Can virtual water 'trade' reduce water scarcity in semi-arid countries? The case of Spain

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1. Introduction

Defined as the volume of water used in producing a commodity, good or service (Allan, 1998), the ‘virtual water’ concept is strongly linked to water productivity and economic geography. From a neoclassical political economy perspective, the logic of virtual water prescribes that water rich countries should produce and export water intensive commodities to water scarce countries (Wichelns, 2004; Roth and Warner, 2008). But, because water is not the main or the uniquely scarce input in practically all traded goods, water scarcity is a poor explanatory factor of virtual water ‘trade’.

Agricultural trade is by far the largest vehicle to move water virtually around the world. Globally, the volume of virtual water associated with crop trade is about 15% of the total water use in crop production. From this 15% only 20% of this virtual water ‘trade’ seems to be due to water scarcity (Yang and Zehnder, 2008). Other key factors, including per capita cropped area and access to secure markets, are powerful explanatory factors of virtual water ‘flows’ (Ma *et al.*, 2006; Verma *et al.*, 2008). Similarly, New Trade Theory argues that international trade is based on imperfect competition and economies of scale. In this respect, other factors than water determine trade. Yang and Zehnder (2007) conclude that the unique nature of water resources (i.e. mobility, time and spatial variability, climate-dependent production) has challenged the economic analysis of virtual water ‘trade’ from the comparative-advantage classical perspective.

For the time being most of virtual water studies have focused on hydrological aspects. In this context, the present study expects to be a down-to-earth contribution to the virtual water debate, contributing with actual and detailed evaluations of virtual water ‘trade’ in Spain.

The objective of this 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 determine whether virtual water ‘trade’ can contribute to reduce water scarcity. In short, the main contributions of our study to the literature are (i) the spatial and temporal analysis, as the study covers all Spanish provinces for the period 1997-2006, and (ii) the econometric analysis of virtual water ‘trade’, making use of spatial and temporal variations of water scarcity value and irrigated land productivity.

2. Methodology

2.1. Virtual water ‘trade’

The present study follows the methodology developed by Hoekstra and Chapagain (2008). First, crop water requirements (CWR, m^3/ha) and effective rainfall (P_{eff}, mm/month) are estimated. Crop water requirements are equal to crop evapotranspiration (ET_c, mm/month) under standard conditions and are calculated by multiplying the reference evapotranspiration (ET_o, mm/month) by the crop coefficient K_c over the growing period (Allen *et al*., 1998).

$$CWR = ET_o * K_c \qquad [1]$$

Effective rainfall is defined as the amount of rainfall water which is actually available to meet crop water requirements (Brouwer and Heibloem, 1986). Green water evapotranspiration (ET_g, mm/month) is calculated as the minimum value between effective rainfall and crop water requirements. Similarly, for irrigated crops, blue water evapotranspiration is equal to the difference between crop water requirements and green water evapotranspiration. This calculation is carried out by crop, Spanish province and month. The water balance is carried out on a monthly approach.

$$ET_g = min\,(CWR, P_{eff}\,) \qquad [2]$$

$$ET_b = max\,(0, CWR - ET_g\,) \qquad [3]$$

Crop water use over is calculated by accumulation of monthly evapotranspiration over the complete growing period.

$$CWU_g = 10*\sum_{m=1}^{lgp} ET_g \qquad [4]$$

$$CWU_b = 10*\sum_{m=1}^{lgp} ET_b \qquad [5]$$

lgp stands for the length of growing period and the factor 10 is to convert mm into m^3/ha.

The above method is applicable to rainfed and irrigated open production systems. Green crop water use is zero in covered systems. Crop evapotranspiration in greenhouse production can be computed as 70-80% of the crop evapotranspiration in open air systems (Fernandes *et al.,* 2003). CWU_b in greenhouse production is equal to crop evaporative demand.

The green component of the virtual water content of a primary crop (V_g, m^3/ton) is calculated as the ratio between green crop water use and crop yield (Y, ton/ha). In parallel, the blue component (V_b, m^3/ton) is calculated as blue crop water use divided by the crop yield. Since yield is different for rainfed and irrigated lands each of them has been estimated separately: calculating one green component for rainfed crops and other green and blue virtual water content for irrigated primary crops.

$$V_g = \frac{CWU_g}{Y} \qquad [6]$$

$$V_b = \frac{CWU_b}{Y} \qquad [7]$$

The total virtual water content of a primary crop (V_c, m^3/ton) is the sum of the green and blue components. For assessing crop virtual water 'exports' we need to know the overall green and blue virtual water content, since crop trade data do not differentiate exports from rainfed and/or irrigated production. A primary crop product might be processed into a number of crop derivatives (e.g. wheat into wheat flour). In such case, we calculate the virtual water content of the processed product by dividing the virtual water content of the primary product by the product fraction. This is done by including a value fraction which is proportional to the value of the derivative. Product (f_p, ton/ton) and value (f_v, US$/US$) fractions were obtained from (Chapagain and Hoekstra, 2004).

Therefore, virtual water content of processed crop products (V_{cp}, m^3/ton) is calculated as:

$$V_{cp} = (V_c + PWU) \times \frac{f_v}{f_p} \qquad [8]$$

The virtual water content of live animals (V_l, m^3/ton) is calculated based on the virtual water content of their feed and the volumes of drinking and service water required during their lifetime. For data on both live animals and livestock products virtual water content we use the values obtained by Chapagain and Hoekstra (ibid.). Following the methodology described above we can calculate the virtual water content of livestock products (V_{lp}, m^3/ton).

Virtual water 'trade' is calculated by multiplying commodity trade flows by their associated virtual water content. This is expressed as:

$$VW[ne, ni, j] = V[ne, j] \times T[ne, ni, j] \qquad [9]$$

In which, VW (m^3/yr) denotes virtual water 'trade' from exporting n_e to importing n_i country as a result of trade in commodity j; V (m^3/ton) the virtual water content of commodity j in exporting and producing country n_e and T (ton/yr) the commodity traded from the exporting to the importing country.

2.2. Economic value of water

There is a growing body of literature focusing on virtual water and 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.

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 1, 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 50^{th} percentile the scarcity level is 1. Scarcity level 2 corresponds with a volume stored between 25^{th} and 50^{th} percentiles. Scarcity level 3 is defined between 10^{th} and 25^{th} percentiles and the scarcity level 4 occurs when the stored volume is lower than 10^{th} percentile.

Table 1. Water Scarcity values and scarcity levels

River basin	Province	Scarcity level	Scarcity value[1] (€/m^3)	Volume stored[2] (s) (in % over total storage capacity)
Duero	Ávila, Burgos, León, Palencia, Salamanca, Segovia, Soria, Valladolid, Zamora	1	0	s > 75.2
		2	0.06	63.2 < s < 75.2
		3	0.12	56.4 < s < 63.2
		4	0.361	s < 56.4
Ebro	Álava, La Rioja, Navarra, Huesca, Lleida, Zaragoza, Tarragona, Teruel	1	0.01	s > 80.2
		2	0.06	71.7 < s < 80.2
		3	0.09	71 < s < 71.7
		4	0.15	s < 71
Guadalquivir	Cádiz, Córdoba, Jaén, Sevilla	1	0.005	s > 66.2
		2	0.1	46.2 < s < 66.2
		3	0.25	18 < s < 46.2
		4	0.96	s < 18
Guadiana	Ciudad Real, Badajoz, Huelva	1	0.033	s > 65.8
		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, Cuenca, Valencia	1	0.07	s > 33.3
		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: Own elaboration based on [1] Albiac *et al.* (2006), Calatrava and Garrido (2005), Iglesias *et al.* (2003; 2007), Gómez-Limón and Berbel (2000), Pulido-Velázquez *et al.* (2008) and Varela-Ortega (2007); [2] MMA(2008).

2.3. 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:

$$BVWE_{it} = \alpha + \beta_1 SV_{it} + \beta_2 LP_{it} + \varepsilon_{it} \quad [10]$$

$BVWE_{it}$ denotes blue virtual water 'exports' expressed in volumetric terms, that, is in 1000m^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 1; LP_{it} is the land productivity of irrigated production in province i and year t, measured in € of crop value per hectare.

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

$$\hat{\beta}_{GLS} = (X'V^{-1}X)^{-1} X'V^{-1} y \quad [11]$$

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

$$V = \begin{bmatrix} \sigma_1^2 I & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \sigma_n^2 I \end{bmatrix} \quad [12]$$

Model [10] 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 [10] permits both general estimations as well as regional estimations. This strategy will be pursued by estimating the model for all provinces, only Mediterranean provinces and only the inland provinces. That is, if we control for the geographical 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 interior 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.

$$BVWE_{it} = \alpha + \beta_1 SV_{it} + \beta_2 LP_{it} + \sum_i \beta_{3i} SR_i + \varepsilon_{it} \quad [13]$$

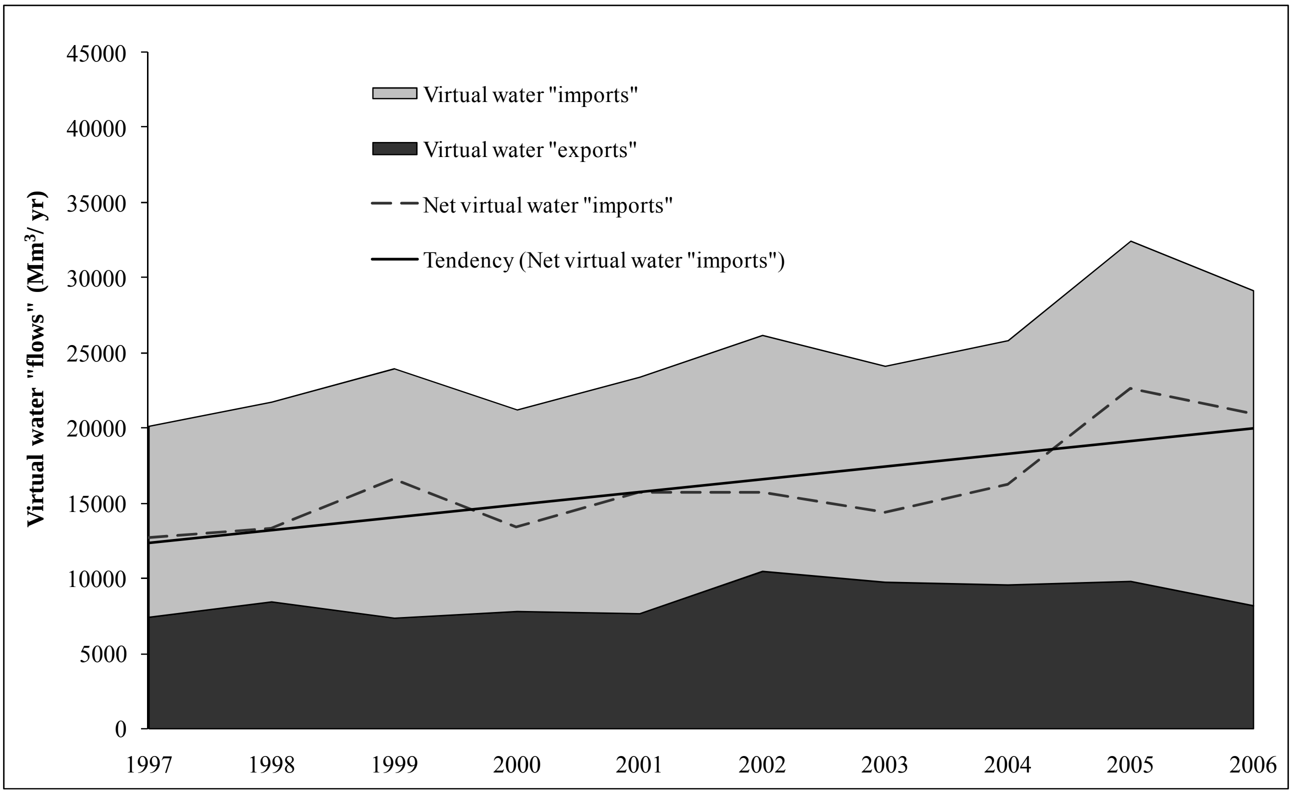
In which, SR_t controls for each river basin coefficient. There are a total of 12 basin variables in the model. Once the geographical differences are controlled by coefficients β_{3i}, model [13] allows for testing the hypothesis of whether larger scarcity permits lower values of blue virtual water 'exports'.

3. Virtual water 'flow'

3.1. National and regional results

Spain is a net virtual water 'importer' country. In terms of volume, net virtual water 'imports' amount to an average of 12,800 million m^3 for the period 1997-2006, as shown in Figure 2. International trade data reveals that Spain exports high valued 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'.

Figure 2. Agricultural virtual water ‘flow’ for period 1997-2006 (Million m^3/yr)



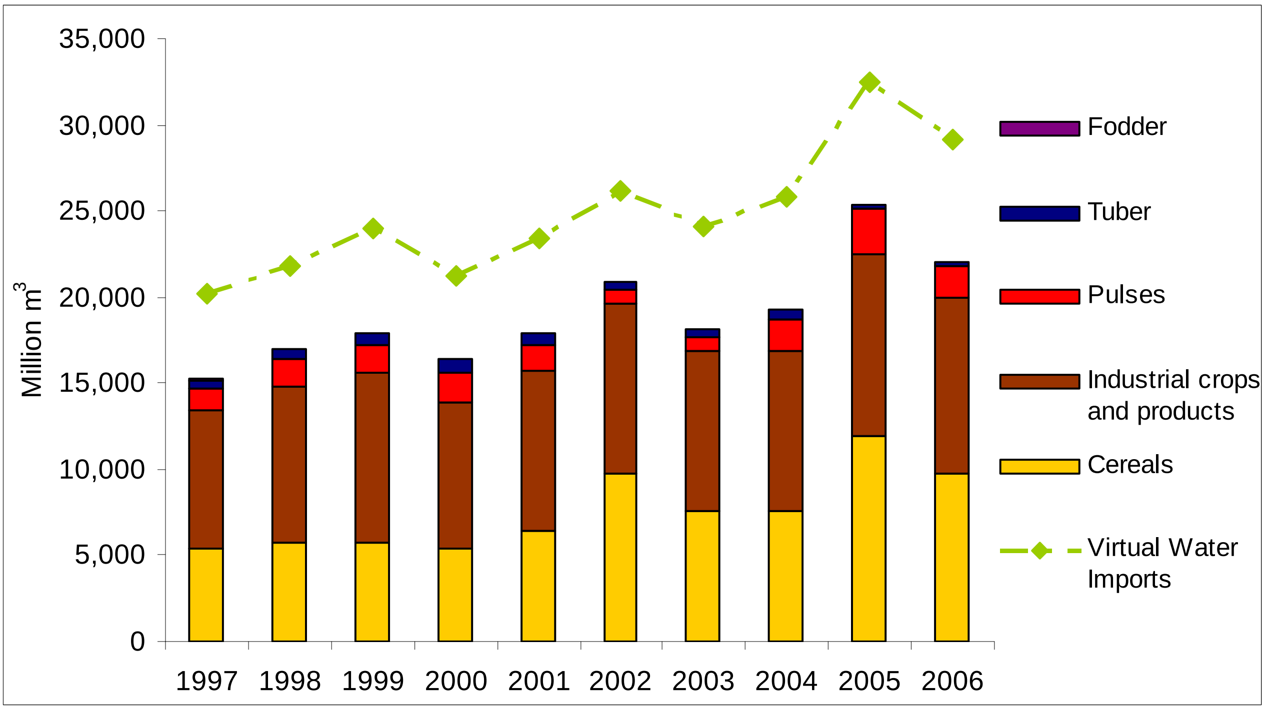
Source: Own elaboration

As illustrated in Figures 2 and 3, virtual water ‘imports’ totalled 20,147 million m^3 in year 1997 and increase up to 29,150 million m^3 in year 2006. A maximum of 32,500 million m^3 was reached in year 2005, which in terms of precipitation was also the driest year of the series. Even though farm trade responds 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 of virtual water 'imports' are directly connected to the livestock sector. Almost 100% of the soya cake consumption and 75% of cereals and pulses' consumption is used for animal feeding (MAPA, 2008). Spanish meat production has grown from 3.6 to 5.8 million tones during the period 1992-2007 (ibid.).

Figure 3.Virtual water 'imports' related to livestock production

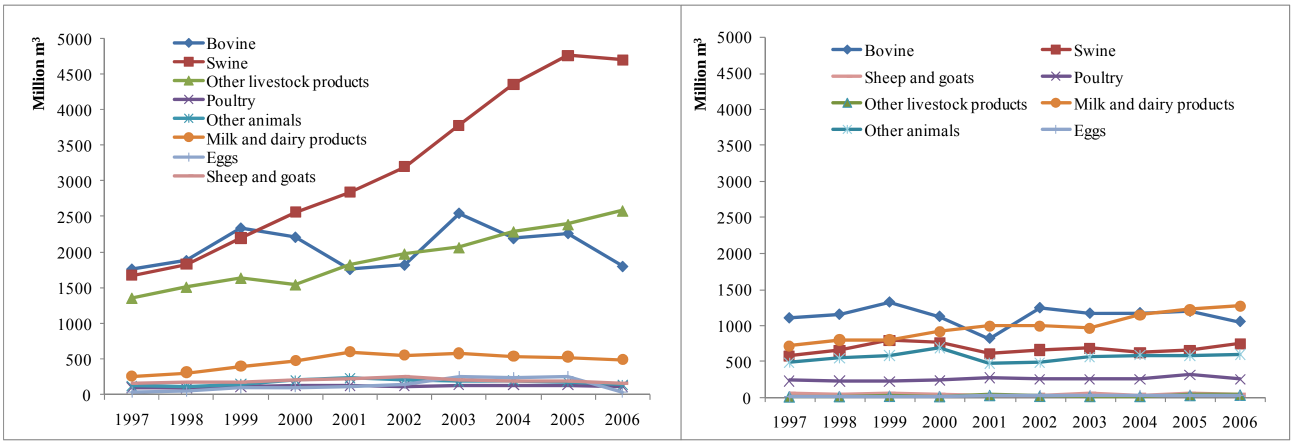


Source: Own elaboration

According to official data, livestock direct water use is about 260 Mm^3 (MMA, 2008). However, Spain has virtually 'exported' about 10,000 million m^3 per annum by means of animal product exports. As Figure 4 shows, 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 4500 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.

Figure 4. Livestock virtual water ‘flow’

a. Virtual water ‘exports’ b. Virtual water ‘imports’

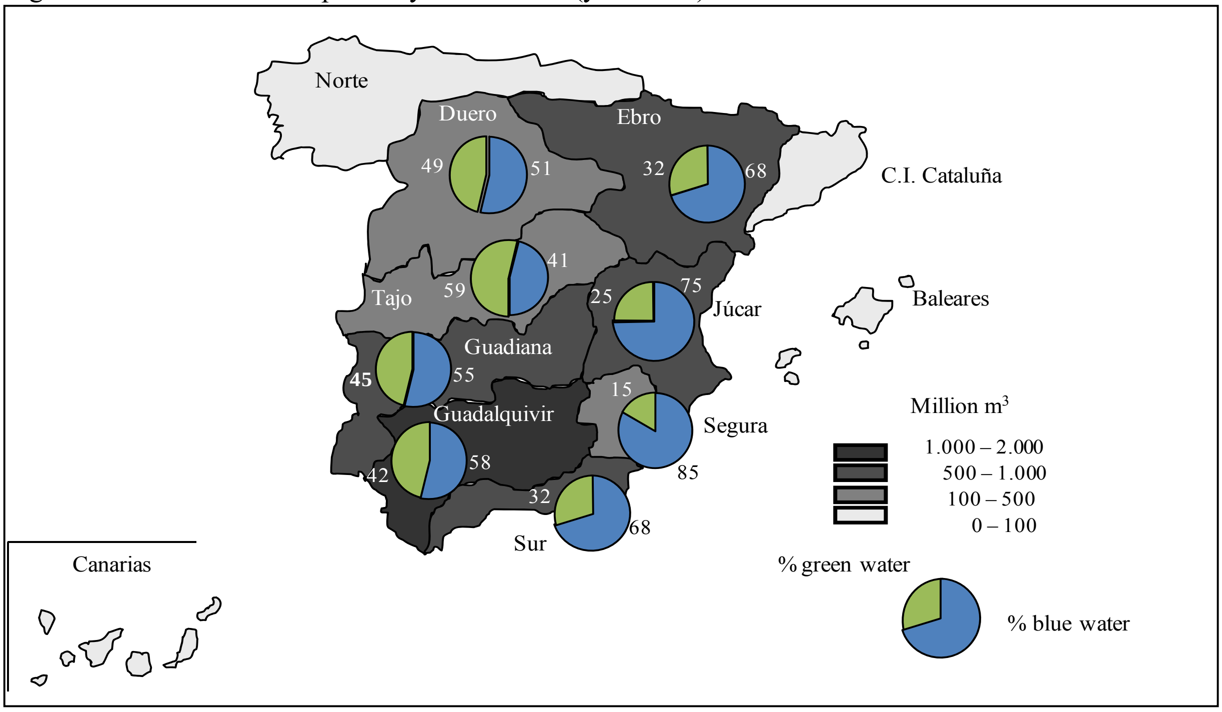


Source: Own elaboration

Figure 5 shows the virtual water ‘exports’ for each major basin, with an indication of the blue and green water components. Climatic conditions favor crops with intense water demand, which can grow to its full potential only with irrigation water. The Guadalquivir basin is the one with largest virtual water ‘exports’, totaling 1650 million m^3 per annum

Olive oil is the main exported product from the Guadalquivir basin. But since most olives’ acreage is cropped under rainfed systems, only 58% of the exports represent blue water abstracted in the basin. The Jucar basin comes second and ‘exports’ about 900 million m^3, citrus crops being the major exported crops. Because the Jucar and Segura basins are very arid, most ‘exported’ water is blue. In the mainland basins, primarily Tajo, Ebro and Duero, most ‘exported’ water is green water embedded in rainfed cereal crops. Note that the most water stressed basins, Mediterranean Southeast basins, are those that 'export' more virtual water through high valued crops.

Figure 5. Virtual Water 'Exports' by River Basin (year 2006)



Source: Own elaboration

3.2. Econometric analysis: regression results

As Figure 5 shows there are very large differences of green and blue water use in agriculture across basins. 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 10. Tables 2 and 3 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 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.

Table 2. 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<0.05*, p<0.01**						

Table 3. 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		
p<0.05*, p<0.01**			

Basin (β_{3i})	Coef.	Std.Err	Basin	Coef.	Std.Err	Basin	Coef.	Std.Err
Ebro	55.8346**	3.4548	Segura	232.9477**	9.4501	Canarias	44.5612**	5.0822
Guadalquivir	200.5525**	17.2891	Tajo	8.5104**	2.0861	Baleares	15.5284**	3.8057
Guadiana	71.2109**	4.9076	Sur	115.9937**	7.7616			
Júcar	132.112**	7.1650	Catalonia	1.1457	3.3966			
p<0.05*, p<0.01**								

The estimation of model [13] 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 what influences more the amount of 'exported' water in each province, than the water scarcity component.

4. Conclusions

Spain's farm trade has increased significantly during the 10-year period of analysis 1997-2006. Virtual water 'trade' has also grown in both directions, but embedded in entirely different products. By far the largest virtual water 'imports' are linked to cereals and animal feed products, totaling a water amount that is equivalent to total water use in Spain. The virtual water 'exports' are linked to exports of animal products, fruits and vegetables. Spain is clearly a net and increasing 'importer' of virtual water 'trade'. 'Imported' virtual water varies with drought cycles and cushions the effect of lower cereal yields cause by droughts. The animal sector is thus sheltered from domestic supply shocks, and keeps its competitive edge in the EU market, independently of the domestic cereals and feed production. Virtual water 'trade' is one way to reduce the vulnerability of the agri-food sector to climate instability, even in countries, like Spain, which are both large importers and exporters of food products. It reinforces the competitive advantages of its natural endowments and capital investments in agriculture.

In light of Spain's observed virtual water 'trade', one can conclude that as semi-arid economies expand they become bigger water net 'importers'. But virtual water 'exports' may grow too, because trade allows for land and water substitution that in turn allows for more production specialization and bigger farm exports. In the case of Spain, the clear advantage of its benign climate is accompanied by the not so clear competitive advantage of intensive animal production, which may be linked to less stringent environmental enforcement than in other EU countries.

This paper 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.

It can then be concluded that in the Spanish economy, agricultural trade flows are to a large extent decoupled from water use and water scarcity signals and respond primarily to region-specific natural conditions and capital accumulation patterns. Virtual water trade facilitates specialization and competitiveness, adding more valuable products to the domestic and international markets than would be the case without it.

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