Water Scarcity and Virtual Water Trade in the Mediterranean

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ABSTRACT

Virtual water trade refers to the implicit content of water in the production of goods and services. When trade is undertaken, there is an implicit exchange of water. Furthermore, when water gets scarce, water intensive goods become more expensive to produce and the economy compensates through higher water imports.

This paper is about applying the concept of virtual water trade to the problem of future water scarcity in the Mediterranean area, also induced by the climate change. The aim is assessing to what extent water trade is a viable adaptation option to the problem of water scarcity. To this end, a computable general equilibrium model is extended with satellite data on sectoral water consumption, and used to assess future scenarios of water availability.

It is found that virtual trade may curb the negative effect of water scarcity, yet the consequences in terms of income and welfare remain quite significant, especially for some regions. This suggests that specific water policies (water supply and demand management) will be needed.

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KEYWORDS: Computable General Equilibrium Models, Water, Virtual Water, Water Scarcity, Climate Change.

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1. Introduction

Water availability is a key factor in many societies, shaping cultures, economies, history and national identity. This is especially true in the Mediterranean, where water resources are limited and very unevenly distributed over space and time.

There is a growing concern about water resources in this region. On the demand side, during the second half of the 20th century, water demand has increased twofold, reaching 280 km^3/year (UNEP, 2006). Much of the demand comes from agricultural activities (45% in the North, 82% in South and East), but other industries also contribute significantly (most notably, tourism) and more competition for water resources can be easily foreseen in the near future.

On the supply side, many countries are already affected by over-exploitation of renewable water resources (often generating salt-water intrusion) and exploitation of non-renewable resources (including the so-called "fossil water"). In addition, most regional climate models predict a reduction in precipitation and water run-off in low-latitude regions, including the Mediterranean (although forecasts are affected by relevant uncertainty). Reduced precipitations are often associated with droughts, desertification, increased variability over time (which, somehow paradoxically, may give raise to floods).

Much can be done through improved water management, proper water pricing and international cooperation in the management of transboundary rivers and aquifers. It is estimated (UNEP, ibid.) that improved water demand management would make it possible to save 25% of water demand. Additional measures, such as the use of return water from agricultural drainage, the reuse of treated wastewater for irrigation, freshwater production through desalination of seawater or brackish water, may prove to be effective.

Water pricing is also an important issue (OECD, 2009). Water is sometimes free, under-priced, or subsidized, especially in agriculture. Economic theory suggests that when prices are not in line with the social marginal values, resources are inefficiently allocated. On the other hand, introducing water pricing is not easy and it would significantly affect the structure of regional economies and trade flows (Berritella et al., 2008). In the same vein, transboundary rivers and aquifers (e.g., the Jordan river) are often plagued by a classic "Tragedy of the Commons"[1], possibly bringing about social tensions and conflicts. Some pessimistic viewers have even envisaged future "water wars".

Since water is an essential production factor, especially in agriculture, its scarcity would result in higher production costs and lower productivity. This effect may operate through both market and non market mechanisms. If water is priced and its price gets higher, more production costs will bring about higher market prices for water intensive products. If water is not priced, there will be lower yield per unit of conventional production factor (labour, capital, land). In any case, this would be a reduction in the supply of water-needing goods, and the law of supply and demand in each market would push prices upward.

We can therefore expect water scarcity to cause higher prices and lower production volumes for water intensive industries and for those regions which are more severely constrained in terms of water resources. In turn, this loss of competitiveness would imply a shift away from water intensive

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[1] "Tragedy of the Commons" refers to a situation in which one resource is collectively owned but privately exploited. Since users do not (fully) internalize the social externality generated by the private consumption, the resource is over-exploited and may eventually be depleted.

activities in production and consumption, which ultimately saves water.

How strong is this market-mediated water saving effect? To what extent may this effect complement other policies in water management and supply? To better investigate these and other related questions Allan (1993) introduced the useful concept of "virtual water", that is, the implicit content of water in the production of goods and services, whereas "virtual water trade" refers to the implied exchange of water through conventional trade (Chapagain and Hoekstra, 2003).

A large and flourishing literature on virtual water, as well as on the related concept of water "footprint", is now available (for a critical review, see Yang and Zehnder, 2007). Recently, even the National Geographic (2010) magazine provided a map of virtual water trade flows in the world.

It may be worth to notice that the idea behind the virtual water concept is not restricted to water, but applies equally well to any resource, for example carbon, so we can also discuss about "virtual carbon" trade (Atkinson et al., 2010), that is, carbon emissions generated by foreign consumption (more often named "carbon leakage"). Assessing the amount of carbon leakage and virtual trade is essential for the international coordination of climate change mitigation policies.[2] Similar issues arise in the context of water resources management.

So far, however, virtual water has been primarily used as a descriptive device. Some critics point out that estimation of virtual water flows simply amount to converting actual trade flows to a different unit of measure, with little significance and policy usefulness. We basically agree with this critique, as we think that the virtual water concept may be more fruitfully adopted in the assessment of counterfactual scenarios, where changes in policy or in exogenous factors are simulated (Velazquez, 2007, Galan-del-Castillo and Velazquez, 2010).

To this end, this paper innovates to the virtual water literature by presenting an analysis of virtual water trade through simulation experiments, carried out with a Computable General Equilibrium (CGE) model of the world economy. CGE models are widely used for the quantitative analysis of trade, fiscal and other economic policies. They have sometimes been applied to water issues (e.g., Dixon, 1990, Seung et al., 2000, Gomez et al., 2004, Horridge et al., 2005, Berritella et al., 2007, 2008) but, to our knowledge, never in association with virtual water.

Computable General Equilibrium models provide a systemic and disaggregated representation of national, regional and multi-regional economies. They fully account for circular income flows, inter-sectoral and market linkages. Model parameters are calibrated using real data from social accounting and input-output matrices, whereas simulations are obtained by changing exogenous variables under behavioral assumptions of Walrasian perfectly competitive markets.

The typical output of a CGE model includes: changes in industrial prices and production volumes, changes in wages and capital returns, variations of trade patterns and consumption structure. By linking the CGE output to estimations of the virtual water content, it is therefore possible to obtain valuable information on the implications of a given scenario (not necessarily driven by water policies or water-related variables) in terms of pressure on domestic and foreign water resources. This is the simulation strategy adopted in this work.

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[2] For example, a much discussed issue is about the possible introduction of "border tax adjustments" (BTA), to compensate for the loss of competitiveness in international markets of industries located in countries where a stricter policy on greenhouse gases is introduced. The aim is avoiding that domestic reductions of emissions would be offset by increases of emissions abroad.

The paper is organized as follows. In the next section, the concept of virtual water is discussed in more detail, and some estimates of virtual water trade for Mediterranean countries are presented and examined. On the basis of these estimates, a computable general equilibrium model of the world economy, specifically disaggregated for the Mediterranean, is used to quantitatively assess future scenarios of climate change and water availability. Simulation results of this model are presented and discussed in section 3. Section 4 briefly discusses the limitations of the exercise and some directions for future research. A final section provides some concluding remarks.

2. Virtual Water Trade in the Mediterranean region

The virtual water content of a good is defined as the volume of water that is actually used to produce that product. This will depend on the production conditions, including place and time of production and water use efficiency. Producing one kilogram of grain in an arid country, for instance, can require two or three times more water than producing the same amount in a humid country (Hoekstra, 2003).

When a good is exported, its virtual water content is implicitly exported as well. Vice versa, when one good is imported, the water used in its origin country of production is virtually imported. A trade matrix of value or quantity flows could then be translated in terms of virtual water equivalent flows, allowing one to see whether one country is a net importer or exporter of virtual water, and which are its trade partners.

In international economics theory, the Hecksher-Ohlin theorem states that a country will be a net importer in goods and services whose production is intensive in those factors which are relatively scarce in the nation. Conversely, a country should export in industries using significant amounts of relatively abundant factors. When applied to water, the Hecksher-Ohlin theorem implies that water scarce (abundant) countries would be virtual water importers (exporters).

It is important to understand that this result is simply due to market functioning and competition. If markets do not work properly, the Hecksher-Ohlin theorem cannot be readily applied. In this respect, water is a very special case. In many countries, markets for water services are heavily regulated, property rights are not or cannot be enforced, water management is poor and resources are over-exploited. In other words, water prices are kept artificially low, sometimes reversing the Hecksher-Ohlin result: water scarce countries turn out to be virtual water exporters (and vice versa).

In order to see whether virtual water trade in the Mediterranean is broadly consistent with the Hecksher-Ohlin theorem, and what are its general characteristics, we classify the world in 14 regional economies, obtained through aggregation from the GTAP 7.1 database.[3] These are: Albania, Croatia, Cyprus, Egypt, France, Greece, Italy, Morocco, Spain, Tunisia, Turkey, Rest of Europe, Rest of Middle East and North Africa, Rest of the World.

Chapagain and Hoekstra (2004) provide estimates of total water consumption for 164 crops in 208 countries. We aggregate the data to the 14 regions and 7 agricultural industries of the GTAP data base, and we make a comparison between water consumption, by crop and region, and value of production (in 2004). This allows us to create an estimate of direct water usage by unit of output (in monetary terms).

The direct water usage should not be confused with the unit virtual water content, as the latter

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[3] See: http://www.gtap.org .

includes the water indirectly consumed through the use of intermediate production factors. Unfortunately, much of the literature on virtual water relies on direct water consumption, or use the two concepts inconsistently, with only a few exceptions (Velazquez, 2006, Dietzenbacher and Velazquez, 2007, Zhao et al., 2009). On the other hand, the adoption of a correct methodology for the estimation of virtual water coefficients brings about quite different results, both quantitatively and qualitatively.[4]

In order to consider indirect water consumption, let us call a_{ij} the domestic input-output coefficient in a square matrix A, whose dimension is the number of industries considered in a certain region. The (domestic) input-output coefficient expresses the intermediate consumption of factor i (produced by domestic industry i), per unit of output in industry j. If we call w the vector of sectoral virtual water coefficients (virtual water consumption per unit of output, in the region) and v the corresponding vector of direct water usage, then the w vector can be obtained from the v vector, by the following matrix equation:[5]

$$w = v(I - A)^{-1} \tag{1}$$

When the unit virtual water coefficients w are combined with origin/destination matrices of trade flows, it is possible to translate trade flows in virtual water equivalents. The sum of all virtual water trade matrices provides an overall picture of virtual water trade. In this work, we only consider trade in agricultural products.

The matrix of bilateral virtual water trade flows is presented in Appendix B (Table B1). Table 1 summarizes the virtual water balance of trade (VWBT) for all regions in the set, where negative (positive) numbers mean that a country is a net exporter (importer) of virtual water. In other words, the VWBT estimates the amount of water saved through international trade in agriculture.

As we can see, all Mediterranean countries, with the exception of France and Turkey, are net importers of virtual water through trade in agricultural products. Italy is the largest importer of water, but figures depend on the magnitude of trade flows and, therefore, on the size of the regional economy. To highlight how much each individual economy depends on virtual water flows, we divide the trade balance (VWBT) by the *sum* of exports and imports,[6] to get a size-neutral index, shown in the column VWBT-R.

According to this index, the regions which are most dependent on virtual water imports are Cyprus, Italy, Albania and Egypt. The Rest of Europe and Middle-East / North Africa are also significantly dependent on imports. This result is not completely in line with expectations about water availability, suggesting that in some countries water resources could be under-priced and over-exploited (e.g., in Spain, Morocco, Tunisia, Turkey).

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[4] Virtual water coefficients, when intermediate factors are taken into account, are always greater than the corresponding unit direct usage coefficients. Some industries, having relatively low direct water usage (e.g., food processing), may turn out to have high virtual water content per unit of production. Consequently, some seeming virtual water importing regions could actually be exporters, or vice versa.

[5] If n is the number of industries in the region, w and v are ($1 \times n$) row vectors, $(I - A)^{-1}$ is a ($n \times n$) Leontief inverse matrix (computed using only domestic intermediate flows). If there are several regions in a model, it is possible to compute all virtual water coefficients simultaneously with a single matrix equation (see the BTIO method described in Atkinson et. al., 2010).

[6] If M stands for virtual water imports and X for exports, then $VWBT = M-X$, $VWBT\text{-}R = (M-X)/(M+X)$.

	VWBT	VWBT-R
Albania	696	64%
Croatia	413	18%
Cyprus	856	70%
Egypt	12780	51%
France	-8551	-12%
Greece	2900	28%
Italy	28287	54%
Morocco	542	4%
Spain	8112	14%
Tunisia	650	10%
Turkey	-1652	-8%
Rest.Euro	151968	62%
Rest MENA	68724	75%
RoW	-265725	-78%

Table 1 – Virtual Water Trade Balance (Mm^3)

From the trade flows matrix (Table B1) it is also possible to compute the net virtual water exchange for all pairs of regions. Figure 1 displays, on a map of the Mediterranean, the largest flows, and their direction. The thickness of the arrow line depends on the magnitude of the flow: larger lines are for net flows exceeding 3G m^3, the others are associated with flows between 1G and 3G m^3.

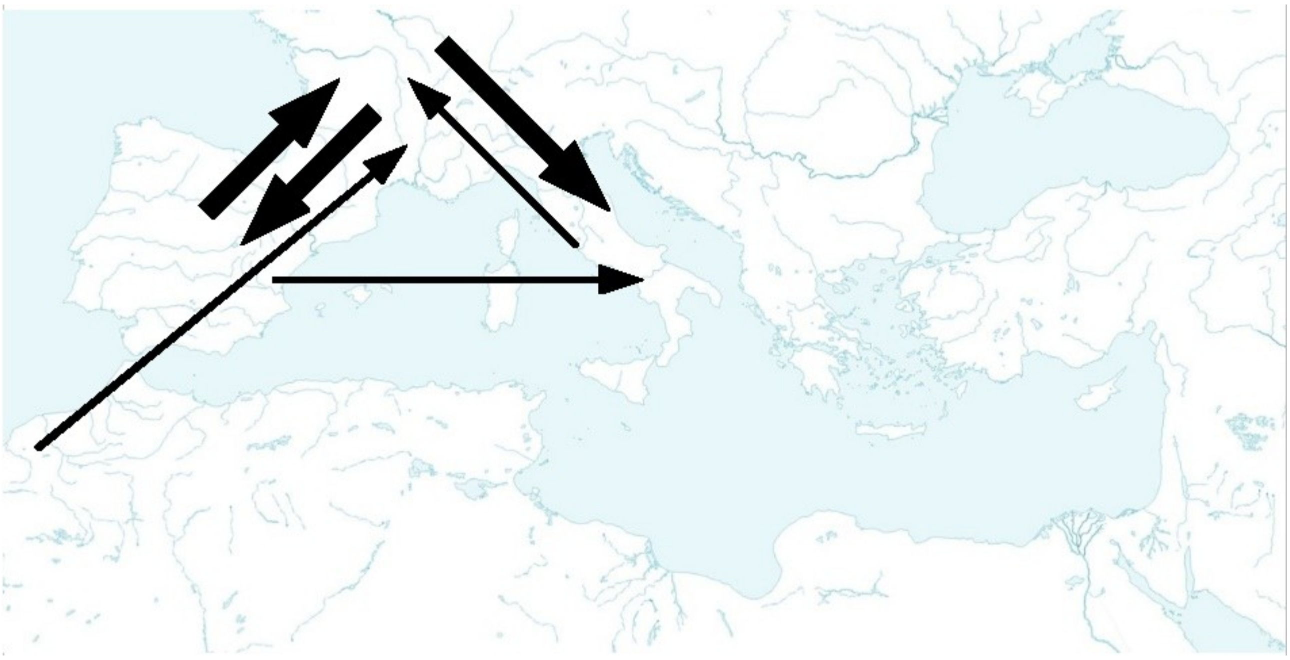

Figure 1 – Largest net flows of virtual water trade in the Mediterranean

We can see that the most significant exchanges of virtual water are bilateral flows between the largest North-Mediterranean economies. This outcome is due to the fact that both direct and indirect use of water has been taken into account; production of all goods and services requires water and water trade flows are correlated with gross trade volumes.

3. Assessing future water availability and virtual trade in a general equilibrium model

Our analysis of future water availability in the Mediterranean is based on data provided by Strzepek and Boehlert (2009), summarized, for some countries,[7] in Table 2.

	M.A.R. 2000	Ag. 2000	MI 2000	EFR	WCI	W 2050	D 2050
Albania	114.2	6.8	2.5	38.1	0.0	95.3	89.4
Cyprus	0.7	0.2	0.1	0.2	0.4	0.7	0.7
Egypt	60.2	89.7	16.4	0.6	1.0	60.4	60.5
France	138.8	9.7	37.3	42.8	0.0	120.6	114.3
Italy	93.6	9.6	24.4	42.2	0.4	88.0	78.8
Morocco	10.8	9.9	1.6	3.4	1.0	4.7	5.7
Spain	11.1	2.5	1.8	3.9	0.5	10.3	8.4
Tunisia	3.3	3.8	0.6	0.9	1.0	3.2	4.3
Turkey	131.6	26.6	9.5	42.0	0.3	99.0	129.7

Table 2 – Data on water consumption and future availability (Mm^3)

The second column in the table shows, for each country, the Mean Annual Runoff of water in the year 2000. The following three columns display estimates of water use for agriculture, municipal and industrial consumption (2000), and "environmental flow requirement", that is, the amount of water which is considered to be necessary to preserve aquatic ecosystems (all from Strzepek and Boehlert, ibid.).

We build an index of water constraint (WCI), by considering the ratio of water consumption in agriculture over the net MAR after non-agricultural water use (in 2000). The WCI is equal to this ratio, unless the ratio is greater than one (in this case it is set to one) or the ratio is lower than 0.25 (in this case it is set to zero):

$$A=\frac{Ag}{MAR-MI-EFR} \qquad WCI=\left\{\begin{matrix}0 & A<0.25\\ A & 0.25<A<1\\ 1 & A>1\end{matrix}\right\} \tag{2}$$

We build this index to account (admittedly, in a rather cursory way) how much each country is actually constrained by water availability. If the WCI index is greater than one, as it is the case for North African countries, it means that water use currently exceeds the MAR, possibly meaning that non renewable water reservoirs are exploited. If, vice versa, the WCI is zero, it means that water resources are abundant, and relatively minor variations in water availability would have no effects on the economy. The intermediate case ($0.25 < WCI < 1$) is for countries that can be considered "partially water constrained". Although the MAR exceeds total water use in 2000, we cannot exclude (since data cover the whole region and one year) that water scarcity may be a problem in some areas and in some periods of the year.

The remaining two columns show estimates of future mean annual runoff, for the year 2050,

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[7] Data for Croatia and Greece are missing in the original data set. Whenever appropriate, we applied data of countries having similar climatic characteristics (Italy and Spain, respectively), expressed in percentage changes, so as to make variables independent of the country size.

generated by two global climate models (from CSIRO and NCAR), combined with the CLIRUN II hydrologic model (Strezepek et al., 2008). The two climate scenarios are labeled "W" (NCAR) and "D" (CSIRO), as the former predicts a relatively wetter climate, whereas other one is relatively drier.[8] We can see that the climate models predict a reduction of precipitations and run-off for most Mediterranean countries, with dramatic effects for Morocco, whereas some other countries are not significantly affected. In addition to the W and D cases, we consider an intermediate one (labeled "M"), which is a simple average of W and D estimates. This latter scenario is introduced to provide a central value and a sensitivity analysis for our results.

We use the information above to simulate the climate change effects on agricultural productivity and virtual water in a general equilibrium model, whose structure is briefly described in Appendix A. We consider the 2000-2050 percentage change in the MAR for the three scenarios (W, M, D), and we assume that the multifactor productivity in all agricultural sectors varies by the same change, multiplied by the WCI. This means that, if a country is already water constrained, any reduction in surface water availability directly translates into lower yield for all crops. Conversely, if the country is only partially constrained, only some of the water change will be felt through the productivity impact.

Clearly, this working assumption is a quite strong one. The productivity response to water stress and changing climate conditions depends on the specific crop, as well as on a variety of other factors (e.g., irrigation mode). Unfortunately, no information is currently available on this aspect, particularly at the time and space scale of our model,[9] although research in this area is in progress.[10]

Since the exogenous shock is introduced in the general equilibrium model as a shift in multifactor productivity for agriculture, we can expect that the new equilibrium will be characterized by loss (gain) of competitiveness for those industries and regions which have high (low) water intensity, whenever water availability is assumed to be lower in the future. Following the basic Samuelson-Heckscher-Ohlin logic, which can be applied here because the CGE model is based on neo-classic assumptions, countries will tend to specialize in those productions which are intensive in the factors which are relatively abundant, including water. Trade flows will adjust accordingly, with more virtual water flowing towards water-stressed regions.

Before examining the simulation results in terms of virtual water, let us consider some aggregate macroeconomic indicators, accounting for the overall impact of the varying water availability on national income and welfare. Table 3 presents simulation results for the Gross Domestic Product (GDP) and the Equivalent Variation (EV). The latter is a measure of welfare, amounting to the hypothetical variation in income (at constant prices) which would have generated the same impact in terms of consumer utility of the exogenous shocks considered in the simulations.

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[8] This holds globally, not necessarily at the regional level.

[9] The general equilibrium model considers aggregated agriculture industries (several crops), with national or larger regions (different climatic zones), at a yearly scale (different vegetation periods).

[10] For example, improving aggregate yield response estimates is one objective of the European research project WASSERMed (http://www.wassermed.eu).

	var. GDP %			EV (M US$)		
	W	**M**	D	W	**M**	D
Albania	-0.03	**-0.04**	-0.06	-9	**-13**	-17
Croatia	-0.28	**-0.51**	-0.74	-108	**-192**	-276
Cyprus	-0.23	**-0.13**	-0.04	-35	**-23**	-12
Egypt	0.1	**0.11**	0.13	162	**171**	181
France	-0.01	**-0.01**	-0.01	-522	**-623**	-723
Greece	-0.64	**-1.32**	-1.99	-1,388	**-2,816**	-4,244
Italy	-0.2	**-0.34**	-0.49	-3,450	**-5,830**	-8,210
Morocco	-15.7	**-14.4**	-13.1	-7,529	**-6,891**	-6,253
Spain	-0.53	**-1.07**	-1.61	-5,215	**-10,559**	-15,903
Tunisia	-1.02	**2.81**	6.63	-262	**817**	1,897
Turkey	-1.67	**-0.88**	-0.1	-4,684	**-2,443**	-203
Rest.Euro	-0.22	**-0.22**	-0.22	-18,515	**-18,816**	-19,117
Rest MENA	-0.74	**-0.74**	-0.74	-5,485	**-5,458**	-5,431
RoW	0.34	**0.34**	0.34	86,122	**86,142**	86,16

Table 3 – Simulation results: macroeconomic indicators

Most climate models predict a reduction of water availability in the Mediterranean, with negative consequences in terms of national income and welfare. The loss depends on the amount of reduction of water resources, but also on the share of agricultural activities in the economy. There is a special case here, where the model predicts a dramatic fall of about 14.4% of the GDP in Morocco, which is already water constrained and it is supposed to face a significant reduction of precipitations and run-off. Tunisia, another water-constrained country, may gain under the D scenario. Significant reductions of GDP and welfare are estimated for Spain and Greece. Only one country gets (minor) benefits in all settings: Egypt. This is not because of an increase in water resources (which are basically unchanged) but because of improvements in relative competitiveness vis-à-vis its trading partners and competitors (which are mostly neighboring countries).[11]

Table 4 shows the *increase* in virtual water *imports*, by country. In other words, this is a measure of water savings obtained through trade in agricultural goods. Of course, those countries which are experiencing larger reductions in agricultural productivity, induced by water shortage, are also the ones which are getting more virtual water from abroad. Morocco, for example, virtually imports some additional 16787 Mm^3 of water in the M scenario.[12]

There is, of course, a relationship between reductions of productivity in agriculture and virtual water imports. Figure 2 plots on a diagram the pairs (variations in productivity, additional net imports of virtual water – relative to trade volume), for each country. It also plots some other points, obtained through a simple linear interpolation. It is found that, on average, a reduction of 1% in agricultural productivity in some Mediterranean country is associated with additional net virtual water imports, which are 2.19% of the sum of baseline virtual water imports and exports. This

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[11] For example, if agricultural productivity in Egypt is unchanged, but other countries in Middle-East and North Africa face a water shortage problem, agricultural products from Southern Mediterranean become more expensive, but Egyptian products partly replace those from other countries in international trade.

[12] We are implicitly assuming that there is enough water in the exporting countries to accommodate the additional foreign demand.

amounts to 1277 Mm^3 of water in Spain, 1158 in Italy, 547 in Egypt, 437 in Turkey, 326 in Morocco, 226 in Greece, 145 in Tunisia.

	W	**M**	D
Albania	42	44	46
Croatia	185	286	388
Cyprus	71	60	49
Egypt	721	697	668
France	-1818	-1783	-1747
Greece	912	1687	2462
Italy	2877	4596	6315
Morocco	18282	16787	15292
Spain	3867	8169	12472
Tunisia	882	-2062	-5005
Turkey	4565	2547	528
Rest.Euro	18134	18191	18248
Rest MENA	20003	20145	20287
RoW	-68723	-69365	-70002

Table 4 – Increases in VW Imports (millions of m^3)

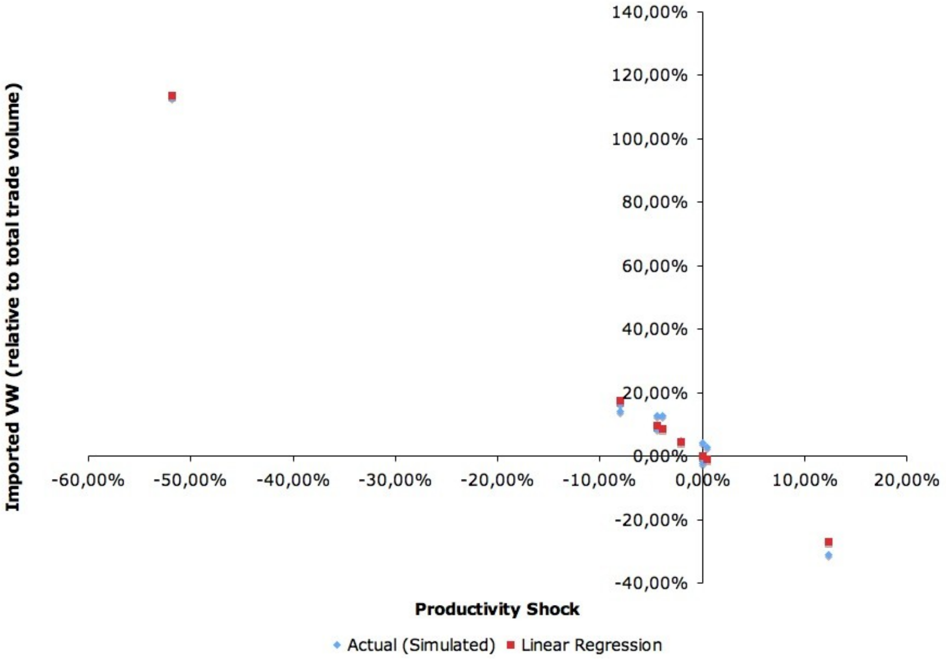

Figure 2 – Virtual Water / Productivity relationship

How effective is the virtual water mechanism in curbing the effects of water scarcity? Generally speaking, we could say that its effectiveness is related to the degree of flexibility in the economic system, that is, how easy it may be substituting factors in production processes, consumption goods, or origin of imported products.

To understand how much of the negative productivity shock can be absorbed through the virtual water trade, we conduct an additional simulation experiment. We run the general equilibrium model under the "middle" scenario M, but this time we constrain one country (Spain) not to increase its imports (or exports) of agriculture goods, thereby not increasing virtual water imports (or exports).[13] By comparing the results with those in the previous simulation, it is possible to assess how costly may be (for Spain and its trading partners) *not to have* virtual water trade. Results in terms of GDP and EV are reported in Table 5, together with differences with respect to the unconstrained case.

	var. GDP %		EV (M US$)	
	M	Difference	**M**	Difference
Albania	-0.05	-0.01	-13	0
Croatia	-0.51	0	-193	-1
Cyprus	-0.13	0	-24	0
Egypt	0.11	0	171	0
France	-0.01	0	-713	-90
Greece	-1.32	0	-2,813	3
Italy	-0.34	0	-5,799	31
Morocco	-14.45	-0.05	-6,891	0
Spain	**-1.34**	**-0.27**	**-13,099**	**-2,540**
Tunisia	2.79	-0.02	782	-35
Turkey	-0.89	-0.01	-2,439	5
Rest.Euro	-0.22	0	-18,748	68
Rest MENA	-0.74	0	-5,465	-7
RoW	0.34	0	85,895	-247

Table 5 – Macroeconomic indicators for the M-Spain constrained simulation

We can see that imposing a "no virtual water" constraint for Spain reduces GDP and EV not only for Spain, but also for all its trading partners. In particular, Spanish GDP is reduced by an additional -0.27%. The welfare impact is equivalent to a reduction of 2,540 millions of US$ for Spain, and to 2,813 millions US$ for the whole world. This may be considered as the cost of the virtual water constraint or, equivalently, the global value of Spanish virtual water trade.

The volume of virtual water trade depends on how easily it may be to substitute domestic production with imports, and imports sources among themselves. In general equilibrium models like the one we are using in this simulation exercise, it is customary to assume that goods within the same sector, but produced in different places, are imperfect substitutes.[14] When relative prices change, so does the import pattern, where the sensitivity of import shares to relative prices is determined by exogenously given elasticity of substitution parameters.[15]

Table 6 shows how results would change, again only for the M scenario, when elasticities of

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[13] This was done by keeping exogenously fixed at the baseline level those trade flows of agricultural goods, involving Spain, which were increasing under the M base simulation.

[14] This is called "Armington assumption". It accounts for product heterogeneity in large aggregates, by which, for example, Tunisian agricultural goods are indeed different products than Italian agricultural goods.

[15] In models based on the standard GTAP frameworks, there is a two levels process. First, domestic products are substituted (in production and consumption) with an import composite. Second, within the import composite, there is substitution among alternative foreign supplies.

substitution for all agricultural products are reduced by 50%.[16]

	M	M-low	variation	relative var.
Albania	44	24	-20	-45%
Croatia	286	182	-104	-36%
Cyprus	60	32	-28	-46%
Egypt	697	411	-286	-41%
France	-1783	-1386	397	-22%
Greece	1687	951	-736	-44%
Italy	4596	2871	-1.725	-38%
Morocco	16787	10140	-6.647	-40%
Spain	8169	4838	-3.331	-41%
Tunisia	-2062	-1179	882	-43%
Turkey	2547	1476	-1.071	-42%
Rest.Euro	18191	10166	-8.025	-44%
Rest MENA	20145	11399	-8.745	-43%
RoW	-69365	-39925	29.439	-42%

Table 6 – Increases in VW Imports with reduced elasticities (millions of m^3*)*

As expected, countries which were importing virtual water now import much less, whereas virtual water exporters now export less. The last column of Table 6 show relative variations, that is the percentage change in virtual water imports relative to the percentage change in substitution elasticities (here -50%). Results are fairly homogeneous: halving the substitution elasticities implies reducing virtual water imports of about 40%.

Since the volume of virtual water trade depends on the elasticities of substitution, one may wonder what determines the value for these parameters, and what could make them change. In general, elasticities of substitution tell us how easy the substitution process may be for consumers and firms. Elasticities will be high (and the virtual water trade mechanism more effective) when goods produced in different locations are perceived as similar, in the sense that they have similar effects on production processes, or on consumer's utility.

Reducing transportation costs or other barriers to trade would also increase virtual water trade, of course. However, only by increasing elasticities of substitution in the model we can make the economy more reactive (in terms of virtual water trade) to exogenous shocks.

4. Caveats

In this paper we presented a procedure for analyzing the virtual water trade response to a possible water scarcity scenario in the Mediterranean. Results, however, are affected by uncertainty and a number of weaknesses. Future research will address some of these points.

First, at the present time, global climate models do not appear to provide reliable, consistent and robust estimates at the regional level, especially for variables different from temperature, like

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[16] This is simply to test how sensitive the results are to different values for the elasticities of substitution.

precipitations. For example, models used in this study forecast a strong decrease of water availability in Morocco and some increase in Tunisia, whereas different climate model provide different scenarios.

In this study, we focused on variations in the Mean Annual Runoff, but a more correct estimate of water availability should take into account groundwater and non-conventional water supply (e.g., recycling, desalination). Furthermore, we have not addressed the issue of future variations in non-agricultural water uses. These appears to be problematic, especially for southern Mediterranean countries, where demographic and urbanization trends cannot be disregarded.

Finally, in our simulations we assumed a constant marginal productivity of water, ruling out any substitution possibility with other factors. Actually, variations in water availability may have a very differentiated impact, depending on the type of crop and on specific conditions. A number of agronomic studies are available, analyzing the relationship between volume of irrigated water and crop yield, but the main problem in this context is adapting these estimates for models in which heterogeneous agricultural products are considered within the same sector, into a broad region and at yearly scale.

Addressing the points above will not be easy, as it will require a strong interdisciplinary approach and cooperation. On the other hand, it is important to understand that the work is innovative, since very few studies have tackled the issue of macroeconomic and systemwide consequences of water scarcity. Most studies consider, as a geographical unit, the hydrological basin, typically assuming as given climate conditions and a number of socio-economic factors, like water demand. To get an integrated assessment of water resources management, different models with different scales need to be interfaced, for example by using the hydrological basin (even across countries) as a unit to allocate water flows, matching them with administrative boundaries.

5. Concluding remarks

Virtual water trade is nothing new. Any time there is trade in goods, whose production involves some consumption of water, we can say there is a virtual water exchange. What is interesting to see is how effective is this, autonomous, market driven adjustment mechanism in curbing the negative impact of water scarcity, particularly in relation to climate change.

Climate change is expected to alter the precipitations pattern, and consequently the availability of surface and ground water. Water availability will increase in some countries, which are often already water abundant, whereas it will decrease in some other regions, most notably in the Mediterranean. Water scarcity translates into higher prices for water intensive goods and services, thereby reducing exports and increasing imports, which can be interpreted as implicit net imports of water.

This paper is, to our knowledge, the first one in the literature on virtual water trade to assess scenarios of future water availability by means of CGE simulations. Our results suggest that the virtual water mechanism can help in reducing the impact of water scarcity, but it can only do that marginally. In other words, virtual water trade alone cannot solve the problem. Public policies are therefore needed to adjust the existing infrastructure and to better manage water demand.

The effectiveness of virtual water trade is related to the degree of flexibility within the regional economic systems. More flexible production processes, more globalization and integration, lower transport costs and other barriers to trade, they would all contribute in making economic systems more resilient to outside shocks, including those related to water scarcity and agriculture productivity.

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Appendix A

A brief description of the GTAP model

The Global Trade Analysis Project (GTAP) is an international network which builds, updates and distributes a comprehensive and detailed data base of trade transactions among different industries and regions in the world, framed as a Social Accounting Matrix (SAM).

The SAM is typically used to calibrate parameters for a Computable General Equilibrium (CGE) model, and the GTAP data base is accompanied by a relatively standard CGE model and its software. The model structure is quite complex and it is fully described in Hertel and Tsigas (1997). We only summarize here the meaning of the main groups of equations, and show in Figure A1 a graphical representation of income flows in the model (from Brockmeier, 2001).

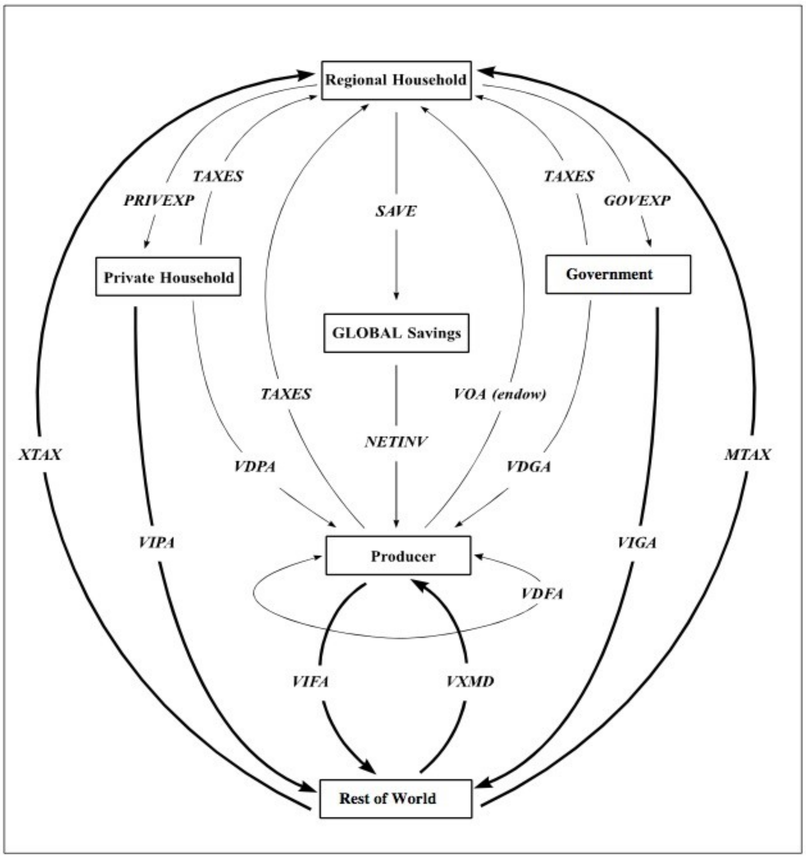

Figure A1 – Income flows in the GTAP Model

Equation and identities in the model include the following conditions:

- production of industry *i* in region *r* equals intermediate domestic consumption, final demand (private consumption, public consumption, demand for investment goods) and exports to all other regions;
- endowments of primary factors (e.g., labour, capital) matches demand from domestic industries;
- unit prices for goods and services equals average production costs, including taxes;

- representative firms in each regional industry allocate factors on the basis of cost minimization;
- available national income equals returns on primary factors owned by domestic agents;
- national income is allocated to private consumption, public consumption and savings;
- savings are virtually pooled by a world bank and redistributed as regional investments, on the basis of expected future returns on capital;
- the structure of private consumption is set on the basis of utility maximization under budget constraint;
- intermediate and final demand is split according to the source of production: first between domestic production and imports, subsequently the imports among the various trading partners. Allocation is based on relative market prices, including transportation, distribution, and tax margins. Goods in the same industry but produced in different places are regarded as imperfect substitutes;
- there is perfect domestic mobility for labour and capital (single regional price), but no international mobility;
- there is imperfect domestic mobility for land (industry-specific price), but no international mobility. Land allocation is driven by relative returns.

From a mathematical point of view, the model is a very large non-linear system of equations. Structural parameters are set so that the model replicates observational data in a base year.

Simulations entail changing some exogenous variables or parameters, bringing about the determination of a counterfactual equilibrium. The partition between endogenous and exogenous variables, as well as the regional and industrial disaggregation level, is not fixed but depends on the scope of the simulation exercise. In this paper, simulations have been obtained by changing total factor productivity parameters in agricultural industries.

Appendix B

	Albania	Croatia	Cyprus	Egypt	France	Greece	Italy	Morocco	Spain	Tunisia	Turkey	Xeur	XMENA	RoW	**Tot EXP**
Albania	0,00	0,83	0,11	0,36	10,43	10,85	62,44	0,08	2,88	0,04	5,50	63,34	1,75	41,29	**199,90**
Croatia	10,01	0,00	3,97	4,41	25,21	6,03	132,52	0,93	10,25	0,28	5,32	460,15	12,56	254,99	**926,63**
Cyprus	0,14	0,84	0,00	0,88	4,82	9,39	12,02	0,04	2,37	0,03	9,06	93,96	23,14	28,15	**184,84**
Egypt	22,77	5,05	9,47	0,00	124,46	118,52	413,81	42,24	123,79	52,71	169,94	1.638,05	1.598,14	1.770,80	**6.089,76**
France	28,35	16,35	110,15	54,84	0,00	638,84	5.264,37	901,28	4.731,69	260,75	112,74	21.810,38	3.174,53	4.055,97	**41.160,25**
Greece	112,34	21,63	81,48	19,21	89,17	0,00	398,14	2,37	62,88	5,10	74,98	2.339,32	85,36	422,92	**3.714,90**
Italy	38,81	92,97	13,76	15,49	1.418,05	338,74	0,00	11,96	607,78	18,62	79,29	6.764,65	699,07	2.185,19	**12.284,37**
Morocco	1,14	6,48	1,75	15,61	2.078,17	25,56	353,33	0,00	943,44	24,58	12,22	2.038,11	167,26	1.494,68	**7.162,33**
Spain	3,03	42,53	13,99	11,69	4.846,94	187,11	2.179,05	76,60	0,00	48,96	69,92	15.470,60	538,98	1.608,68	**25.098,07**
Tunisia	0,82	3,13	2,36	4,73	480,15	14,42	734,20	78,28	300,42	0,00	15,27	571,97	273,80	498,45	**2.977,98**
Turkey	30,07	25,85	2,33	74,25	541,85	242,09	921,78	23,55	269,79	35,38	0,00	4.824,42	1.058,50	2.742,27	**10.792,11**
Xeur	102,31	456,16	202,26	263,49	7.019,01	1.446,55	6.729,49	368,31	5.776,60	450,96	1.480,95	0,00	6.130,25	15.691,53	**46.117,86**
XMENA	2,00	7,66	53,99	197,28	639,94	97,55	599,67	31,06	275,16	57,54	237,03	2.109,23	0,00	7.292,14	**11.600,25**
RoW	544,25	660,60	545,05	18.207,83	15.330,97	3.479,60	22.770,10	6.167,49	20.103,10	2.673,43	6.867,50	139.901,50	66.560,77	0,00	**303.812,19**
Tot IMP	**896,03**	**1.340,06**	**1.040,66**	**18.870,07**	**32.609,19**	**6.615,25**	**40.570,91**	**7.704,18**	**33.210,17**	**3.628,36**	**9.139,71**	**198.085,67**	**80.324,11**	**38.087,07**	

Table B1 – Baseline virtual water trade flows (Mm^3)