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Trade-offs in water policy: System-wide implications of changing water availability and agricultural productivity in the Mediterranean economies by 2050

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Abstract

We evaluate the structural consequences of water availability scenarios in the Mediterranean, following a multidisciplinary approach and a sequential modelling methodology. This includes an assessment of future water availability and a general equilibrium macroeconomic analysis of changes in agricultural productivity. Lower productivity in agriculture, induced by reduced water availability, generates negative consequences in terms of real income and welfare. The magnitude of the loss depends on the amount of the productivity shock, but also on the share of agricultural activities in the economy and on the stringency of the environmental regulation. We find evidence of a dramatic cut in the supply of water for agriculture in the Middle East. We consider alternative scenarios, differing in terms of stringency of environmental regulation and assumptions about water efficiency. The largest welfare losses turn out to be in Morocco and Tunisia, in the “worst” scenario NM. Other very relevant impacts can be observed in Turkey, Italy and Rest of Middle East and North Africa (XMENA). There are also clear differences among the scenarios. First, applying a constraint on access to environmental water reserves only for Europe does make a big difference for non-European countries (Morocco, Tunisia and XMENA), implying that governments in the Middle-East could respond to increasing water scarcity by accepting, to some extent, lower environmental quality (deterioration of aquatic environments). Second, improvements in water efficiency, as envisaged in the simulation exercise, appear to curb the economic impact of water scarcity quite significantly. This is especially true for countries in the North, whereas efficiency does not compensate for a strict environmental policy in the South.

Keywords

Climate change, water use, agriculture, General Equilibrium Models, Mediterranean.

JEL Codes

C68, Q15, Q25, Q56.

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1. Introduction

Mediterranean agriculture accounts for one quarter of the global trade of food products and it is directly influenced by climatic conditions and availability of water resources. Water is also necessary for human consumption, economic activities (e.g., tourism, energy production) as well as for the provision of essential ecosystem services (Metzger *et al.*, 2006).

There are two main reasons of concern about the future of water resources in the region: one is related to the increase in water demand associated with the strong economic and demographic growth in the south/eastern Mediterranean; the other one is the likely reduction in water supply brought about by global warming and reduced precipitation. The stress imposed by climate change and economic development on water resources may intensify regional disparities and conflicts, as well as the overall economy of Mediterranean countries (Alcamo *et al.*, 2007, Allouche, 2011). The issue is part of a broader, global sustainability problem related to the availability and use of water resources in the world (Rosenzweig *et al.*, 2004, Khan and Hanjra, 2009, de Fraiture and Wichelns, 2010, Hanjra and Qureshi, 2010).

A few studies are now available, quantifying the effects of climate change on water resources in the region (García-Ruiz *et al.*, 2011, Iglesias *et al.*, 2011), which are based on global and regional climate models. Unfortunately, these studies fall short in carrying over the quantitative analysis to the consequences of reduced water supply on the water demanding sectors. More generally, there is a lack of quantitative information on the macroeconomic consequences of reduced water availability.

Coping with increasing water scarcity requires a complex approach (Pereira, Cordery and Iacovides, 2002), combining a limited water supply expansion with efficient water demand management, which is about setting priorities among alternative water uses (Antonelli, Gilmont and Roson, 2012). Such an approach would need an evaluation of the effects of changing water availability for the different economic sectors.

Possibly the only recent work providing a quantitative assessment of the link between water scarcity, economic performance and trade of agricultural products in the Mediterranean is Yang, Wang and Zehnder (2007). These authors conduct an econometric estimation of the relationship between trade of agricultural goods (cereals, oil seeds, sugar, fruits, vegetables), water availability, income and irrigation. Using projections of future water availability, they estimate changes in the trade balance of various crops for several countries in south/eastern Mediterranean. The projection on food import with respect to the decline in per capita water resources availability results in an increase of 40%, 39% and 14%, respectively, for cereal, vegetable oil and sugar by 2020 in the whole region, holding other factors constant.

This paper, which relies on results from the European research project WASSERMed¹, takes a similar perspective, but provides a much richer array of results. First, climatic scenarios are obtained from a set of regional climate models. Second, water availability for agriculture is estimated by considering both the relationship water stock / runoff and the non-agricultural water demand: industrial, municipal and environmental. Third, a number of alternative policy scenarios and assumptions are assessed. Fourth, impacts on agricultural industries are considered within a structural, global macroeconomic model, which allows evaluating the implications of reduced water availability in terms of national income, relative competitiveness and virtual water trade flows².

The comparison between alternative scenarios highlights a number of policy issues and trade-offs involved in the allocation of scarce water resources. Some emerging questions are:

- Does water availability constitute a bottleneck for the economic development in the Mediterranean?
- Which countries will be more severely affected by future water scarcity?
- Would water scarcity be due primarily to increased demand or reduced supply?
- To what extent may virtual water trade counteract the effects of reduced water availability, and productivity, in agriculture?
- What gains can be obtained from enhanced water efficiency?
- How costly may it be to set minimum environmental flow requirements for the preservation of aquatic habitats?

This paper presents the results of an interdisciplinary, *quantitative* modelling exercise, aimed at exploring the issues above. Clearly, results are subject to multiple uncertainties, but we think they nonetheless provide an informative order of magnitude for the impacts, while underlining the complexity of the effects involved.

The rest of the paper is structured as follows. In the next section, the sequential modelling strategy used in the simulation exercises will be illustrated. Section 3 presents and discusses the results obtained at the various stages. A final section concludes by providing some additional remarks.

2. Modelling Strategy

We evaluate the structural consequences of future water availability in the Mediterranean following a sequential approach (Figure 1), that includes two main components: (1) assessment of future water availability and its impact on agricultural productivity, and (2) general equilibrium analysis of changes in agricultural

¹ WASSERMed (Water Availability and Security in Southern Europe and the Mediterranean Region) is a research project funded by the European Commission in the 7th Framework Program (contract no. 244255). For more information: <http://www.wassermed.eu>.

² Virtual water refers to the water used to produce goods, implicitly traded when goods are exchanged.

productivity. Eleven individual countries are considered (Albania, Croatia, Cyprus, Egypt, France, Greece, Italy, Morocco, Spain, Tunisia, and Turkey) and one aggregated residual region (XMENA, which stands for "Rest of Middle East and North Africa").

The starting point is given by a climate scenario, providing estimates of changes in temperature and precipitation for a set of Mediterranean countries. The data has been obtained from the WASSERMed project, where several regional models were tested and selected on the basis of their capability of replicating historical climate records in the Mediterranean. Estimates used here derive from the output of the Hadley Centre model HadCM3Q0 (resolution: $3,75^\circ \times 2,5^\circ$), based on the SRES Scenario A1B. The climate scenario suggests that precipitation will generally decrease in the Mediterranean in the period 2000-2050, particularly in France (-13%), Morocco (-18%) and Tunisia (-10%). The average temperature is expected to increase of about 2°C . Other climate models produce similar results (Giorgi and Lionello, 2008).

Figure 1. Methodological approach

Future precipitation and temperature data have been converted into estimated changes (not levels) in total annual runoff, using the reduced-form formula proposed by Gardner (2009).

In order to assess the variation in total water supply associated with the change in runoff, we make a distinction between “blue” and “green” water. Blue water is the water stored in lakes, rivers, reservoirs, ground, etc., and can be used for alternative purposes, although only a fraction of total blue water is technically and economically

accessible/exploitable. Green water is the water embedded into the soil moisture, and it can only be used in agriculture, primarily for rainfed cultivations.

Figure 2 displays a graph, where points correspond to the countries considered in this study. The coordinates of each point are the 2010 runoff level per capita (from FAO's AQUASTAT³) and the corresponding per capita blue water availability (our elaboration from data by Gerten *et al.*, 2011). The water stock/runoff relationship is well approximated by a linear function. Since the linear function possesses a non-zero intercept, this means that any reduction in runoff implies a less than proportional reduction in accessible blue water supply. In other words, the scarcer surface water is, the more efficiently it is employed.

We have considered the function above to get estimates of changes in total water supply from variations in runoff. More precisely, changes in the blue water stock are assumed to follow the linear relationship of Figure 2, whereas variations in the green water component are directly proportional to changes in precipitation. This methodology generally implies smaller supply responses in water stressed countries.

Figure 2. Runoff / Water Stock relationship

After considering changes in supply, we have analysed how water is allocated among alternative uses. Figure 3 shows the composition of water consumption, in the different countries, in the baseline years. Water consumption in agriculture has been estimated using data from Chapagain and Hoekstra (2004). Municipal and industrial consumption has been obtained from the FAO – AQUASTAT database.

This study uses projections of the different demand components at the year 2050, to estimate how much water will be available for agricultural production. Industrial water demand has been assumed to grow at 1/3 of the rate equal of total GDP. GDP growth forecasts were elaborated from estimates of the World Bank. The gap between water demand and GDP growth is intended to account for improvements in water efficiency and for the higher share of services in the structure of national income.

³ See: <http://www.fao.org/nr/water/aquastat/main/index.stm>.

Municipal consumption, that is water for human drinking, washing, etc., is generally assumed to follow demographic changes. Population projections have been taken from the World Population Prospect (United Nations Secretariat, 2010), which devises a very strong growth of population in the Middle East. In addition, for some developing countries in our set, we consider the possibility that municipal water demand could increase more than proportionally than population⁴, to reflect improved access to sanitation and freshwater.

Figure 3. Composition of water consumption in the baseline (2000-2005)

All green water is allocated to agriculture in our model. Agricultural demand for blue water is, instead, assumed to cover any difference between total water demand and green water supply. In turn, total water demand from agriculture is estimated as the water necessary to keep production volumes unchanged from the baseline, while considering the extra consumption induced by higher evapotranspiration.

In addition to water consumption, water resources may be necessary to preserve a number of natural environments. The Environmental Flow Requirement expresses this “pseudo-demand” for water as a share of total runoff, so we logically extend the notion to our estimates of blue water availability. The EFR concept is a rather elusive one, as there is no fixed threshold value for environmental preservation, and much depends on collective evaluation. We look at the literature (Smakhtin, Revenga and Döll, 2004, Korsgaard, 2006, Hirji and Davis, 2009) to select some “reasonable values” for the EFR, which in this context means the share of blue water resources that should be set

⁴ After considering changes in population, municipal water demand has been further increased at a rate equal to the growth in per-capita GDP in the period 2000-2050, but only for those countries in which this rate exceeds 100%.

aside for effective protection of the environment. We set the EFR at the 30% of the blue water stock for all countries in our model.

We regard the EFR as a policy variable, since national governments may or may not be willing to save water for environmental purposes. In our numerical experiments, we assume that all countries in the European Union (the group includes Croatia and Turkey as accession countries) must comply with strict environmental regulation, so that the EFR share of (blue) water cannot be made available for consumption. Non-EU countries, on the other hand, are assumed to have more degrees of freedom, so they may opt not to comply with EFR requirements.

Figure 4 summarizes the process of allocation of water resources among alternative uses.

Figure 4. Blue/green water balance

We estimate possible reductions in water availability for agriculture by subtracting from estimated blue water supply at the year 2050 the various non-agricultural demand components (municipal, industrial, possibly the EFR share). If the residual exceeds water demand from agriculture, then water availability would not constitute a constraint for the sector. In the opposite case, we compare available water with potential agricultural demand, to gauge how much water consumption should be reduced.

Whenever water delivery to agriculture is lessened, some reduction of agricultural productivity should be expected. We assume that the cut in water consumption applies homogeneously to all crops, and it is not compensated by changes in other production factors. To convert reductions in water availability into lower production volumes, we use a set of elasticity parameters, estimated in the project WASSERMed, reported in Table 1.

Each elasticity parameter expresses the percentage change in yield, *ceteris paribus*, for a 1% increase in water delivery (both at the national level, annually). The values reported

in Table 1, referred to the seven categories of agricultural products considered in this study, were obtained by combining information on the physical response of the various crops (from agronomic crop models) with an assessment of the technical efficiency of national water systems.

Table 1. Water elasticity parameters, by crop

	Wheat	Cereals	Rice	VegFruits	Oilseeds	Sugar	Other Crops
Elasticity	0.86	0.86	0.85	0.85	0.60	0.60	0.77

To consider the systemic effects of variation in agricultural productivity, induced by lower water availability in the various Mediterranean countries, we inserted the estimated changes as exogenous shocks into a global computable general equilibrium (CGE) macroeconomic model.

A CGE model is a very large non-linear system, providing a disaggregated representation of national, regional and multi-regional economies. The system includes market clearing conditions and accounting identities, to trace the circular flow of income and inter-sectoral linkages inside the whole economic system. The model is calibrated using an extensive database of market transactions among industries and regions, and simulations are performed as comparative statics exercises. This means that two hypothetical equilibria are compared: a baseline reference and a perturbed equilibrium, in which the structural adjustment processes triggered by changes in parameters are simulated. For this reason, CGE models are not designed to get forecasts, but rather to highlight the interdependencies among markets.

In this study, we have developed a special version of the GTAP model (Hertel and Tsigas, 1997), to conduct simulations based on changes in agricultural productivity. We explore four scenarios, depending on whether or not water productivity improves (in agriculture), and whether or not the EFR constraint is imposed on all countries (or just inside the European Union). We label the four cases in the following way: NM, NE, IM and IE, where N stands for no improvements in water efficiency (I for improvements), E for EU-limited EFR regulation (M for Mediterranean-wide).

The output of a CGE simulation is very rich and includes information on: income, consumption levels, welfare, international trade, prices and production volumes. In this study, we present the impact of water scarcity and agricultural productivity, under the various scenarios, on some key macroeconomic indicators. Furthermore, we use estimates of international trade in agricultural goods to assess “virtual water” imports and exports. This is intended to test the conjecture, according to which countries hit by water scarcity could partially curb the problem by increasing virtual water imports (Wichelns, 2001, Novo, Garrido and Varela-Ortega, 2009). A CGE model helps in highlighting the economic mechanisms (Reimer, 2012) bringing about this outcome.

3. Results

3.1 From climate to water availability

Figure 5 displays relevant climatic data for the countries under considerations. The vertical bars show annual precipitation around the year 2000 (decadal average) and 2050. The row under the graph indicates the variation in the mean annual temperature, for the same period.

Figure 5. Climatic data

Information on temperature and precipitation is used to estimate changes in runoff. Changes in runoff are the basis for calculating variations in the stock of blue water, whereas green water is assumed to be proportional to precipitation. The sum of blue and green water stocks constitutes the total water availability in a country, that is the volume of water supply, which is allocated among municipal, industrial, environmental and agricultural uses.

Figure 6 displays the estimated total water available (per-capita) in each country in 2000 and 2050⁵. The underlining row exhibits the corresponding percentage variation in runoff.

⁵ Data in Figure 6 keeps population levels constant, to highlight the consequences of climatic scenarios, net of demographic variations. If growth in population would have been taken into account, water per capita would increase in countries with negative demographic growth (Italy, Spain, Greece), whereas more severe drops would have been observed in countries where population is increasing at a high rate (Morocco, Tunisia, Turkey, X MENA).

Figure 6. Total water availability and runoff

We can see that water supply is generally expected to be lower in all countries, with the exception of Egypt (where it stays approximately constant). The largest reduction is predicted for Morocco, with a drop of 438 m³ of water per capita, annually, which corresponds to -20%. Other significant variations are those of France (-12%), Rest of MENA, Tunisia, Croatia and Italy (all -9%).

3.2 From water availability to agriculture productivity

The highest priority in the allocation of water resources is given to municipal and industrial demand. Figure 7 displays our estimated growth rates in these two components for the period 2000-2050.

Figure 7. Growth in municipal and industrial water consumption 2000-2050

The strongest growth is expected to occur for industrial demand in Egypt and Albania. Both countries, however, possess some “buffer” water resources, which could possibly accommodate for the expansion of non-agricultural water uses. For example, municipal water consumption in Egypt goes from 3.8% to 10% of total water resources. By contrast, municipal consumption in XMENA rises from 7.5% to 22%, industrial consumption in the same region from 7.2% to 22%.

We subtract municipal and industrial consumption from the estimated stock of blue water at the year 2050. We subsequently consider, according to the selected scenario, a possible further cut of 30%, which is allocated to the Environmental Flow Requirement. What is left is blue water available for irrigation in agriculture.

Agricultural blue water demand is assumed to be the difference between total demand and green water supply. Total demand, in turn, takes current crop volumes as given and considers the change in evapotranspiration induced by the higher temperature (+11.7% on average).

The difference between potential agricultural blue water demand and actual (residual) blue water supply identifies (whenever the difference turns out to be positive) the amount of water resources, which would be subtracted to the agricultural sector. The result is contingent on the policy scenario, depending on whether or not the EFR share is considered in all countries (M) or just inside the European Union (E), and whether improvements in water efficiency (-10% water consumption in agriculture) are assumed (I) or not (N). Table 2 presents our estimates of reductions in water available to agriculture for the four scenarios.

Table 2. Reductions in water availability for agriculture

Country	NM (%)	NE (%)	IM (%)	IE (%)
Albania	-	-	-	-
Croatia	-	-	-	-
Cyprus	-	-	-	-
Egypt	-	-	-	-
France	-19.60	-19.60	-10.67	-10.67
Greece	-9.21	-9.21	-	-
Italy	-23.49	-23.49	-14.99	-14.99
Morocco	-30.12	-18.96	-22.35	-9.95
Spain	-17.53	-17.53	-8.37	-8.37
Tunisia	-33.03	-19.92	-25.59	-11.02
Turkey	-21.03	-21.03	-12.26	-12.26
Rest MENA	-53.75	-29.72	-48.61	-21.91

There is a dramatic cut in the supply of water for agriculture in the Middle East, especially in XMENA, but also in Tunisia and Morocco. This effect is significantly dampened only if the EFR constraint is not imposed on southern Mediterranean

countries, suggesting that these countries may find it difficult to set aside precious water resources for the preservation of the environment (as pointed out also by Smakhtin, Revenga and Döll (2004)). Improvements in water efficiency are, of course, beneficial, although the positive effects are mainly felt in the northern countries.

More generally, results are due to the combined impact of reduction in water supply and increase in non-agricultural water demand. The supply-side mechanism is the leading one for countries like France, Italy, Spain and Greece. For the other countries, both effects are clearly at work, although demand effects appear to be prevalent in most cases.

We analyse how reductions in water availability could affect agricultural productivity, taking into consideration that (i) each country has its own mix of agricultural products, and (ii) crops may differ in terms of sensitivity to water shortages. For each crop group, water elasticity parameters (Table 1) are employed to translate changes in water availability for agriculture into changes in agricultural productivity, by industry. As water availability depends on the scenario considered, so do the productivity shocks. For example, Table 3 reports the estimated changes in productivity for the NM scenario.

Table 3. Reduction in agricultural productivity by sector and region (NM scenario)

Country	Wheat	Cereals	Rice	VegFruits	Oilseeds	Sugar	Other crops
France	-16.88	-16.88	-16.60	-16.60	-11.68	-11.68	-15.05
Greece	-7.93	-7.93	-7.80	-7.80	-5.49	-5.49	-7.07
Italy	-20.22	-20.22	-19.90	-19.90	-13.99	-13.99	-18.04
Morocco	-25.93	-25.93	-25.50	-25.50	-17.94	-17.94	-23.12
Spain	-15.09	-15.09	-14.85	-14.85	-10.44	-10.44	-13.46
Tunisia	-28.43	-28.43	-27.97	-27.97	-19.67	-19.67	-25.36
Turkey	-18.10	-18.10	-17.81	-17.81	-12.53	-12.53	-16.15
XMENA	-46.26	-46.26	-45.51	-45.51	-32.01	-32.01	-41.26

3.3 From agriculture productivity to macroeconomic effects

The macroeconomic consequences of a lower agricultural productivity go far beyond a drop in production volumes (yields) in this sector. Indeed, lower output in agriculture brings about an increase in the prices of domestic products, which become relatively more expensive than foreign products. This loss of competitiveness causes some substitution of domestic goods with imports in the production and consumption processes, bringing about a real devaluation of the national currency and a change in the whole structure for the economic system.

We simulate the macroeconomic effects of changes in agricultural productivity by means of a Computable General Equilibrium (CGE) model. Variations in productivity such as those reported in Table 3 as taken as exogenous shocks in the macroeconomic model, which is used to compute a counterfactual equilibrium for the world economy,

simulating the structural adjustment process triggered by the changes in agricultural productivity in the Mediterranean.

Table 4 shows the computed percentage variation in real national income. This is a measure of household purchasing power, accounting for the overall impact on welfare.

Lower productivity in agriculture, induced by reduced water availability, generates negative consequences in terms of real income and welfare. The magnitude of the loss depends on the significance of the productivity shock, but also on the share of agricultural activities in the economy, as well as on the share of imports in domestic food consumption. Furthermore, the various scenarios differ in terms of stringency of environmental regulation and assumptions about water efficiency.

The largest welfare losses turn out to be in Morocco and Tunisia, in the “worst” scenario NM. Notice that impacts on real income do not mirror neither changes in productivity, nor in water availability. For example, XMENA was by far the most severely hit region in terms of cuts in water availability. However, because of the relatively smaller share of agriculture in the GDP, on one hand, and the reliance on food imports outside the Mediterranean, on the other hand, impacts are significantly smaller.

Other very relevant impacts can be observed in Turkey and Italy.

Table 4. Variations in real national income (percentage)

Country	NM	NE	IM	IE
Albania	-0.42	-0.40	-0.20	-0.18
Croatia	-0.10	-0.09	-0.07	-0.06
Cyprus	-0.05	-0.06	-0.03	-0.04
Egypt	0.06	0.01	0.04	0.00
France	-1.66	-1.65	-0.86	-0.85
Greece	-1.34	-1.34	-0.00	-0.00
Italy	-2.47	-2.45	-1.48	-1.46
Morocco	-8.00	-4.66	-5.68	-2.31
Spain	-1.64	-1.63	-0.74	-0.73
Tunisia	-8.34	-4.58	-5.03	-2.39
Turkey	-3.90	-3.90	-2.11	-2.12
XMENA	-4.39	-2.18	-3.80	-1.53

There are also clear differences among the four scenarios. First, applying the environmental constraint on access to EFR water reserves only for Europe does make a big difference for non-European countries (Morocco, Tunisia and XMENA), implying that governments in the Middle-East could respond to increasing water scarcity by accepting, to some extent, lower environmental quality (deterioration of aquatic environments). Second, improvements in water efficiency, as envisaged in this simulation exercise, appear to curb the economic impact of water scarcity quite

significantly. This is especially true for countries in the North, whereas efficiency does not compensate for a strict environmental policy in the South.

The structural adjustment process simulated in the model modifies the industrial profile of the Mediterranean economies, affecting all sectors. Table 5 presents the changes in output volume for all industries in the whole Mediterranean region, in the NM scenario. Notice the very large drop in the production of wheat and other cereals, which are important Mediterranean cultivations.

Another interesting phenomenon is the “rebound effect”, expanding production of manufactured goods. This is due to the fact that the negative shock brings about a real devaluation of national currencies, which is needed to keep the foreign balance in equilibrium. The devaluation makes exported goods more competitive in foreign markets, thereby stimulating production in the Manufacturing industry. A similar effect is not detected in the Services, as much of them are not traded internationally⁶.

Table 5. Changes in industrial output volumes (percentage)

Industries	Output
<i>Rice</i>	-24.70
<i>Wheat</i>	-51.43
<i>Cereals</i>	-53.37
<i>VegFruit</i>	-27.16
<i>Oilseeds</i>	-39.25
<i>Sugar</i>	-53.90
<i>Other crops</i>	-58.67
Tot Crops	-55.14
Animals	-5.51
Manufacturing	2.44
Services	-0.77

Table 6 presents the estimated change in the household consumption of agricultural goods, in each country (NM scenario).

⁶ The CGE model used in this exercise cannot fully capture, for some technical reasons related to the definition of GDP, the impact on tourism. The latter could be very significant in the Mediterranean. Therefore, a similar reasoning should also be applied to tourism, as a real devaluation would make Mediterranean countries more attractive holiday destinations.

Table 8. Percentage change in agricultural household demand, by sector

	Albania	Croatia	Cyprus	Egypt	France	Greece
Rice	-0.32	-0.13	-0.10	-0.15	-0.42	-0.35
Wheat	-0.47	-0.20	-0.14	-0.19	-0.48	-0.33
Cereals	-0.55	-0.20	-0.19	-0.14	-0.42	-0.34
VegFruit	-0.49	-0.24	-0.12	-0.26	-0.46	-0.36
Oilseeds	-0.44	-0.19	-0.10	-0.19	-0.42	-0.31
Sugar	-0.74	-0.15	-0.73	-0.15	-9.65	-3.43
Other crops	-1.44	-0.59	-1.53	-0.13	-11.20	-5.64
	Italy	Morocco	Spain	Tunisia	Turkey	XMENA
Rice	-0.63	-7.39	-0.42	-4.71	-2.40	-0.32
Wheat	-0.54	-7.32	-0.52	-7.44	-2.98	-0.47
Cereals	-0.61	-7.51	-0.56	-6.12	-2.13	-0.55
VegFruit	-0.60	-8.15	-0.54	-8.16	-2.87	-0.49
Oilseeds	-0.56	-6.12	-0.49	-4.59	-2.33	-0.44
Sugar	-8.19	-11.97	-8.94	-10.78	-7.26	-0.74
Other crops	-14.52	-12.21	-9.26	-11.60	-8.63	-1.44

Changes in consumption are driven by changes in income and relative prices. Consumption falls in all countries for the combined effect of lower income and higher prices (see Table 4). Consumption of the different food items is directly influenced by the different sensitivity to income⁷, and by a substitution effect, through which relatively expensive goods are substituted with cheaper ones.

Market prices are actually indices, taking into account the price of imported food (which is itself an index). Therefore, in a country hit by drops in agricultural productivity and with rising domestic prices, consumers would revert to goods for which the share of domestic production is relatively smaller.

Since higher domestic prices foster substitution of domestic goods with imported ones, the larger import of food from abroad can be interpreted as an increase in virtual water imports. We compute the volume of net virtual water imports by considering the water necessary to produce the agricultural goods in their origin country. Figure 8 shows the change in net virtual water import, per capita⁸, for all countries in the NM scenario.

⁷ For example, sugar is more sensitive to changes in income than other crops in our model.

⁸ Data are expressed per capita to account for the different dimension of the various regions. However, population has been kept fixed in the comparison of the two trade patterns.

Figure 8. Variation in net virtual water import per capita

Virtual water trade can be interpreted as a market response to water scarcity or, equivalently, as an indirect way of getting water resources from abroad, through imports. Figure 8 confirms that those countries, which are more severely affected by cuts in agricultural water availability, are generally those expanding imports of food, therefore virtual water imports.

However, we can also see that the response in terms of virtual water trade does not mirror the change in water availability (Table 2). The reason is that the easiness of substitution between domestic and imported goods is not the same among all countries. In the CGE model, goods in the same industry but produced in different regions are treated as imperfect substitutes. Expanding food imports is easier when the share of imports in total consumption is already quite high. This is the case of Tunisia, where water is proportionally reduced by almost the same amount as in Morocco, but where, nonetheless, the change in net virtual imports turns out to be about twice the corresponding variation in Morocco.

Finally, we want to compare our results with those obtained by Yang, Wang and Zehnder (2007) [YWZ], despite the fact that the two approaches are quite different. We do this by computing and comparing the “water trade elasticity” for a set of countries, which are common in the two studies: Egypt, Morocco and Tunisia. By water trade elasticity we mean the percentage change in the volume of food import (for a specific crop) associated with a 1% increase in water availability. Table 9 shows the comparison for the three countries and for three crops considered by YWZ.

Table 9. A comparison of water trade elasticity

Crops	Egypt		Morocco		Tunisia	
	YWZ	<i>This study</i>	YWZ	<i>This study</i>	YWZ	<i>This study</i>
Cereals	-0.91	<i>-0.51</i>	-1.24	<i>-0.95</i>	-0.68	<i>-0.58</i>
Oilseeds	-1.03	<i>-1.68</i>	-0.86	<i>-0.75</i>	-1.29	<i>-0.78</i>
Sugar	-0.52	<i>-2.58</i>	-0.34	<i>-3.23</i>	-0.21	<i>-1.82</i>

Results are broadly similar, in terms of order of magnitude, but our model exhibits a much higher sensitivity in the case of sugar. This should not come as a surprise, as the two methodologies are significantly different. First, YWZ consider total water availability, whereas we consider only water available to agriculture (this should make our figures higher). Second, YWZ use a partial equilibrium approach, whereas we use a general equilibrium framework, where changes in water availability affect all prices and income simultaneously (this should make our figures lower).

4. Discussion

In this paper, we presented an interdisciplinary study on the effects of changing water availability on the Mediterranean agriculture, combining climatologic, hydraulic, agronomic and economic quantitative analysis. To the best of our knowledge, this is the first integrated assessment exercise of this kind.

Our findings are contingent on the assumptions we adopted and are affected by various degrees of uncertainty at every step of the sequential modelling procedure. Uncertainty affects the climate scenario, estimates of baseline water availability and consumption, economic and demographic growth, and several parameters and hypotheses in the macroeconomic model.

We have not considered climate change impacts different from changes in water availability, which could ultimately affect the agricultural sector, either directly or indirectly (see, e.g., Roson and van der Mensbrugghe, 2012). Our choice of constant production volumes in agriculture is admittedly arbitrary and we have not considered various adaptation options: changes in land use, non-conventional water supply (Qadir *et al.*, 2007), different sowing/planting times and crop varieties (e.g., GMOs), alternative allocations of water among the various crops, improved efficiency in non-agricultural water uses, including environmental water engineering (Pittock, Finlayson and Howitt, 2013), etc.

The need to interface physical and economic models forced us to work at a large temporal (year) and spatial (nation) scale. Inevitably, this has not allowed us to consider phenomena like changes in runoff seasonality, extreme events like droughts or floods occurring locally, etc. We think that more conventional hydraulic models, working at the basin or catchment level, are more appropriate tools for this kind of assessment.

For all the reasons above (and possibly others), it is clear that our modelling exercise is not aimed at producing realistic forecasts about the future of the Mediterranean agriculture. Rather, it is intended to provide an internally consistent framework to discuss the interdependencies among the many factors at play, thereby highlighting several policy trade-offs.

A number of key messages emerge from our numerical exercise. First, water scarcity is likely to become a serious problem in the Mediterranean, with sizeable economic consequences. This is due to both the reduction in supply and the increase in demand, the latter being the driving force in the South. The ultimate socio-economic impact of water scarcity is not a direct consequence of the physical effects, but depends in a complex way on several other factors, much of them influenced by policies: mix of agricultural products, share of agriculture in the national income, trade openness, environmental regulation, etc.

A possible drop in agricultural productivity, imposed by lack of water resources, would trigger a structural adjustment in the economy, with system-wide consequences on all sectors. The consequent rise in food imports can be interpreted as an indirect way of getting “virtual water”. However, we noticed that virtual water imports are not easily and equally accessible by all economies in the Mediterranean.

We found that environmental policies aimed at preserving aquatic habitats may be difficult to pursue, especially in the southern Mediterranean. Imposing a “hard constraint” on the access to environmental water could cost more than 3% of national GDP in some countries in the Middle East.

Tunisia and Morocco emerge as the potentially most vulnerable countries. Other regions in the Middle East and North Africa could actually suffer from larger reductions in agricultural productivity, yet the eventual impact on income and welfare could be much smaller, as these economies are much less reliant on agriculture and open to imports of food from outside the Mediterranean.

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