Working papers series

WP ECON 06.06

Virtual water and water trade in Andalusia. A study by means of an input-output model

Erik Dietzenbacher (U. of Groningen)
Esther Velázquez (U. Pablo de Olavide)

JEL Classification numbers: R15, Q25, Q17.
Keywords: Input-Output Models, Virtual Water, Trade and Sustainability

Department of Economics

TITLE- Virtual water and water trade in Andalusia. A study by means of an input-output model

AUTHORS- Erik Dietzenbacher (Faculty of Economics, University of Groningen) **and Esther Velázquez (**Departamento Economía, Métodos Cuantitativos e Historia Económica, Universidad Pablo de Olavide)

ABSTRACT

Andalusian agricultural sectors are relatively small, but consume by 90% of the available water resources. More than 50% of the final demands for agricultural products are exported to other Spanish regions or abroad. Using a virtual water concept with an input-output framework, we find that a substantial part of the Andalusian water consumption is necessary for exports. Considering the water content of its trade, Andalusia is found to be a net exporter of water, whereas it is an extremely arid region. Examining regional policy aspects, a reduction in the exports abroad of agricultural products yields considerable benefits in terms of water savings and only moderate costs.

Key words: Input-Output Models, Virtual Water, Trade and Sustainability

JEL Classification: R15, Q25, Q17.

1. Introduction

In the dry regions of the planet, where the shortage is not only physical, but also social and economic (Aguilera-Klink, 1994), and where it is difficult to allocate this resource to its appropriate uses, it is absolutely necessary to discover new ways to alleviate the pressure on water resources. On the one hand, the transfer of massive quantities of water is difficult, costly, and most of the times, absolutely unsustainable. On the other hand, the building of hydraulic infrastructures is always expensive and problematical in social and environmental terms. This article supports the voices that defend virtual water as a means to mitigate the pressure on water resources, using a input-output framework.

The new approaches have brought about a new idea called Virtual Water (VW), which tries to give an explanation to the demand management. Allan (1993, 1994) first defined this idea in terms of the water embodied in a certain product, that is, the water necessary for creating a product. The most widely accepted definition of VW is that given by Allan in 1998, namely, the amount of water consumed in the production process of a product, that is, the virtual water embodied[1] in the product. The concept of virtual water becomes more relevant if we relate it to trade dealings between different regions since this concept involves a virtual "transfer" of water. To put the matter differently, the exchanges of products between regions enable them to exchange water as well.

Even though the concept of virtual water is rather recent, it is true that the virtual water trade is as old as the goods trade itself. Therefore, virtual water trade is somewhat a reallocation of the water associated to the products that are exchanged.

[1] Allan uses the expression "VW contained in the product". Note that "contained" does not necessarily imply the water which is physically contained within the product but the water used to produce goods or services.

This trade entails a flow of virtual water from exporting to importing regions or countries. Nowadays, all countries are both importers and exporters of this valuable resource although, from an economic point of view and following comparative advantages theory on international trade, water-poor countries should be importers and water-rich countries should be exporters.

Many of the semi arid countries in the Middle East have sorted their problems out by means of food policies and strategies inspired by common sense. Some of these countries, such as Israel or Jordan, have implemented policies that have reduced, or even abandoned, the export and the production of water-intensive crops. Therefore, they have been replaced with either imports or crops that optimise the water resources (Van Hofwegen, 2004). With relation to this, Velázquez (2005) points out the incoherence of the productive specialisation of Andalusia, where most of the produce requires a lot of water in a water-scarce region such as ours. The author points out the incongruity between the productive specialisation of Andalusia and the scarce water resources available in the region because of the water intensive production.

Regarding with the international trade, the idea that it plays an important role in sustainable development has been widely accepted in recent years and has given rise to a substantial body of literature. In particular the analysis of international flows of pollutants (such as CO_2, SO_2, and NO_x emissions) has received a lot of attention, but also the use of natural resources has been extensively investigated. The input-output framework appears to be a very useful framework, because it takes the interdependent structure of production into full account (see, for example, Antweiler, 1996; Kainuma *et al*., 2000; Munksgaard and Pedersen, 2001; Machado *et al*., 2001; Atkinson and Hamilton, 2002; Murudian *et al*., 2002; Sanchez-Chóliz and Duarte, 2004). Much less attention has been paid to analyzing the effects of trade on the preservation of water resources in areas with water deficits. This perspective is different from the previous one because, if a region with a water shortage exports water, the region's sustainability will be negatively affected immediately. In the same way, imports of water from other regions with a surplus of water will exert a positive contribution to the region's sustainability.

Within the input-output framework, virtual water would be defined as the amount of water that is (directly and indirectly) required to produce one unit of final demand for some product or service. Virtual water is thus not the physical amount of water contained in the good, but the water that has been necessary for its production.

It is well known that Andalusia is one of the most arid regions in Europe with a considerable water shortage. At the same time, however, some of its sectors consume water in a highly intensive way. Therefore, water is a strategic factor for the development of the region. In this paper, we focus on the destination of this resource, after it has been embodied into production. That is, using a virtual water concept with an input-output framework, we trace to which final demands the water consumption should be attributed to and whether this destination is domestic (i.e. within Andalusia) or not. This allows us to determine the trade of water that is directly and indirectly embodied in, for example, the exported products and services.

The plan of the paper is as follows. Section 2 briefly discusses some of the geographical and economic characteristics of Andalusia that are relevant for our study. The input-output framework in relation to water consumption is presented in Section 3. As descriptive measures, we will discuss the direct water coefficients and the water multipliers. Section 4 appropriates water consumption to the actual final demands. Regional policy aspects are taken into account in Section 5. We discuss how nullifying certain exports affects the water consumption, the gross regional product, the employment, and the regional trade balance. Section 6 deals with the water content of Andalusian imports and exports, and examines whether its trade pattern is in line with the HO theory. Our conclusions are given in Section 7.

2. Geographical and development aspects

Apart from being a vital element for life, water is also a strategic resource for any economic activity. The extent to which water is available may condition the development of a region in a significant way. In order to determine the role that water plays in the Andalusian economy, we will discuss some geographical features of the region as well as some relevant aspects about water and its main uses in Andalusia.

Andalusia is strategically located in the south of Spain and may be described as a vast triangular plain of 87,561 Km^2 (which is 17% of the Spanish territory). This plain is bordered in the north by the Sierra Morena and the Bética mountains; in the south-west by the Atlantic Ocean; and in the east and south-east by the Mediterranean Sea. Due to this geographical situation, Andalusia has a Mediterranean climate, characterized by irregular rainfall – both over time and across space – and long hot summers with a high evapotranspiration.

The hydrographical network consists of five river basins: the Guadalquivir basin, the Guadiana basin and the Guadalete-Barbate basin, each flowing into the Atlantic Ocean; and the South and the Segura basins flowing into the Mediterranean Sea. The data in Table 1 show the size of the basins and the amount of water they provide (note that the Guadiana basin is split into two parts). The figures in the first column give the total size of each basin (in Km^2). Some basins (in particular Guadiana I and Segura), however, are essentially outside Andalusia. The figures in the second column give the size of each basin within Andalusia, and those in the third column the percentage of the total Andalusian territory that they cover. With 59%, the Guadalquivir basin is clearly the largest within Andalusia. The figures in the fourth and fifth column show how much water (in billion liters per year) is provided by each of the basins. Note that 73% of this is surface water, while 27% is from underground reservoirs.

Table 1. Water resources

	Basin surface (in Km^2)			Resources (in billion liters per year)	
Basin	Total	In Andalusia	Percentage	Surface	Sub terranean
Guadalquivir	57,104	51,477	59	2,255	437
Guadalete/Barbate	6,365	6,365	7	358	85
South	17,820	17,820	20	414	630
Guadiana I	53,067	3,248	4	1	6
Guadiana II	6,871	6,871	8	275	60
Segura	18,870	1,780	2	1	5
Total	160,097	87,561	100	3,304	1,223

Source: Consejería de Medio Ambiente (2004).

The economic development of Andalusia has induced an increase in the demand for water over time. In its turn, this has led to a stronger pressure on the scarce water resources. As we will see in more detail in the next section, the agricultural sectors absorb 90% of the available water resources due to the very large amount of irrigated land. According to Lopez-Fuster and Montoro (2002, p. 3), Spain ranks third in the world and first in Europe, in terms of irrigated land. Andalusia covers 23.3% of the Spanish irrigated land (Consejería de Agricultura y Pesca, 1999,

p. 84). This is a very high percentage if we take into account that Andalusia is the most arid region in the country and the one with the most serious problems of water shortages. The problems are further aggravated because the existing irrigation systems are rather old and only few hi-tech systems that save water are used. Irrigation by gravity is still the system that is used most widely in the region (44.9%).

In addition, the effects of the large number of tourists that visit the Andalusian coast should be mentioned. Together with the agricultural activities, tourism has risen the demand for water to such an extent that the coastal areas are mostly irrigated with underground water. A consequence of this is that intrusion of salty sea water takes place, which raises the problems due to overexploitation even further.

Next to the agricultural sector, also the manufacturing sector has undergone a large development. This occurred mainly in the Guadalquivir river basin – which holds in particular for the food and agricultural products sector, which consumes a considerable amount of water (Velázquez, 2005) – and around the major cities and the main harbours of the region. Finally, tourism has become one of the important drivers of the region. The tourist activities require a lot of water, especially in summer, which conflicts with the use in the agricultural sector.

3. An explorative analysis of water consumption

In this section we will discuss water consumption at the sectoral level. We have used the Andalusian input-output table for 1990 (see Instituto de Estadística de Andalucía, 1995) and data on water consumption (Agencia de Medio Ambiente, 1996). The first column in Table 2 gives the vector **w** with sectoral water consumption (in billion liters). It shows that 90% of all the water consumption takes place in the agricultural sectors (1-6). Manufacturing (sectors 7-19) and services (sectors 20-25) each account for 5% of the water consumption. The second column gives the vector **x** with sectoral production (in million euros). It follows that agriculture accounts for only 8% of the total output, manufacturing for 34%, and services for 58%. So, almost all water is consumed by sectors that are responsible only for a minor share in the output.

Table 2. Aspects of water use at the sectoral level

j	Sector	Water use w_j	Output x_j	Direct Coefficients $y_j = w_j / x_j$	Virtual water multipliers $\Sigma_i y_i l_{ij}$
1	Cereal and legumes	883	482	1,833	1,927
2	Vegetables and fruits	906	1,326	683	693
3	Citrus fruits	321	103	3,129	3,136
4	Industrial plants	183	383	478	505
5	Olive groves	465	836	556	560
6	Other agricultural products	279	1,907	146	258
	Agriculture total	*3,037*	*5,037*	-	-
	average	-	-	*603*	*682*
7	Extractive industry	16	4,705	3	6
8	Water	0	151	0	4
9	Metallurgy	25	1,683	15	19
10	Construction materials	6	1,256	5	9
11	Chemicals and plastics	41	1,727	24	31
12	Machinery	1	1,080	1	4
13	Transportation materials	3	1,542	2	5
14	Food processing	30	6,350	5	190
15	Textiles and apparel	5	1,132	4	41
16	Footwear and leather products	0	99	3	7
17	Wood products	3	823	4	9
18	Paper, printing and publishing	24	629	38	57
19	Miscellaneous manufacturing	1	499	2	5
	Manufacturing total	*155*	*21,676*	-	-
	average	-	-	*7*	*74*
20	Construction	17	7,308	2	7
21	Trade	17	6,107	3	6
22	Hotel and catering trade	71	4,073	17	80
23	Transportation, communications	12	3,748	3	6
24	Sales related services	33	9,188	4	8
25	Non-sales related services	23	5,816	4	8
	Services total	*173*	*36,240*	-	-
	average	-	-	*5*	*15*
	Total	**3,365**	**62,952**	**-**	**-**
	Average	**-**	**-**	**53**	**74**

The third column in Table 2 gives the vector **y** with direct water input coefficients. They are defined as $y_i = w_i / x_i$ and describe the water consumption (in liters) per euro of production. On average this coefficient is 53, but note that there is an extreme variance across sectors. In particular citrus fruits (sector 3) and cereals and legumes (sector 1) require an enormous amount of water per euro output. Also the other four agricultural sectors are well above average. Consequently, the manufacturing and service sectors must have coefficients much smaller than average. We see that only three manufacturing sectors (metallurgy, 9; chemicals and plastics, 11; and paper, printing and publishing, 18) and one service sector (hotel and catering, 22) consume more than 5 liter per euro production.

Although cereals and legumes (sector 1) has a very high direct water input coefficient and absorbs more than 25% of all the water, a large part of its products are sold to the food processing sector (14). So, indirectly, the food products contain a considerable amount of water, because this sector requires cereals and legumes as its inputs. The appropriate way to take all such indirect effects into account is by using an input-output framework. Consider the input-output table (in monetary terms) as given by Table 3.

Table 3. The input-output table

Z	**F**	**x**
$\mathbf{v}'$		
M		
$\mathbf{x}'$		

The typical element z_{ij} of the $n \times n$ matrix **Z** gives the intraregional intermediate deliveries. That is, the deliveries from sector *i* in Andalusia to sector *j* in

Andalusia, with i, j = 1, …, n. The element f_{ij} of the $n \times k$ matrix **F**, gives the deliveries of sector i in Andalusia to the final demand category j (= 1, …, k). The final demand categories are private consumption, public consumption, investments, exports to the rest of Spain, exports to other EU countries, and exports to the rest of the world. The row vector $\mathbf{v}'$ gives the value added in each sector (which comprises wages and salaries, depreciation, operating surplus, and indirect taxes minus subsidies). Note that the sum of this vector gives the total value added in Andalusia, which is its gross regional product (GRP, similar to GDP). The typical element m_{ij} of the $n \times n$ matrix **M** gives the imports that originate in a "foreign" (i.e. either in the rest of Spain or an other country) sector i and that are bought by the Andalusian sector j. The elements x_i of vector **x** give the (gross) output or money value of the production in sector i in Andalusia.

Note that the sectoral outputs may be obtained by summing over the rows or the columns. Summing over the columns yields the following accounting equation; $x_i = \Sigma_j z_{ij} + \Sigma_j f_{ij}$. Direct input coefficients are defined as $a_{ij} = z_{ij} / x_j$ and they indicate the (extra) input in euros from sector i in Andalusia, that is required for the (extra) production of one euro by sector j in Andalusia. Using this definition and collecting the final demand categories (i.e. $f_i = \Sigma_j f_{ij}$), implies that the accounting equation can be rewritten as $x_i = \Sigma_j a_{ij} x_j + f_i$, or as $\mathbf{x} = \mathbf{Ax} + \mathbf{f}$ in matrix notation.

If the matrix **A** with direct input coefficients is assumed to be constant, it is possible to evaluate how much output each sector must produce for any given (i.e. exogenously specified) final demand vector (say $\widetilde{\mathbf{f}}$). The solution yields $(\mathbf{I} - \mathbf{A})^{-1}\widetilde{\mathbf{f}} = \mathbf{L}\widetilde{\mathbf{f}}$, where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ denotes the Leontief inverse or multiplier matrix. Taking $\tilde{\mathbf{f}} = (0,...,0,1,0,...,0)'$, i.e. the jth unit vector, provides the interpretation of the elements of the Leontief inverse. That is, l_{ij} gives the (extra) output in sector i that is necessary for one (extra) euro of final demand in sector j. These elements of **L** take all direct and indirect effects into consideration. Taking the column sums of the Leontief inverse gives the so-called output multipliers. That is, $\Sigma_i l_{ij}$ indicates the total (extra) output that must be produced for one (extra) euro of final demand in sector j.

Multiplying the elements l_{ij} by the direct water input coefficient y_i (i.e. $y_i l_{ij}$) tells us how many (extra) liters of water would be (directly and indirectly) involved in sector i for generating one (extra) euro of final demand in sector j. Summing over i gives the total (extra) amount of water that is required per (extra) euro of final demand in sector j. These water multipliers (i.e. $\Sigma_i y_i l_{ij}$) are given in the fourth column of Table 2.

Note that the average water multiplier is 38% larger than the average direct water input coefficient. The first is obtained as the total water consumption (3,365 billion liters) divided by the total final demands (45,651 million euros). It thus gives the weighted average of the separate water multipliers, using sectoral final demands as weights. The second is obtained by dividing the total water consumption by total production (62,952 million euros). The average direct water input coefficient uses sectoral outputs as weights.

The results in Table 2 for the water multipliers again show the distinction between the agricultural sectors (1-6) and the other sectors. Two of these sectors that should be mentioned are food processing (sector 14) and hotel and catering trade (22). Both have considerable multipliers but only modest direct water input coefficients.

This means that relatively little water is consumed by the sectors themselves, but indirectly a fairly large amount of water is necessary for their products. The matrix **A** of intermediate input coefficients confirms that hotel and catering trade strongly relies on inputs from food processing, which in its turn relies heavily on inputs from the agricultural sectors that are highly water intensive.

4. Appropriation of water consumption

The Andalusian input-output table lists several final demand categories. For our analyses, we have aggregated them into the following four. Domestic (i.e. Andalusian) final demand (indicated by the vector $\mathbf{f}^{AND}$), which covers private and public consumption and investments; exports to the rest of Spain ($\mathbf{f}^{RoS}$); exports to the rest of the European Union ($\mathbf{f}^{RoEU}$); and exports to the rest of the world ($\mathbf{f}^{RoW}$). These final demand vectors are listed in the first four columns of Table A1 in the Appendix. They show that more than 50% of the final demands in agriculture (sectors 1-6) are exports. Given the extremely large water multipliers, it may be expected that Andalusia indirectly exports a substantial amount of water.

To analyze the total (i.e. direct and indirect) water consumption that is necessary for the actual final demands (in million euros) we have calculated $\Sigma_{i=1}^{25} y_i l_{ij} f_j^{AND}$ for j = 1, …, 25. This gives the water consumption (in billion liters) that can be appropriated to the actual Andalusian final demand for product j. For the other categories we have $\Sigma_{i=1}^{25} y_i l_{ij} f_j^{RoS}$, $\Sigma_{i=1}^{25} y_i l_{ij} f_j^{RoEU}$, and $\Sigma_{i=1}^{25} y_i l_{ij} f_j^{RoW}$, respectively. The results are given in the fifth to eighth column in Table A1. For example, the 34.6 million euros of Andalusian final demand for cereals and legumes have required, directly and indirectly, 66.3 billion liters of total water.

A summary of the detailed results in Table A1, is given in Table 4. The sectors have been aggregated into Agriculture (sectors 1-6), Manufacturing (7-19) and Services (20-25). The results give the final demands and the appropriated water consumption as a percentage of the total (45,650.8 million euros and 3,364.7 billion liters). It turns out that the final demands for agricultural products are only 6% of the total final demands but require no less than 54% of all water consumption. Final demands for services, on the other hand, amount to 61% of the total and are responsible for only 13% of the actual water consumption. The exports are 27% of all final demands, but account for more than half (52%) of the water consumption.

Table 4. Aggregated results for the final demands and the virtual water contents

	Final demand categories				
	Andalusia	Exports to the Rest of Spain	Exports to the Rest of the EU	Exports to the Rest of the World	Total
	Final demands (*as % of total final demands*)				
Agriculture	2.7	2.1	0.9	0.1	5.8
Manufacturing	11.2	15.7	3.4	3.1	33.4
Services	59.0	1.8	0.0	0.0	60.8
Total	72.9	19.6	4.3	3.2	100.0
	Virtual water content (*as % of total water consumption*)				
Agriculture	23.5	19.0	10.0	1.2	53.7
Manufacturing	11.7	16.2	3.5	2.3	33.7
Services	12.5	0.1	0.0	0.0	12.6
Total	47.7	35.3	13.5	3.5	100.0

The most striking result is that the exports of agricultural products are only 3% of the total final demands, but they require 30% of the total water consumption. Another major water-using sector is food processing. From Table A1 it follows that its final demands are 11% (its exports 7%) of the total final demands, while the appropriated water consumption is 29% (respectively 19%) of the total water consumption.

5. Policy aspects

The results in the previous section show that 49% of the actual water consumption could have been saved, if Andalusia had stopped exporting agricultural products and food processing goods (which, together, account for only 10% of the total final demands). Of course, in considering such a drastic reduction also other effects need to be taken into account. A decrease of the exports implies a fall in production and thus also a drop in employment and value added (or gross regional product, GRP). In addition, the regional trade balance is affected.

In this section we will calculate the effects of a complete nullification of the "foreign" exports (i.e. to the rest of the EU and to the rest of the world). It is assumed that the exports to other Spanish regions remain as they are. The effects on the water consumption can be readily obtained from summing the elements in the seventh and eighth column of Table A1. To derive the effect on value added, define the direct value added coefficient as $\mu_i = v_i / x_i$, indicating value added per unit of output. A full reduction of the foreign exports of sector j reduces the GRP by $\Sigma_{i=1}^{25} \mu_i l_{ij} (f_j^{RoEU} + f_j^{RoW})$. The employment effect could have been obtained in a similar way, if the data had been available. As an approximation, we have computed the reduction in the labour costs. Define $\omega_i = w_i / x_i$, with w_i the wages and salaries (including employers' contributions) paid in sector *i*. Then $\Sigma_{i=1}^{25} \omega_i l_{ij} (f_j^{RoEU} + f_j^{RoW})$ gives the reduction in labour costs due to nullifying the foreign exports of sector *j*. If this reduction is expressed as a percentage of the total labour costs, it equals the percentage reduction in employment if the average wage rate is the same in all sectors. Because this will not be the case, the reduction in labour costs can only be used as an approximation of the employment effect.

If the foreign exports of sector j are nullified, the regional trade balance (defined as Andalusian exports minus imports) deteriorates by $f_j^{RoEU} + f_j^{RoW}$. Because the production is reduced as a consequence of the decline in exports, less imports (from the rest of Spain, the rest of the EU and the rest of the world) are required. The decrease in imports amounts to $\Sigma_{i=1}^{25}\eta_i l_{ij}(f_j^{RoEU} + f_j^{RoW})$, with $\eta_i = m_i / x_i$ the direct import coefficients, where m_i denotes the total imports of sector i. Hence, the total deterioration of the regional trade balance due to the nullification of the foreign exports of sector j yields $(1 - \Sigma_{i=1}^{25}\eta_i l_{ij})(f_j^{RoEU} + f_j^{RoW})$.

A summary of the results is given in Table 5. The first six rows report the effects of the nullification of each agricultural sector separately. The row "Total Agriculture" shows the effects if the foreign exports are nullified in all agricultural sectors. In the same way, the findings in the row "Total Manufacturing" give the effects of a complete export reduction in all manufacturing sectors (7-19). Given its importance, the results for the food processing sector (14) are also shown separately. The row "Total Services" gives the effects of nullifying the foreign exports in all service sectors (20-25) and the final row "Total" shows the effects for the case in which all foreign exports are abolished.

The findings in Table 5 indicate that substantial savings in water consumption may be obtained at relatively low costs (in terms of reducing GRP, labour costs and the trade balance). Consider the nullification of the foreign exports by the agricultural sectors and the food processing sector. Their foreign exports amount to 1,341.1 million euros, which is 3% of the total final demands (and 11% of the total Andalusian exports, including those to the rest of Spain). The water consumption reduces by 16% while the decrease in GRP is only 3%. The 5% fall in labour costs (which may be used as a rough approximation of the reduction in employment) is somewhat higher but still modest. The export reduction implies that also the imports are reduced (by 295.1 million euros) so that the Andalusian trade balance deteriorates by 1,046.0 million euros.

Table 5. The effects of the nullification of "foreign" exports

	Exports[1]	Water Use[2]	Value added[2]	Labor Costs[2]	Trade Balance[3]
Cereal and legumes	0.10	2.51	0.10	0.14	34.7
Vegetables and fruits	0.73	6.86	0.79	2.17	290.0
Citrus fruits	0.02	1.17	0.03	0.19	11.3
Industrial plants	0.03	0.19	0.02	0.09	8.2
Olive groves	0.00	0.01	0.00	0.01	0.6
Other agricultural products	0.12	0.42	0.12	0.18	46.0
Total Agriculture	*1.00*	*11.17*	*1.07*	*2.80*	*383.8*
Food processing	1.94	4.99	1.84	2.67	662.2
Total Manufacturing	*6.52*	*5.83*	*5.41*	*9.56*	*1,942.6*
Total Services	*0.05*	*0.00*	*0.06*	*0.02*	*23.4*
Total	7.57	17.00	6.54	12.38	2,349.7

1) Exports as percentage of the total final demands. 2) Reduction in water use (value added, labour costs) as percentage of the actual water use (resp. value added, labour costs). 3) Deterioration of the Andalusian trade balance in million euros.

The nullification of the foreign exports in a set of sectors may seem to be a very heroic assumption. It should be emphasized, however, that the model we have used for our calculations is linear. This implies that the results in Table 5 can be used for any other reduction. For example, reducing the foreign exports in vegetables and fruits by 60% and those in food processing by 20% would result in a saving of water by $0.6 \times 6.86 + 0.2 \times 4.99 = 5.11\%$, while the GRP falls by 0.84% and the labour costs by 1.84%.

6. The water content of trade

The results in the previous sections have shown that the goods produced by the agricultural sectors and by food processing are highly water intensive (using 82.6% of of annual water consumption). At the same time, only 38.3% of these products are destined for the domestic Andalusian final demands. We could say that Andalusia exports a major part of its available water, although it is one of the most arid areas in Europe. The question, however, is whether it is a net exporter of water. It might be the case that it imports even more water than it exports.

According to the well known Heckscher-Ohlin (HO) theory of trade, a country exports the products in which it has a comparative advantage. These are the products that intensively use those factors, which are relatively abundant in the country. Similarly, countries import products that intensively use factors which are relatively scarce in the country. Taking water into account as a production factor, Andalusia has anything but a comparative advantage in producing water-intensive goods.

The first empirical test of the HO theory was by Leontief (1953, 1956). He calculated the extra – direct and indirect – labor and capital requirements necessary to satisfy $1 million of extra exports. In the same way, the decreases in requirements were calculated for the case where a reduction of domestic output was replaced by extra imports (to the amount of $1 million). The US was found to export labor intensive goods and to import capital intensive goods, whereas it was commonly believed to be the most capital abundant country at that time. This result has become known as the Leontief paradox and still continues to trigger ample scientific research.

In this section we will calculate the water content of the exports and imports. It is assumed that the exports, for example those to the rest of Spain, are increased by one million euros using the product mix of the current exports. Hence, we construct a vector $\bar{\mathbf{f}}^{RoS}$ that has the same distribution as $\mathbf{f}^{RoS}$, but its elements sum to one million. That is, $\bar{f}_j^{RoS} = 1{,}000{,}000 \times f_j^{RoS} / \Sigma_i f_i^{RoS}$. The water requirements (or water content) of the extra exports of product j are then obtained as $\Sigma_{i=1}^{25} y_i l_{ij} \bar{f}_j^{RoS}$. Leaving the regional trade balance unaffected, it is assumed that also the imports (in this case from the rest of Spain) increase by one million euros. This implies that these products do not need to be produced in Andalusia anymore, so that the regional water requirements decrease. Denote the vector of imports by $\mathbf{m}^{RoS}$, then a one million euro increase of the imports implies that the imports of product j are raised by $\overline{m}_j^{RoS} = 1{,}000{,}000 \times m_j^{RoS} / \Sigma_i m_i^{RoS}$. The water requirements then decrease by $\Sigma_{i=1}^{25} y_i l_{ij} \overline{m}_j^{RoS}$ due to the increased imports of product j.

The total extra water requirements due to the extra exports are given by $\Sigma_{j=1}^{25} \Sigma_{i=1}^{25} y_i l_{ij} \bar{f}_j^{RoS}$ and the total decrease in water requirements due to the extra imports yield $\Sigma_{j=1}^{25} \Sigma_{i=1}^{25} y_i l_{ij} \overline{m}_j^{RoS}$. (In matrix notation the expressions are given by $\mathbf{y}'\mathbf{L}\bar{\mathbf{f}}^{RoS}$ and $\mathbf{y}'\mathbf{L}\overline{\mathbf{m}}^{RoS}$, respectively.) According to the HO theory, a region that is scarce in water would be expected to save water by increasing trade. That is, $\mathbf{y}'\mathbf{L}\overline{\mathbf{m}}^{RoS} > \mathbf{y}'\mathbf{L}\bar{\mathbf{f}}^{RoS}$. In other words, the water content of its imports should be larger than the water content of its exports.

We have calculated the water content for trade with the rest of Spain, with the rest of the EU, with the rest of the world, and total trade. The results are given in Table 6. It should be mentioned that the import vectors we had to use only covered imports by production sectors. For trade with the rest of Spain and for trade with the rest of the EU, Table 6 reports that the water content of Andalusian exports is approximately twice as large as the water content of its imports. For trade with the rest of the world, the exports contain “only” 25% more water than the imports. The results in the total trade case are weighted averages of the separate results, using the actual imports and exports as weights (the imports -in million euros- are 6898 with the rest of Spain; 804 with the rest of the EU; and 2013 with the rest of the world. The corresponding exports are 8930, 1995, and 1466 million euros).

In explaining why the exports have a substantially higher water content than the imports have, two aspects stand out. First, the share of agricultural products (which are extremely water intensive) in Andalusian exports is much larger than their share in imports, except for trade with the rest of the world. Second, although the shares of manufacturing in exports and in imports are very similar, it turns out that the share of (relatively water intensive) food processing in exports is a multitude of its share in imports.

Table 6. Virtual water content of one million euros of imports and exports

	Import distribution (as percentage)	Virtual water content (in million liters)	Export distribution (as percentage)	Virtual water content (in million liters)
Trade with the rest of Spain				
Agriculture	5.3	39.3	10.8	71.6
Manufacturing	76.0	31.7	80.1	60.9
(of which food processing)	(10.2)	(19.4)	(27.8)	(52.8)
Services	18.8	1.1	9.0	0.5
Total	100.0	72.2	100.0	133.1
Trade with the rest of the EU				
Agriculture	13.7	80.7	20.3	168.8
Manufacturing	86.0	21.6	78.9	58.8
(of which food processing)	(3.6)	(6.8)	(26.9)	(51.1)
Services	0.3	0.0	0.8	0.1
Total	100.0	102.3	100.0	227.6
Trade with the rest of the world				
Agriculture	7.4	52.3	3.6	26.6
Manufacturing	92.4	12.6	95.8	53.6
(of which food processing)	(2.6)	(4.9)	(23.7)	(44.9)
Services	0.1	0.0	0.7	0.0
Total	100.0	64.9	100.0	80.3
All trade				
Agriculture	6.4	45.4	11.5	82.0
Manufacturing	80.2	26.9	81.8	59.7
(of which food processing)	(8.1)	(15.4)	(27.2)	(51.6)
Services	13.4	0.8	6.7	0.4
Total	100.0	73.2	100.0	142.1

7. Conclusions

Andalusia has a considerable water shortage, but at the same time 90% of its water consumption is localized in the agricultural sectors. Therefore, water is a strategic factor in the development of the region. In order to cope with the increasing problems due to the water shortages, an expanded and more effective regulation of water consumption seems necessary. Also a serious reconsideration of the production processes in which the region chooses to specialize in seems appropriate.

Our findings indicated that only 48% of the water consumption should be attributed to regional (i.e. Andalusian) final demands. Hence, no less than 52% of all water consumption appears to be necessary for producing goods and services that are exported to other Spanish regions or other countries. Our calculations have shown that substantial savings in water consumption may be obtained at relatively low costs, in terms of a reduced GRP, a loss of employment and a deterioration of the regional trade balance. For example, stopping the exports to other countries by the agricultural sectors and the food processing sector would reduce water consumption by 16%, while GRP falls only by 3%.

Andalusia is found to be a net exporter of products that intensively use its scarce factor water. Although the agricultural sectors generate only a small part of the Andalusian production and although the agricultural exports are only 15% of all exports, these products contain so much water that the water content of an average million euros of exports is substantially larger than the water content of an average million euros of imports. This finding seems to be in sharp contrast to the HO theory of trade. At the same time, however, it should be mentioned that the Andalusian climate is such that it has a comparative advantage in producing several agricultural products (such as citrus fruits) that require a large amount of sunshine and high temperatures. These "sun intensive" products, however, constitute only a relatively small part of the Andalusian production and exports. No matter whether the results contradict the HO theory or not, the fact remains that one of the most arid regions in Europe is a net exporter of water.

Our central conclusion is that it is necessary to pay attention to cases like water consumption in Andalusia, where a relatively small part of the regional production structure depends heavily on a very limited resource. If policy makers aim at changing this situation in order to arrive at a more sustainable economy that uses the scarce resource less intensively, there seem to be two options. The first is the one that is usually brought to the fore, i.e. technological change. By investing in R&D, new techniques might be developed (e.g. irrigation systems) that reduce the direct water coefficients and additional investments would enable their implementation. The second option is the one that is typically not even taken into consideration. That is, restructuring the production structure, for example by reducing exports that require large amounts of water and stimulating exports of products that are less water intensive. The findings in this paper have shown that the benefits may be substantial while the costs remain modest.

References

Agencia de Medio Ambiente (1996) *Las Tablas Medioambientales de Andalucía. 1990. Aproximación a la integración de las variables medioambientales en el modelo input-output*, Monografías de economía y medio ambiente, 7 (Junta de Andalucía, Sevilla).

Aguilera-Klink, F. 1994. "Agua, economía y medio ambiente: interdependencias físicas y la necesidad de nuevos conceptos". Revista de Estudios Agrosociales, 167. Allan, JA. 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be imposible. In ODA, Priorities for water resources allocation and management, ODA, London, pp.13-26.

Allan, JA. 1994. Overall perspectives on countries and regions. In Rogers, P.; Lydon, P. Water in the Arab World: perspectives and prognoses. Harvard University Press, Cambridge, Massachusetts, pp. 65-100.

Allan J.A. (1998) Virtual Water: a strategic resource. Global solutions to regional deficits, *Groundwater*, 36, 545-546.

Antweiler, W. (1996) The pollution terms of trade, *Economic Systems Research*, 8, 361-365.

Atkinson G. and Hamilton K. (2002) International trade and the ‘ecological balance of payments’, *Resource Policy,* 28, 27-37.

Consejería de Agricultura y Pesca (1999) *El Plan de Modernización de la Agricultura Andaluza, 2000-2006* (Junta de Andalucía, Sevilla).

Consejería de Medio Ambiente (2004) *Andalucía: Datos Básicos, 2002* (Junta de Andalucía, Sevilla).

Fishelson, G. (1994) The allocation of marginal value product of water in Israelí agricultura, in: J. Isaac and H. Shuval (eds) *Water and Peace in the Middle East* (Elsevier, Amsterdam), pp. 427-440.

Instituto de Estadística de Andalucía (1995) *Contabilidad regional y tabla input-output de Andalucía, 1990. Presentación de resultados* (Junta de Andalucía, Sevilla).

Kainuma, M., Matsuoka, Y. and Morita, T. (2000) Estimation of embodied CO_2 emissions by general equilibrium model, *European Journal of Operational Research,* 122, 392-404.

Lenzen, M. and Foran, B. (2001) An input-output analysis of Australian water usage, *Water Policy*, 3, 321-340.

Leontief, W. (1953) Domestic production and foreign trade; the American capital position re-examined, *Proceedings of the American Philosophical Society*, 97, 332-349.

Leontief, W. (1956) Factor proportions and the structure of American rade: further theoretical and empirical analysis, *Review of Economics and Statistics*, 38, 386-407.

López-Fuster P. and Montoso, A. (2002) El ahorro como principal recurso de agua para el futuro, Paper presented at Jornada Autonómica de la Comunidad de Castilla La Mancha, Toledo.

Machado, G., Schaeffer, R. and Worrell, E. (2001) Energy and carbon embodied in the internacional trade of Brazil: an input-output approach, *Ecological Economics*, 39, 409-424.

Munksgaard, J. and Pedersen, K.A. (2001) CO2 accounts for open economies: producer or consumer responsibility?, *Energy Policy*, 29, 327-334.

Murudian, R., O´Connor, M. and Martínez-Alier, J. (2002) Embodied pollution in trade: estimating the 'environmental load displacement' of industrialised countries, *Ecological Economics,* 41, 51-67.

Sanchez-Chóliz, J. and Duarte, R. (2004) CO_2 emissions embodied in international trade: evidence for Spain, *Energy Policy*, 32, 1999-2005.

Velázquez, E. (2006) An input-output model of water consumption: analysing intersectoral water relationships in Andalusia, *Ecological Economics* 56: 226-240.

Wilchelns D. (2001) The role of 'virtual water' in efforts to achieve food security and other national goals, with an example from Egypt, *Agricultural Water Management*, 49, 131-151.