virtual water from a hydrological and economic perspective. The combination of spatial and time dimensions offers a unique empirical setting to determine whether virtual water *trade* can contribute to reduce water scarcity. The study reveals that Spain is a net and increasing *importer* of virtual water. By far the largest virtual water *imports* are linked to cereals and animal feed products whilst the virtual water *exports* are linked to exports of animal products, fruits and vegetables. Virtual water *trade* is one way to reduce the vulnerability of the agri-food sector to climate instability. It reinforces the competitive advantages of its natural endowments and capital investments in agriculture. The econometric analysis using provincial water exports for 10-years shows that water exports are invariable to cyclical water scarcity, and largely explained by fixed factors. Virtual water *trade* does not exacerbate water scarcity, though it is certainly a source of pressure for resource management. Adequate water pricing would make virtual water trade more efficient.

Keywords: virtual water trade, Spain, food production, agricultural trade

1 INTRODUCTION

Trading water virtually is a means to cope with water scarcity, but no trading partner exchanges goods based on the embedded quantity of a resource that is not properly priced. While labor, capital and other inputs have formal and tangible prices, water does not. This implies that virtual water trade occurs as an underlying process that is generally connected to differences in natural endowments and competitive advantage for food production, filtered out or influenced by commercial agreements, but not directly linked to the level of water scarcity or stress of the trading partners.

And yet, global trade establishes an *invisible* and indirect link between water demand and water consumption sites. The literature on virtual water *trade* has emphasized the options available to arid and semiarid countries to use international trade to deal with water resources scarcity (Allan, 2003; Chapagain *et al*., 2006; CAWMA: Comprehensive Assessment of Water Management in Agriculture, 2007; Yang & Zehnder, 2007; Aldaya *et al*., 2008; Novo *et al*., 2009; Garrido *et al*., 2010). However, determining whether this strategy is economically and environmentally efficient will depend on whether the real opportunity cost of water resources is properly internalized, and whether the trade is actually based on differences in competitive advantage among trading partners. It is also doubtful that virtual water *trade* should be termed a *strategy*, because up to now no government has been documented to pursue it directly. Rather, it is a process that is naturally linked to the trade and exchange of goods, with the main exception of arid and semi-arid countries in the Middle East and North Africa (MENA) region.

Since water is a limiting resource for many food importing countries, in most cases the observed patterns of trade are more consistent with relative differences of production costs, and highly dependent on trade regimes. Relative levels of water scarcity among trading partners do not seem to be an important explanatory factor. While global benefits can be associated with virtual water trade (Hoekstra & Chapagain, 2008; Garrido *et al*., 2010), there are pitfalls in pursuing the idea to its most extreme format, which is to import virtually water *and* land. Furthermore, many countries engage in two-way flows of trade (Spain imports mainly cereals and feed and exports oranges, grapes, wine, etc.). While one can trace back the region or basin from which virtual water exports originate, it is almost impossible to record the imports and assign them to specific geographical zones.

Up until recently, virtual water *trade* was primarily an unintended consequence of farm commodities trade. When countries have deliberately sought to *import* water, very soon they have seen the advantages to *import* land and natural endowments as well. Recent massive land purchases in Africa through state negotiations are the genuine expression of virtual *trade* of natural resources. The ethical consequences of these exchanges have not been yet thought out in detail. Purchasing states provide capital, technology and know-how, land selling states offer abundant land and water in exchange for hard currency or some other compensation. It has been reported that between 15 and 20 million hectares of African farmland have been sold to food-importing or water-scarce countries, China leading the group.

Another potentially damaging effect of virtual water *trade* is the specialization of water *exporters* in goods that are water-intensive. This can exacerbate water scarcity for domestic users, and increase the price of food for the poorest. Ensuring food self-sufficiency was seen as an objective of massive costs for an importing country, but the costly reliance on international food markets has revisited the concept of self-sufficiency and the value of food sovereignty. Furthermore, pressures to develop water works so that more crops can be produced for the importing countries may bring the scarcity pressure to adjacent basins or catchments, from which water resources can be transferred. Foreign food demand may become thus an indirect source of pressure for exporting countries.

Underlying the ethical and political dimensions of land-purchases, there are clear and unambiguous economic signs of the gains from trade and the efficiencies that can be achieved by expanding the capital base of many African agricultural areas. As von Braun & Meinzen-Dick (2009: 4) state: “Foreign investment can provide key resources for agriculture, including development of needed infrastructure and expansion of livelihood options for local people”. In a very different vain, Peter Brabeck-Letmathe, President of Nestlé, stated: “The purchases weren’t about land, but water … they should be called the great water-grab” (The Economist, 2009). But at the same time, it may be a consequence of the repeated failure of industrialized countries to help African countries get away from their undeveloped situation.

In this chapter, we analyze the economic implications of virtual water *trade* with a double objective. On the one hand, we summarize the findings from a more extensive work carried out by Garrido *et al*. (2010), in which economic evaluations of *exported/imported* water of Spain were performed. On the other hand, we take the case of Spain to reflect on the economic meaning of the predictions of worldwide water scarcity, and its implications for food global demand and production.

We first review the major criticisms and reflections on virtual water *trade*, then synthesize the most recent literature on water scarcity and food demand worldwide. In the fourth section we review the Spanish virtual *trade*, summarizing and extending the main conclusions of Garrido *et al*. (2010). The fifth section highlights the main conclusions.

2 MAJOR ECONOMIC CRITICISMS ABOUT VIRTUAL WATER TRADE

International virtual water *trade* can be evaluated in terms of comparative advantage (first explicitly formulated by the British economist David Ricardo) (Rosegrant *et al.*, 2002), and the fact that natural resources are unevenly distributed over space and time. It is claimed that nations can profit from trading if they concentrate on, or specialize in, the production of goods and services for which they have a comparative advantage, while importing goods and services for which they have a comparative disadvantage.

Whether international trade actually helps alleviate global water stress is still an issue that has not been settled in the literature (Falkenmark & Rockström, in press; Hoff *et al.*, in press). Nevertheless, an increasing number of authors recognize this role (Aldaya *et al.*, 2008; Comprehensive Assessment of Water Management in Agriculture, 2007). Worldwide global water savings as a result of trade is estimated to have reached 450 km^3/yr (Oki & Kanae, 2004; Hoekstra & Chapagain, 2008). Most of these savings come in the form of international trade of cereals, protein crops and oil crops (Hoekstra & Chapagain, 2008).

Several conceptual and practical problems about virtual water *trade* remain relevant. Some of these are:

- Green and blue water components are crucial to determine whether observed exchanges contribute to a sustainable world economy.
- The virtual water metaphor addresses resource endowments but not production technologies. Hence, the metaphor does not include the concept of comparative advantage (Wichelns, 2004).
- Political and economic considerations often outweigh water scarcity concerns, limiting the potential of trade as a policy tool to mitigate water scarcity (Fraiture *et al.*, 2004). Very little of the calculated virtual water *trade* is due to water scarcity.
- Other factors, like land, nitrogen, phosphorous and potassium, should be added to water scarcity measurements.
- Emphasizing virtual water *imports* is not a neutral policy for a water-scarce country, since this affects, among other things, urbanization, rural-urban migration and income distribution (Roth & Warner, 2008)
- Expanding agricultural commodities trade generates overall welfare gains, but also winners and losers among trading partners (Berrittella *et al.*, 2007).
- Virtual water *trade* may be exacerbating water scarcity in water-stressed regions, as shown for the case of India by Verma *et al.* (2008). In explaining virtual water flows, these authors identify key explanatory factors other than water scarcity, including per capita gross cropped area (an indicator of land concentration and population density) and access to secure markets (an indicator of institutional performance).

None of these studies, except for Garrido *et al.* (2010), have evaluated the economic value of the imported or exported water.

3 UPDATE OF WORLDWIDE WATER SCARCITY EVALUATIONS

Concern about worldwide water scarcity and its relation to food production has inspired a number of recent studies. In addition to CAWMA (2007), other studies by UNESCO (2008), Formas (2008), Falkenmark & Rockstrom (in press) have looked in detail in the implications of water resources and food production.

For one thing, the linkages between water availability and economic development are weak for developed and developing countries. In Figure 1 (taken from FAO, 2009), per capita water resources are plotted against the percentage of undernourished people for a number of countries.

However, according to CAWMA (2007), achieving the Millennium Development Goals or erasing poverty by 2030 imply substantial increases of world water use, as shown in Figure 2. Very often the water scarcity problem is taken as a synonym of a food problem.

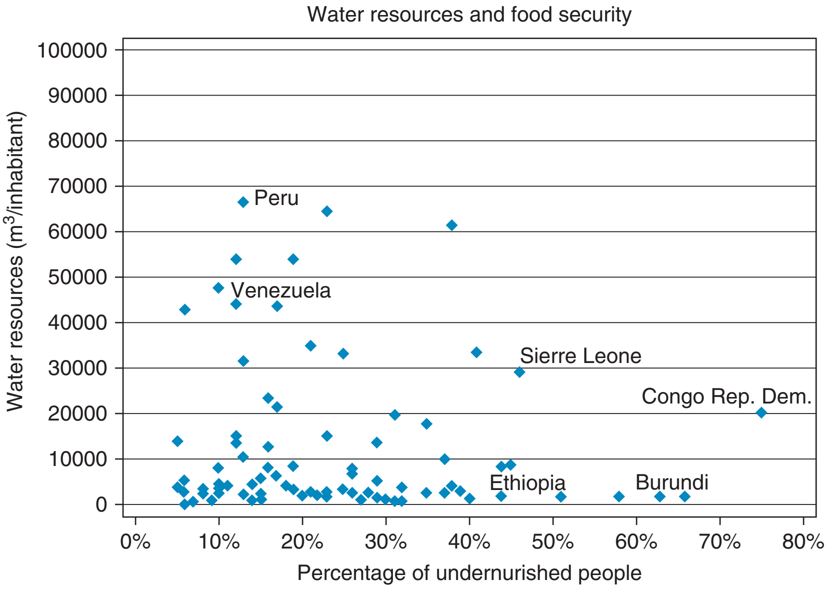

Figure 1. Water resources and food security in developing countries.
Source: FAO (2009).

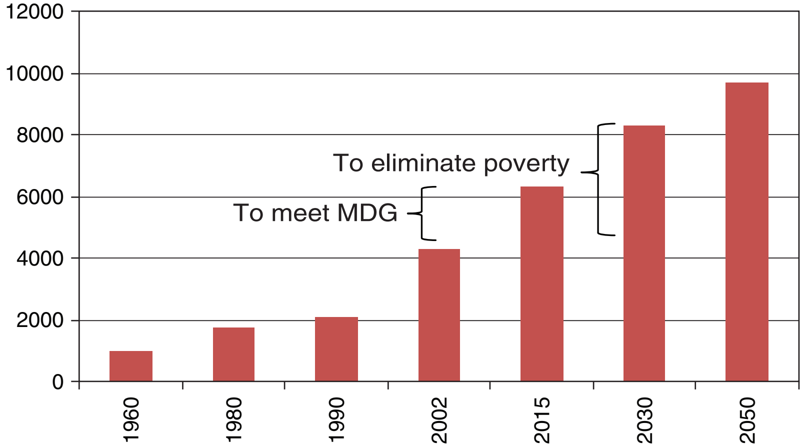

Figure 2. Projections of human water uses (in km^3) in different scenarios.
Source: CAWMA (2007).

World physical systems have also been modeled to project future impacts on precipitation, evapotranspiration, run-off and land-cover. It is impossible to summarize the findings of the most recent literature on the subject. Alcamo *et al*. (2003) concluded that by 2050 water stress will be increasing over most developing regions, but decreasing to a significant extent of industrialized regions. Bates *et al*. (2008) showed that the tropical and subtropical regions, together with those that have a Mediterranean-type climate (the Mediterranean itself, South Africa, large parts of the Southwest of North America), will experience lower and more unstable precipitation regimes. Nevertheless, Bates *et al*. (2008) already warn that the model used for water predictions are inadequate. Therefore, these projections are rather uncertain.

Table 1. Regional available resources and present utilization.

			Freshwater utilization by purpose						
		Total volume of freshwater utilization	Domestic use		Industrial use		Agricultural use		Utilization as % of resources
	IRWR*	km^3/yr	km^3/yr	%	km^3/yr	%	km^3/yr	%	
World	43,764	3,811.3	376.2	9.9	783.0	20.5	2,652.1	69.6	9
Latin America and Caribbean	13,570	265.1	50.4	19.0	27.4	10.3	187.3	70.7	2
Near East and N Africa	516	322.6	25.1	7.8	19.5	6.0	278.0	86.2	63
Sub-Saharan Africa	3,856	98.1	6.9	7.0	2.8	2.9	88.3	90.1	3
East and SE Asia	8,720	977.4	71.2	7.3	192.3	19.7	714.0	73.0	11
South Asia	1,761	917.8	58.7	6.4	39.6	4.3	819.6	89.3	52
Oceania developing	874	0.1	0.1	35.5	0.0	28.4	0.1	36.2	0

*Internal Renewable Water Resources
Source: CAWMA (2007).

As on May 2009, the list of *Low-Income Food-Deficit Countries* (LIFDC) included 77 countries, five less than in 2008. In April out of the 82, 44 are located in Africa, 25 in Asia, 6 in Oceania, 3 en Central America and 4 in Europe, comprising an urgent demand for 85 × 10^6 t of cereals [t = tonne = 1,000 kg]. Most analyses assume that a healthy diet requires about 1,700 m^3/yr per person (Kuylenstierna *et al*., 2008).

Increasing food demand, global warming and more unstable precipitation regimes worldwide are the three major factors that back the somber projections for the future. Do they stand a closer scrutiny in light CAWMA's continental evaluations about available resources and current utilization rates? (see Table 1).

UNESCO (2008) reports that by 2025 there will be 1,800 million people living in regions with absolute water scarcity. Gleick (2009) discusses the concept of *peak water* as a parallel concept to *peak oil* (a point which is reached when half of existing stock of petroleum has been depleted and the rate of production peaks). Gleick, in discussing the differences between oil and water, claims that while oil can be transported economically water cannot. It certainly can, and much cheaper than oil, simply because the footprint of food production is the largest among all economic goods in the economy and have large abundant water embedded in it. So water can be transported embedded in commodities.

As Garrido & Dinar (2009) show, most world water problems materialize most severely in a number of known watersheds and basins, where water use and water pollution may have gone beyond any possible threshold of sustainability. Reversing these trends is a daunting and extremely expensive task, even for developed countries.

In this sense, the notion of *peak ecological water* proposed by Gleick (2009) and the transition from *more crops and cash per drop* to *more cash and care of nature per drop* are relevant means to think about water resources.

In any case, virtual water *trade* is by far the easiest and most economic way to save water resources without threatening the most pressing human needs.

In Table 2 we report various national data about water resources, arable land and irrigation for selected countries from Africa, South America and the European Union. The purpose of putting together basic data from quite disparate countries is to highlight the vast untapped resources of many world countries for food production. According to FAO, countries like Angola, Ethiopia, Mozambique, Brazil, Colombia, Nigeria or Bolivia, to cite just a few, can multiply their present irrigated acreage by a factor of 5 or more. Whereas more mature countries in terms of water utilization rates, like Egypt, Spain, Israel, USA, Mexico or Australia have very few opportunities to

Table 2. Basic water and agricultural land statistics of selected countries from Africa, South America and the European Union.

	Renewable resources (km^3)	Withdrawal (km^3)	Per capita withdrawal (m^3/yr)	Arable land (10^3 ha)	Irrigated land (10^3 ha)	Irrigation potential (10^3 ha)	Potent/ actual
Africa							
Angola	184	6.07	22	3,000	60	3,700	61.7
Cameroon	285	0.99	61	5,960		290	
Ethiopia	110	5.56	72	10,000	300	2,700	9.0
Madagascar	337	14.96	804	2,900	899	1,500	1.7
Mali	100	6.55	484	4,634	232	566	2.4
Mozambique	216	0.63	32	3,900	117	3,070	26.2
Niger	33.7	2.18	156	14,483	145	270	1.9
Nigeria	286.2	8.01	61	28,200	282	2,330	8.3
Sudan	154	37.32	1,030	16,233	1,786	2,700	1.5
Zambia	105	1.74	149	5,260	158	523	3.3
South America							
Argentina	814	29.19	753	27,800	1,390	6,200	4.5
Bolivia	622	1.44	157	2,928	117	2,000	17.1
Brazil	8,233	59.3	318	57,640	2,306	29,000	12.6
Colombia	2,132	10.71	235	2,818	564	6,600	11.7
Paraguay	336	0.49	80	2,850	57		
Uruguay	139	3.15	910	1,373	206	1,700	8.3
Venezuela	1,233	8.37	313	2,595	441	1,700	3.9
EU							
France	189	33.16	548	18,440	2,397		
Germany	188	38.01	460	11,804	472		
Italy	175	41.98	723	8,479	2,035		
Spain	111	37.22	864	13,400	3,300		
UK	160	11.75	197	5,876	176		

Sources: AQUASTAT (FAO), FAOSTAT, Gleick (2009).

increase food production at faster rates than those enabled by technical and scientific developments (less than 1% per year).

In Table 3 we report the most recent data on production and yields of three basic commodities (rice, corn and wheat). Yields in less developed countries are still far from the largest potential. The case of Sudan is noteworthy: while wheat yields are comparable to those of Spain and Italy, total production is extremely low. Apart from its serious political and civil conflicts, it is clear that, from its resource base, there is an extraordinary potential to increase food production in Sudan. The fact that Sudan sold 690,000 ha to private entrepreneurs helped by the government of South Korea attests for the potential of the country.

4 THE CASE OF SPAIN[1]

The objective of this part of the study is to assess the virtual water *trade* in Spain, differentiating the green (soil water) and blue (surface water and/or groundwater) components of virtual water from both a hydrological and economic perspective. As Spain encompasses very diverse agricultural regions, the combination of spatial and time dimensions offers a unique empirical setting to

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[1] This section borrows from Garrido *et al.* (2010).

Table 3. Rice, corn and wheat yields and production in selected countries from Africa, South America and the European Union.

	Yields (kg/ha)			Production (10^6 t)		
	Rice	Corn	Wheat	Rice	Corn	Wheat
Argentina	7,061.0	5,902.9	2,623.4	1.193	14.446	14.663
Bolivia	2,651.2	2,607.0	1,111.2	0.446	0.894	0.144
Brazil	3,879.8	3,382.3	1,592.6	11.527	42.662	2.485
Cameroon	1,300.0	1,888.8	1,333.3	0.052	0.850	0.000
Ethiopia	1,868.8	2,640.4	1,904.0	0.012	4.030	2.779
France	5,533.0	8,585.6	6,740.7	0.095	12.902	35.367
Germany		8,030.6	7,200.6		3.220	22.428
Italy	6,277.1	8,728.5	3,729.5	1.419	9.671	7.182
Madagascar	2,699.4	1,500.0	2,380.9	3.485	0.495	0.010
Mali	2,553.3	1,730.0	2,422.9	1.053	0.707	0.009
Mozambique	619.8	852.0	1,052.6	0.099	1.418	0.002
Niger	3,708.2	812.5	1,499.2	0.078	0.007	0.008
Nigeria	1,483.3	1,818.1	1,126.9	4.042	7.100	0.071
Paraguay	3,000.0	4,878.0	2,191.7	0.126	2.000	0.800
Spain	6,799.1	9,743.6	2,875.4	0.724	3.356	5.522
Sudan	3,439.1	1,046.3	3,831.9	0.026	0.109	0.669
UK			8,036.5			14.747
Venezuela	4,950.2	3,334.1	301.3	1.123	2.337	0.000
Zambia	972.5	1,815.6	5,494.6	0.014	1.424	0.094

Source: FAOstat (www.fao.org).

determine whether virtual water *trade* can contribute to reduce water scarcity. In short, the main contributions of our study to the literature are: 1) the spatial and temporal analysis, as the study covers all Spanish provinces for the period 1997–2006; and 2) the econometric analysis of virtual water *trade*, making use of spatial and temporal variations of water scarcity value and irrigated land productivity.

Spain is considered a semi-arid country, but nationally it is relatively well-endowed with blue water resources (more than 2,000 m^3 of renewable resources per capita). Geographically, resources are abundant in the less-populated basins and scarce in the most populated regions, especially the Mediterranean arc and the South.

The water footprint of Spain has been estimated at about 45,000 Mm^3/yr for the period 1997–2006 (Garrido *et al.*, 2010). This, on a per capita basis, is about 1,100 m^3/yr per capita, suggesting that, despite the fact that Spain is usually classified as an arid country, its average is close to the global average of around 1,300 m^3/yr per capita. This figure is close to the global average of around 1,700 m^3/yr per capita, which also corresponds to a food supply need of 3,000 kcal/day per person, out of which 20% are animal products (Kuylenstierna *et al.*, 2008).

The largest water user, in line with global trends (although not necessarily developed countries of a similar level), is the agricultural sector. Considering both green and blue crop consumption and livestock water use, agricultural water use represents about 85% of the total water use, while it contributes about 3% of the GDP (26,000 million €) and employs 5% of the economically active population (1 million jobs).

There is a growing body of literature focusing on virtual water and the water footprint. However, few of these studies deal with the economic valuation of virtual water. From an economic perspective, only blue water is valued. Green water has certainly an economic value both for agricultural production and natural ecosystems. However, it is complex to attach an opportunity cost to green water since it cannot be easily allocated to other uses.

Table 4. Water scarcity values and scarcity levels.

River Basin	Provinces	Scarcity level	Scarcity value €/m^3	Volume stored (s) (in % over total storage capacity)
Duero	Ávila, Burgos, León,	1	0	$s > 75.2$
	Palencia, Salamanca,	2	0.06	$63.2 < s < 75.2$
	Segovia, Soria,	3	0.12	$56.4 < s < 63.2$
	Valladolid, Zamora	4	0.361	$s < 56.4$
Ebro	Álava, La Rioja,	1	0.01	$s > 80.2$
	Navarra, Huesca,	2	0.06	$71.7 < s < 80.2$
	Lleida, Zaragoza,	3	0.09	$71 < s < 71.7$
	Tarragona, Teruel	4	0.15	$s < 71$
Guadalquivir	Cádiz, Córdoba,	1	0.005	$s > 66.2$
	Jaén, Sevilla	2	0.1	$46.2 < s < 66.2$
		3	0.25	$18 < s < 46.2$
		4	0.96	$s < 18$
Guadiana	Ciudad Real,	1	0.033	$s > 65.8$
	Badajoz, Huelva	2	0.058	$57.5 < s < 65.8$
		3	0.137	$16.8 < s < 57.5$
		4	0.678	$s < 16.8$
Júcar	Castellón, Alicante,	1	0.07	$s > 33.3$
	Cuenca, Valencia	2	0.19	$23.2 < s < 33.3$
		3	0.35	$18.6 < s < 23.2$
		4	0.52	$s < 18.6$
Segura	Murcia, Albacete	1	0.12	$s > 22.5$
		2	0.27	$19.7 < s < 22.5$
		3	0.52	$12.1 < s < 19.7$
		4	0.61	$s < 12.1$

Source: Garrido *et al*. (2010).

For the purpose of this study, the economic value of blue water is defined in terms of shadow prices or scarcity values. Using the shadow price of water to measure the economic value of blue water seems consistent with the analysis of virtual water *trade* in arid and semiarid countries, where the distinction between green and blue water is essential to relate land and water management to drought and climate variability.

The shadow prices or scarcity value of blue water, as reported in Table 4, have been selected based on a comprehensive literature review. Blue water values are defined for each river basin and scarcity level. In this framework, each Spanish province is identified with a specific river basin, although the administrative and basin boundaries do not perfectly overlap. Blue water scarcity value varies depending on the scarcity level, which in turns depends on the volume of water stored in each river basin. Scarcity levels are defined on a scale from 1 to 4, being 4 the scarcest level. For each river basin, storage thresholds are defined based on a percentile analysis for the period 1997–2006. Thus, when in a certain year the volume stored in May is higher than the 50th percentile the scarcity level is 1. Scarcity level 2 corresponds with a volume stored between 25th and 50th percentiles. Scarcity level 3 is defined between 10th and 25th percentiles and the scarcity level 4 occurs when the stored volume is lower than 10th percentile.

4.1 *Econometric analysis*

Our data generation process allows for testing the hypothesis that the blue virtual water *exports* are dependent on water scarcity and land productivity. Basic economic theory would suggest that as water and land become scarcer, users would be more efficient.

Making use of the spatial and temporal variations of both water scarcity and land productivity, we can pose the following model, only relevant for irrigated agriculture:

$$BVWE_{it} = \alpha + \beta_1 SV_{it} + \beta_2 LP_{it} + \varepsilon_{it} \tag{1}$$

$BVWE_{it}$ denotes blue virtual water *exports* expressed in volumetric terms, that, is in 1,000 m^3 of blue water of province i and year t; SV_{it} represents the water scarcity value in €/m^3, which varies across years and basins, using the parameterisation shown in Table 4; LP_{it} is the land productivity of irrigated production in province i and year t, measured in €/ha of crop value.

The time-series and panel structure of our database can be best estimated using *Feasible Generalised Least Squares*, assuming heterocedastic, but uncorrelated panels (provinces).

$$\hat{\beta}_{GLS} = (X'V^{-1}X)^{-1}X'V^{-1}y \tag{2}$$

Where matrix V, with n being the number of provinces, is as follows:

$$V = \begin{bmatrix} \sigma_1^2 I & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & \sigma_n^2 I \end{bmatrix} \tag{3}$$

Model [1] hypothesises that coefficient β_1 could be negative. Parameter β_1 measures the effect that the SV_{it} has on the blue virtual water *exports*. Model [1] permits both general estimations as well as regional estimations. This strategy will be pursued by estimating the model for all provinces, only for Mediterranean provinces and only for the inland provinces. That is, if we control for the geographic provinces, one would expect that as water becomes scarcer, provinces would *export* less virtual water in the form of farm exports.

In terms of the model's variables and crops' demand, these major *regions* differ in two essential aspects: a) the lower percentage of irrigated land in the inland regions than in the Mediterranean regions; b) the fact that water is scarcer in economic terms in the Mediterranean regions than in the inland regions.

β_2 could be either positive or negative. Positive (negative) means that higher irrigated land productivity would increase (reduce) the volume of blue virtual water *exported*. Note that the direction of the causality would either assume that as land becomes more productive more water would be virtually *exported* in the form of farm products, or that higher land productivity could be caused by scarcer water for irrigation so that less water could be *exported* in farm production.

Since both water scarcity and land productivity values differ among river basins, a set of dummy variables is introduced to explain as much of these inter-basin differences.

$$BVWE_{it} = \alpha + \beta_1 SV_{it} + \beta_2 LP_{it} + \sum_i \beta_{3i} SR_i + \varepsilon_{it} \tag{4}$$

In which SR_t controls for each river basin coefficient. There are a total of 12 basin variables in the model. Once the geographical differences are controlled by coefficients β_{3i}, model [4] allows for testing the hypothesis of whether larger scarcity permits lower values of blue virtual water *exports*.

4.2 *Virtual water flows*

Spain is a net virtual water *importer* country. In terms of volume, net virtual water *imports* amount to an average of 12,800 Mm^3 for the period 1997–2006. International trade data reveals that Spain exports high value crops, such as fruits and vegetables, and imports less valuable crops, such as cereals and industrial crops. This fact shows the importance of considering both volume and economic value of the virtual water *exchanged*.

Virtual water *imports* totaled 20,147 Mm^3 in the year 1997 and increased up to 29,150 Mm^3 in the year 2006 (Garrido *et al.*, 2010). A maximum of 32,500 Mm^3 was reached in the year 2005, which in terms of precipitation was also the driest year of the series. Even though farm trade responds

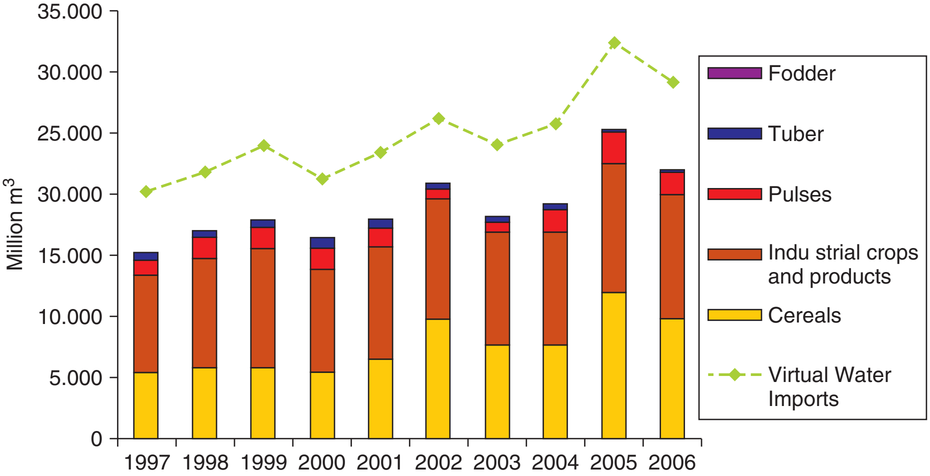

Figure 3. Virtual water *imports* related to livestock production.
Source: Own elaboration.

primarily to the relative prices and resources' productivity, variations in agricultural trade patterns might to some extent be explained by climatic variability.

The main groups of imported crops are cereals and industrial crops (and their products), which represent 70% of total virtual water *imports*. Major virtual water volumes are *imported* from France, Argentina, Brazil and USA, where primary crops are mainly cultivated under rainfed conditions. Therefore, their virtual water *exports* are predominantly green and consequently with a lower opportunity cost. The case of exports from France may be slightly different since maize is by far the most important irrigated crop in France. The Spanish imported maize could embed blue water resources that have a non-negligible cost.

Most virtual water *imports* are directly connected to the livestock sector (see Figure 3). Almost 100% of the soya cake consumption and 75% of cereals and pulses' consumption is used for animal feeding (MARM, 2008). Spanish meat production has grown from 3.6×10^6 to 5.8×10^6 t during the period 1992–2007 (*ibid*.).

According to official data, livestock direct water use is about 260 Mm^3 (MARM, 2008). However, Spain has virtually *exported* about 10,000 Mm^3/yr by means of animal product exports. During the 1997–2006 animal-related virtual water *exports* have experienced a steady growth, although *imports* have remained fairly stable. The swine sector expansion underscores the growth of *exports*, reaching a maximum of 4,500 Mm^3 in 2005. The bovine exports, second in importance, exhibit more variability. The sanitary and veterinary crisis experienced in the bovine sector explains its virtual water *trade* variability and its decline in the most recent years.

4.3 *Econometric analysis: Regression results*

Garrido *et al*. (2010) show that there are very large differences of green and blue water use across basins in agriculture. In addition, water scarcity varies also significantly across years, due to drought cycles. The question of whether virtual water *trade* increases or reduces water scarcity at regional level can be tested using a regression analysis with the cross-section and time-series data developed in this research.

We run a number of specifications using the styled model described above in equation [1]. Tables 5 and 6 summarize the main results. As hypothesized earlier, coefficient β_1 is significant and negative in Mediterranean regions, but non-significant and positive in the mainland provinces. Mediterranean blue virtual water *exports* are more responsive to changes in scarcity values than

Table 5. Blue virtual water *exports* in Mediterranean and Inland regions, period 1997–2006.

	Mainland regions			Inland regions		
	Coef.	Std. Err.	Elasticity ey/ex	Coef.	Std. Err.	Elasticity ey/ex
Scarcity value (β_1)	−226.4286*	39.9971	−0.3868	4.0493	10.7320	0.0096
Irrigated land productivity (β_2)	−6.2016*	0.7644	−0.3719	9.1597*	1.0612	0.8589
Constant α	201.5281*	10.5028	–	4.1305	2.8381	–
Number of obs.	190			220		
Number of groups	19			22		
Time periods	10			10		

$p < 0.01$*

Table 6. Blue virtual water *exports* by provinces, period 1997–2006.

	Coef.	Std. Err.	Elasticity ey/ex
Scarcity value (β_1)	3.7581	6.2427	0.0062
Irrigated land productivity (β_2)	−3.0540*	0.4018	−0.1832
Constant α	23.003*	1.254874	
Number of obs.	410		
Number of groups	41		
Time periods	10		

Basin (β_{3i})	Coef.	Std. Err.	Basin (β_{3i})	Coef.	Std. Err.
Ebro	55.8346*	3.4548	Tajo	8.5104*	2.0861
Guadalquivir	200.5525*	17.2891	Sur	115.9937*	7.7616
Guadiana	71.2109*	4.9076	Catalonia	1.1457	3.3966
Júcar	132.112*	7.1650	Canarias	44.5612*	5.0822
Segura	232.9477*	9.4501	Baleares	15.5284*	3.8057

$p < 0.01$*

inland regions, the elasticity being significant and different in both equations by more than one order of magnitude.

Our model also hypothesized that irrigated land productivity can have an impact on the blue virtual water *exports*. While this variable is significant in both models, the direction of the effect is negative in Mediterranean provinces and positive in the mainland provinces. This indicates that higher irrigated land productivity decreases the blue virtual water *exports* in the provinces where blue water is scarcer. In the inland regions, higher irrigated land productivity is generally explained by higher blue water availability and larger productions. In turn, more blue virtual water is *exported*. These findings suggest that the export-oriented Mediterranean provinces are generally more responsive to variations of water scarcity and land productivity than mainland provinces.

The estimation of model [3] provides a complementary interpretation. As we control for the basins, we indirectly control for the water scarcity levels. The resulting effect is that the scarcity value of water becomes insignificant, while the basins' controls become very significant, except for the internal basins of Catalonia. The geographical latent conditions –temperature and precipitation regimes– become more relevant than the time-variation of water availability and economic scarcity. This implies that these natural endowment factors have more explanatory power of the volumes of *exported* water than the scarcity conditions prevailing in each region and year. So one can conclude that virtual water *trade* does not aggravate water scarcity, which is in fact caused by the greater competitive advantage of those regions with better natural endowments. Furthermore, we see a higher response of blue water *exports* to changes in irrigated land productivity. This means that it is the allocation of land and water that influences more the amount of *exported* water in each province, than the water scarcity component.

5 CONCLUSIONS

The Spanish water economy, like most developed and many emergent and developing countries', has become increasingly globalised. About half of all imports come from the southern hemisphere, and its virtual water *trade* in terms of *exports* and *imports* actually accounts for a volume larger than the water actually used in the country. Exports have been effectively decoupled from the fluctuations in water availability for two main reasons: first, animal product exports rely primarily on imported products (animal feed from cereals and soy), which complement national production. Second, exports originating in Mediterranean provinces show little variation in total water use.

Not all traded m^3 are equally valuable: as a general rule, green ones are less *valuable* than blue ones. There are years when water in exactly the same location is twice as valuable as in other years because surface reservoirs storage levels are lower due to drought cycles. Nevertheless, these results will need to be reassessed when reliable data on the role of groundwater storage are available. This is a gap in Spain, as well as in most countries.

At a global scale, it is essential that water values are presented jointly with virtual water *trade* economic evaluations. Even if gathering this information is a significant challenge, existing water stress indicators that are currently recorded at national or basin levels (see CAWMA, 2007) can be used to help placing a monetary value to virtual water *traded* globally. Based on the work carried out by Hoekstra & Chapagain (2008) at the global level, it is likely that the value of virtual water *trade* is much more significant than originally estimated because water savings could translate into euro savings as well.

Water policies must be placed in a global context. Water users in semi-arid countries need a way to internalise the international crop prices, in competition with foreign producers. The EU policy has taken a bold step by pushing to integrate water policy as a requirement of the new *Health Check* of a revised Common Agricultural Policy. Spain has seen large increases in farm water productivity, especially in the provinces where land and water were once less productive. A main reason is that farmers have been able to open their farms increasingly to global competition, whilst simultaneously reducing their dependence on subsidies that targeted specific crops over others, therefore distorting market signals and isolating farmers from key market information of shifts due to increased globalisation. Spain has in fact saved billions of m^3 by opening its farming and livestock industries to world market opportunities, and has been able to offer foreign consumers competitively priced products. Farm trade has in turn helped the Spanish rural economy to cope better with droughts, and it will also help the country face the upcoming challenge: to change the now outdated motto *more crops and jobs per drop* to *more cash and care nature per drop*.

This chapter also examined the hypothesis of whether virtual water *trade* aggravates water scarcity in the most competitive and exporting regions. Instead of looking at nation-wide trade, we scaled down the analysis to examine the regional and time differences of virtual water *exports* based on the variations of both water scarcity and irrigated land productivity. The findings show that virtual water *exports* do not respond to changes in water scarcity, but essentially to the natural and capital endowments of the provinces. So we conclude that farm trade, and the virtual water *trade* that comes with it, adds a degree of latent pressure to the water resources of the exporting provinces. But farm exports show very little response to variations of economic water scarcity, and seem to evolve quite invariably to the variations of water availability and economic value. To ensure that virtual trade offer robust policy prescription, water should be adequately priced in the exporting countries. By taking into account the varying scarcity value of water, commodity exports would internalize its value and the trade regime would be consistent international trade postulates.

The economics of virtual water trade is still in its infant stage. Despite the comprehensive evaluations of Hoekstra & Chapagain and Hong & Zehnder, we know very little about the actual value of the water that is used in the exporting countries. While it is known that most of it is green water –certainly with less economic value than blue water–, there are initiatives in China and Turkey which are meant to use blue water for the production of low-value commodities.

What the virtual water *trade* literature has not yet come to grips is the risk that food crises, like the one of 2007 and 2008, represent for food importing countries. Possibly one of the main reasons is that an adequate analysis is still missing on the main causes of that crisis (corruption, oligopolies, biofuels, oil price increase, economic crisis and others). Those wealthy enough paid the prices of the commodities as asked in the international markets, and more recently resorted to purchase and lease suitable land with accessible water resources. The poorest among the poor did not and will not have that option. And yet, ironically those countries selling the land stand among the poorest in the world. This means that with capital and know-how they should be able to feed themselves. It is not the lack of water resources that explain the world's hunger and malnutrition.

REFERENCES

Alcamo, J.; Döll, P.; Henrichs, T.; Kaspar, F.; Lehner, B.; Rösch, T. & Siebert, S. (2003). Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences*, 48(3), 317–337.

Aldaya, M.M.; Hoekstra, A. & Allan, J.A. (2008). *Strategic importance of green water in international crop trade*. Value of Water Research Report Series No. 25, March. UNESCO-IHE; Institute for Water Education. Delft, the Netherlands.

Allan, J.A. (2003). Virtual Water – the water, food, and trade nexus useful concept or misleading metaphor? *Water International*, 28(1): 4–11.

Bates, B.C.; Kundzewicz, Z.W.; Wu, S. & Palutikof, J.P. (eds.) (2008). *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, Switzerland. 210 pp.

Berrittella, M.; Hoekstra, A.Y.; Rehdanz, K.; Roson, R. & Tol, R.S.J. (2007). The economic impact of restricted water supply: a computable general equilibrium analysis. *Water Research*, 42: 1799–1813.

CAWMA (Comprehensive Assessment of Water Management in Agriculture) (2007). *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. D. Molden (ed.). Earthscan, London, UK; and International Water Management Institute, Colombo, Sri Lanka.

Chapagain, A.K.; Hoekstra, A.Y. & Savenije, H.H.G. (2006a). Water saving through international trade of agricultural products. *Hydrology and Earth System Sciences*, 10: 455–468.

Falkenmark, M. & Rockström, J. (in press). Integrating agricultural water use with the global water budget. In: A. Garrido & H. Ingram (eds.), *Water for Food in a Changing World*. Routledge.

FAO (2009). *Aquastat*. [http://www.fao.org/nr/water/aquastat/main/index.stm].

Formas (ed.) (2008). *Water for Food*. Sweedish Research Council (Formas). Stockholm, Sweden.

Fraiture, C.; Cai, X.; Amarasinghe, U.; Rosegrant, M. & Molden, D. (2004). Does international cereal trade save water? The impact of virtual water trade on global water use. Comprehensive Assessment Research Report 4. Comprehensive Assessment Secretariat, Colombo, Sri Lanka [online]. Available from: [http://www.iwmi.cgiar.org/Assessment/FILES/pdf/publications].

Garrido, A. & Dinar, A. (eds.) (2009). *Managing Water Resources in a Time of Global Change: Mountains, Valleys and Flood Plains*. Routledge Publishers.

Garrido, A.; Llamas, M.R.; Varela-Ortega, C.; Novo, P.; Rodríguez-Casado, R. & Aldaya, M.M. (2010). *Water footprint and virtual water trade of Spain: policy implications*. Springer, New York, USA.

Gleick, P. (2009). *The World's Water: 2008–2009. The biennial report on freshwater resources*. Island Press, Washington, D.C., USA.

Hoekstra, A.Y. & Chapagain, A.K. (2008). *Globalization of water: Sharing the planet's freshwater resources*. Blackwell Publishing. Oxford, UK.

Hoff, H.; Falkenmark, M.; Gerten, D.; Gordon, L.; Karlberg, L. & Rockström, J. (in press). Synthesis article: Greening the global water system. *Journal of Hydrology*.

Kuylenstierna, J.; Destouni, G. & Lundqvist, J. (2008). Feeding the future world – securing enough food for 10 billion people. In: Swedish Research Council Formas (ed.), *Water for Food*. Formas, Stockholm, Sweden: 9–22.

MARM (2008). *Agricultural and statistics yearbook*. Spanish Ministry of the Environment, and Rural and Marine Affairs [online]. Available from: [http://www.mapa.es/es/estadistica/pags/anuario/introduccion.htm].

Novo, P.; Garrido, A. & Varela-Ortega, C. (2009). Are virtual water "flows" in Spanish grain trade consistent with relative water scarcity? *Ecological Economics*, 68: 1454–1464.

Oki, T. & Kanae, S. (2004). Virtual water trade and world water resources. *Water Science and Technology*, 49 (7): 203–209.

Rosegrant, M.; Cai, X. & Cline, S. (2002). *World water and food to 2025*. International Food Policy Research Institute (IFPRI). Washington, D.C., USA.

Roth, D. & Warner, J. (2008). Virtual water: Virtuous impact? The unsteady state of virtual water. *Agricultural and Human Values*, 25: 257–270.

The Economist (2009). *Outsourcing's third wave*, May 21st.

UNESCO (2008). *El agua, una responsabilidad compartida*. 2º Informe de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos el Mundo. Estatal Expoagua, Zaragoza, Spain.

Verma, S.; Kampman, D.A.; van der Zaag, P. & Hoekstra, A.Y. (2008). Going against the flow: A critical analysis of inter-state virtual water trade in the context of India's National River Linking Program. *Physics and Chemistry of the Earth*, 34(4–5): 261–269.

von Braun, J. & Meinzen-Dick, R. (2009). "Land Grabbing" by Foreign Investors in Developing Countries: Risks and Opportunities. IFPRI Policy Brief, 13. April.

Wichelns, D. (2004). The policy relevance of virtual water can be enhanced by considering comparative advantages. *Agricultural Water Management*, 66: 49–63.

Yang, H. & Zehnder, A.J.B. (2007). Virtual water: An unfolding concept in integrated water resources management. *Water Resources Research*, 43, W12301.