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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 bottom-up methodology. This includes an assessment of future water availability and a general equilibrium 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. Our results suggest that countries in Middle East and North Africa could respond to increasing water scarcity by accepting, to some extent, lower environmental quality (deterioration of aquatic environments). Furthermore, improvements in water efficiency appear to curb the economic impact of water scarcity quite significantly, especially for northern Mediterranean countries.

JEL Codes

C68, Q15, Q25, Q56

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

1 Introduction

2 Estimating the system-wide effects

2.1 Study design

We evaluate the structural consequences of water availability scenarios following a bottom-up 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 productivity.

The first step requires the estimation of scenarios of hydrological runoff derived from climate change scenarios, and the estimation of water availability for agriculture based on runoff. The idea is subtracting non-agricultural water uses from the total (plus possibly adding extra water supply like desalination or recycling). The elasticity of agricultural productivity to water is evaluated combining physical response by crops with realism about actual conditions in a large aggregate scale.

Figure 1 Methodological approach

The geographic extent of the analysis is the Mediterranean region, with eleven individual countries (Albania, Croatia, Cyprus, Egypt, France, Greece, Italy, Morocco, Spain, Tunisia, and Turkey) and one aggregated estimate for the rest of the region

(XMENA, which stands for "Rest of Middle East and North Africa"). These countries represent the major agro-climatic zones in the region (Iglesias et al. 2011). The low and very variable precipitation in the summer months typical of the Mediterranean climate makes irrigation necessary to attain high yields. Over 20 % of agricultural land is irrigated, and irrigation is the major water user in the region. Climate, water management and social conditions shape the agricultural systems of the agricultural systems selected for this study.

2.2 *From climate scenarios to runoff*

To assess future climate conditions, we use data from the European research project WASSERMed¹, which in turn have been obtained from a set of Regional and Global Circulation Models. Estimates used here derive from the output of the Hadley Centre model HadCM3Q0 (resolution: 3,75° x 2,5°), 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).

Total water availability has been estimated on the basis of water runoff (surface water). More precisely, theoretical water runoff has been first computed, at the country level, using the formula by Gardner (2009), providing a rough calculation of water runoff on the basis of precipitation and temperature, thereby avoiding the use of a full-fledged hydrological model. Such a model is not generally available for all countries in our study. When available, it usually differs in terms of spatial and temporal scale. This formula is:

$$R = P * \exp(-PET / P) \quad (1)$$

where R stands for runoff, P is annual precipitation in mm and PET is potential evapotranspiration, computed as a function of temperature T (Kelvin degrees):

$$PET = 1.2 * 10^{10} * \exp(-4620 / T) \quad (2)$$

The theoretical runoff is a purely abstract concept, which is not meant to provide any estimate of actual runoff².

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.wassarmed.eu>.

2.3 From runoff to per capita water availability

We define water availability as the total amount of water, which is actually accessible and economically exploitable in a given country. Water availability is the result not only of natural runoff but also of social investment in terms of hydraulic infrastructure and water management practices, especially those aimed at smoothing seasonal and geographical variability (e.g., storage, aqueducts, recycling and desalination). Therefore, changes in water availability may be very different from changes in runoff.

We consider *blue* water, which is surface water stored in lakes, rivers, reservoirs, etc., and *green* water, which is embedded into the soil moisture (used for rainfed cultivations). Only a fraction of total blue water is technically and economically accessible/exploitable. We estimate total water availability as the sum of accessible blue and green water, elaborating on data provided by Gerten *et al.* (2011). We do not (explicitly) take into account groundwater and “produced” water (desalinated, recycled).

The potential runoff in each country is compared with total per-capita water availability (Figure 2). The two variables are clearly correlated. A linear regression (red line in the figure) reveals that the relationship between the two variables can be approximated by the linear function:

$$TWA = 3638 + 20.4R \quad (3)$$

² Its computation implicitly assumes constancy of climatic conditions; in this context, over large geographical areas and for a long time period (one year). Heterogeneity over time and space could entail profound differences between theoretical and current runoffs.

Figure 2 Relationship between runoff and per-capita water availability

Notice that some countries (Egypt, Morocco, Tunisia), which have a close to zero theoretical runoff, nonetheless appear to own some water resources, meaning that water supply is little influenced by local climate conditions. Egypt is an exemplary case: because of high temperature and low precipitation, this country should virtually have no water. However, it is known that much of the water used in Egypt is delivered by the Nile, whose volume is not significantly affected by climate in Egypt, but rather by climate in Central-Eastern Africa.

We use the linear relationship (3) to assess how changes in temperature and precipitation could affect water supply in each country. Table 1 presents the change in theoretical runoff in the period 2000-2050, and the associated variation in estimated total water availability. Our estimates predict a significant drop in water availability for France (-34%), Italy (-14%), Turkey (-11%), Croatia (-10%) and Spain (-8%), whereas countries in southern Mediterranean would be barely affected, as their water resources are supposed to be relatively independent from local climate.

There are many potential explanations for this. Most water could come from outside the country, or could be pumped from underground reserves, or could be obtained through desalination, recycling, etc. Water-scarce countries may well be much more water efficient than countries in which water is abundant. Whenever this happens, the higher efficiency could partly compensate for the combination of low precipitation and high temperature, which implies small values for the theoretical runoff. In other words, where rain is a rare event, almost every raindrop is saved.

Table 1 Temperature and precipitation changes, Variations in theoretical runoff and water availability.

Country	Temperature change 2000-2050 (°C)	Precipitation change 2000-2050 (%)	Theoretical runoff change 2000-2050 (%)	Total water availability change 2000-2050 (%)
Albania	1.83	-1.7	-19	-7
Croatia	2.18	-4.9	-24	-10
Cyprus	1.21	-0.9	-21	-4
Egypt	2.19	+11.1	-45	0
France	2.13	-12.5	-35	-34
Greece	1.7	+3.3	-12	-2
Italy	2.04	-2.8	-25	-14
Morocco	1.71	-17.8	-98	0
Spain	1.83	-2.9	-26	-8
Tunisia	1.83	-9.9	-85	0

Turkey	1.91	-2.4	-24	-11
XMENA	2.06	-9.5	-99	0

2.4 *From per capita water availability to water availability for agriculture*

Our approach estimates changes in water availability through a balance between water supply and demand. We start by taking into account the water balance at present time for several Mediterranean countries, that is the relationship between water supply (sources) and water demand (uses) for one average year. Three uses of water are appraised: municipal, industrial and agricultural. Green water can only be used by agriculture, where it is supplemented by blue water through irrigation or other means (it is assumed that blue water covers no less than 10% of agricultural water demand).

By construction, we do not allow water consumption to exceed water supply. Any difference between available blue water and consumption in the three categories above (where agricultural consumption is considered only for the part exceeding the green water stock) is interpreted either as unused water or water deliberately left for the preservation of aquatic ecosystems, which we refer to as Environmental Flow Requirement (EFR). Water consumption by agriculture in the baseline (2000-2005) has been estimated using data from Chapagain and Hoekstra (2004). Municipal and industrial consumption has been obtained from the FAO – AQUASTAT database³. Figure 3 shows the composition of water demand among different usage classes for the Mediterranean countries considered in this study, in the baseline.

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

Shares of sectoral water demand w.r.t. Total water availability.

M = municipal (orange)

I = industrial (grey)

A = agricultural (green)

R = residual (blue)

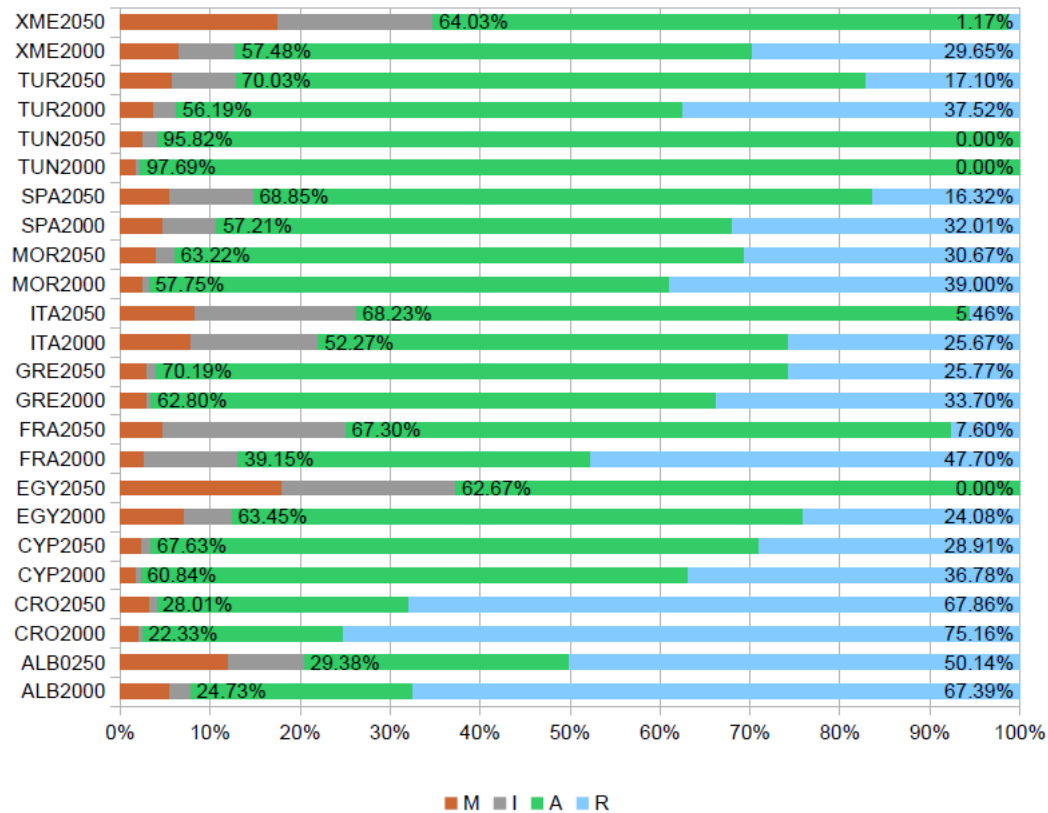


Figure 3 Composition of water consumption in the baseline (2000-2005)

To assess how much water will be available to agriculture in 2050, values for all supply and demand components have been projected to the future, using different assumptions and methodologies, as illustrated in Figure 4. For water consumption in agriculture, our reference point is a hypothetical situation in which agricultural production volumes stay unchanged (of course, this is not meant to be a realistic scenario, but only a reference benchmark). Even with constant production levels, however, water demand would increase, because of higher temperature and evapotranspiration, by an amount of about 10% (depending on the country, from +7% for Cyprus to +13% for France). This increment can be compensated under specific policy scenarios, to be analyzed later in this paper, through speculative improvements in water efficiency/productivity.

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 population, to reflect improved access to sanitation and freshwater.

Figure 4 Methodology to estimate water availability for agriculture

Industrial consumption is assumed to increase at a rate equal to 1/3 of the national GDP. GDP forecasts have been derived from World Bank Statistics⁴. The lower rate for industrial water consumption is assumed to approximate the changing composition of the national income, with a lower share for manufacturing industries, as well as improvements in efficiency.

In addition to water consumption, water resources may be needed 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 itself 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 (Korsgaard, 2006; Hirji and Davis, 2009) to select some “reasonable values” for the EFR, which in this context

⁴ <http://www.databank.org>.

means the share of blue water resources that should be set aside for effective protection of the environment.

We regard the EFR not as a constraint but as a policy variable. In other words, 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 (partially or completely) with EFR requirements.

When municipal and industrial consumption, and possibly EFR, are subtracted from total blue water, what is left is water potentially available for the agricultural sector, supplementing green water. This “water potential” can be compared with estimates of agricultural water demand at fixed production levels (with or without improvements in water efficiency). If potential water exceeds water demand, agriculture is not water constrained, at least if current production volumes do not significantly increase. Otherwise, (blue) water delivered to agriculture must be cut by a certain amount.

2.5 From water availability for agriculture to agricultural productivity

Our estimation of the agricultural productivity response to changes in water availability is based on crop models. Dynamic process-based crop growth models were specified and validated for 11 sites, representative of the main agro-climatic regions of the selected countries.

The validated site crop models are useful for simulating the range of conditions under which crops are grown. Variables explaining a significant proportion of the yield variance are crop water (sum of precipitation and irrigation) and temperature over the growing season.

Crop models were used to compute initial estimates of elasticities of yield to water availability. The elasticities were estimated by log-linear functions derived from model results, considering 100% efficiency of the irrigation system and management. The initial elasticity values have been modified to account for limitations in infrastructure, technology, management, and value of production. The actual efficiency of the irrigation system and management was estimated using five indicators, listed in Table 2. A

country was considered to have high efficiency when it has either 3 or more high indicators, or 2 high indicators and no low indicator. A country was considered to have low efficiency when it has either 3 or more low indicators or 2 or more low indicators and no high indicator. The rest of the countries were considered to have medium efficiency. According to these decision rules we consider 4 countries with high efficiency (Cyprus, Egypt, France and Spain); 3 countries with medium efficiency (Italy, Greece and Turkey); and 4 countries with low efficiency (Albania, Croatia, Morocco and Tunisia). The regional aggregates are considered with medium efficiency. Potential efficiency improvements in the future were estimated based on assumptions on irrigation efficiency, and are illustrated in Figure 5.

Table 2 Assumptions on real irrigation water efficiency

Indicator	High	Medium	Low
Infrastructure	Mostly pipes	Mostly open air covered canals	Mostly open air non-covered canals
Irrigation technology	> 20% localised	10 to 20% localised	< 10% localised
Irrigation advisory services	Yes, largely	Yes, some farmers	Almost none
Value of the irrigated production	More than 80% of total value of production	50 to 80% of total value of production	Less than 50% of total value of production
Land holding structure (%ownership)	More than 80%	50 to 80%	Less than 50%

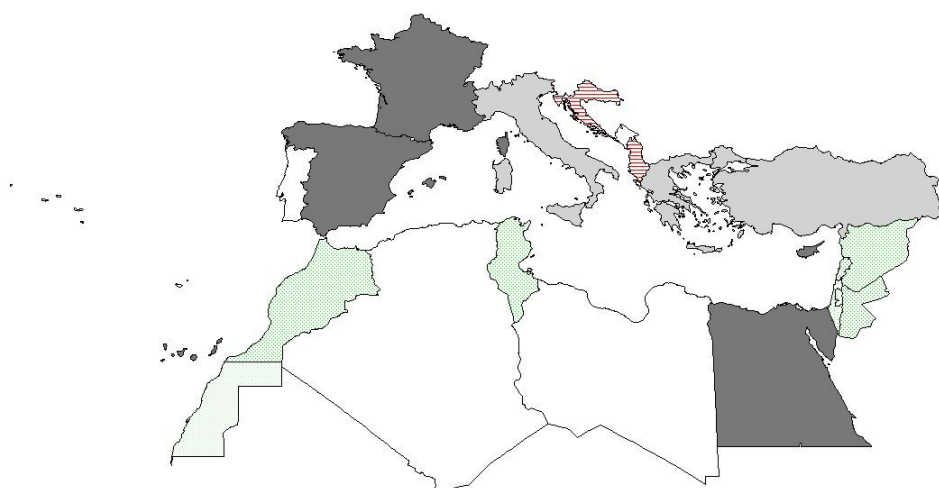


Figure 5 Water efficiency, estimated potential future improvements. Dark grey: high to high; Light grey: Medium to high; Green: Low to Med; Red: Low

2.6 From the physical changes to structural trade-offs

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.

These system-wide effects have been analyzed in this study by means of a Computable General Equilibrium (CGE) model. A CGE model is a very large non-linear system, which provides a systemic and disaggregated representation of national, regional and multi-regional economies. The system includes market clearing conditions and accounting identities, to consider the circular flow of income and inter-sectoral linkages inside the whole economic system. Therefore, the economic behaviour described in the model is utilised here to address autonomous adaptation in term of factor substitution within sectors, as described by Aaheim et al. (2012).

The model used in this exercise is the GTAP model, calibrated at the year 2004 and regionally aggregated for the Mediterranean region. The mathematical structure of the model is quite complex and it is fully described in Hertel and Tsigas (2007).

3 Results

3.1 *Future water availability and impact on agricultural productivity*

This section describes our estimates of variations in agricultural productivity for the Mediterranean, induced by changing water availability. The reference year is 2050, and only water supply is considered among the many possible causes (including climate change) that could bring about variations in agricultural productivity. Quite naturally, estimates are surrounded by multiple uncertainties. Lack of information, structural model weaknesses, uncertain policy response and degree of adaptation are all factors making the evaluation of future agricultural productivity highly debatable. For these reasons, we do not aim at producing “forecasts”, but rather a set of “not implausible scenarios”, based on a consistent methodology and, sometimes, subjective judgement.

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: NE, NM, IE and IM, where N stands for no improvements in water efficiency (I for improvements), E for EU-limited EFR regulation (M for Mediterranean-wide). Table 3 presents our estimates of reductions in water available to agriculture in the four scenarios, for all countries in 2050.

Six countries are found to have insufficient water resources, at the year 2050, to sustain current production levels in agriculture. Because of lower precipitation and higher temperature, France and Italy will be affected by a drop in water resources, with a larger impact for agriculture in Italy, because relatively more blue water is used there. Tunisia, Egypt, Morocco and Rest of Middle East / North Africa will also lack water for agriculture, but for different reasons. In Egypt and the Middle East the climate change impact on total water availability will be negligible, as in this area much of the water is imported, pumped from the ground, desalinated or recycled. However, non agricultural water uses are expected to grow at a significant rate. The MENA region is a special case, because our estimates reveal that demand for blue water resources coming from the industrial and municipal sectors would exceed availability in 2050. As a consequence, we assume that agriculture would be forced to surrender all its irrigation water, which is assumed to be 10% of its total water consumption.

In Tunisia, water resources are overexploited already in the baseline (see Figure 2.1); any further increase in water demand would not be sustainable.

Table 3 Reductions in water availability for agriculture

	NM	NE	IM	IE
Albania	-	-	-	-
Croatia	-	-	-	-
Cyprus	-	-	-	-
Egypt	-32%	-12%	-25%	-2%
France	-15%	-15%	-0.4%	-0.4%
Greece	-	-	-	-
Italy	-19%	-19%	-4%	-4%
Morocco	-4%	-0.5%	-3%	-
Spain	-	-	-	-
Tunisia	-20%	-11%	-12%	-
Turkey	-	-	-	-
Rest MENA	-10%	-10%	-10%	-10%

We analyze how reductions in water availability could affect the agricultural productivity. To this end, it is important to observe that (i) each country has its own mix of agricultural products, and (ii) crops may differ in terms of sensitivity to water shortages.

We consider seven classes of agricultural products: wheat, cereals, rice, vegetables and fruits, oilseeds, sugar, other products. For each crop group in each country, a “water elasticity” parameter was estimated (Table 4), which expresses the percentage change in annual yield when the water input is varied by 1% (keeping all other production factors unchanged). This entails accounting for both the physical characteristics of the crop and the overall efficiency of the water delivering system.

Table 4 Water elasticities by crop for each country

	Wheat	Cereals	Rice	Veg&Fruits	Oilseeds	Sugar	Other Crops
Albania	1.0397	1.0397	0.8970	0.8970	0.6134	0.6134	0.8500
Croatia	1.0397	1.0397	0.8970	0.8970	0.6134	0.6134	0.8500
Cyprus	2.5521	2.5521	2.6145	2.6145	1.5946	1.5946	2.2537
Egypt	2.8613	2.8613	3.6493	3.6493	3.6963	3.6963	3.4023
France	3.0746	3.0746	2.1266	2.1266	1.3861	1.3861	2.1958
Greece	1.8195	1.8195	1.5698	1.5698	1.0734	1.0734	1.4875
Italy	1.8195	1.8195	1.5698	1.5698	1.0734	1.0734	1.4875
Morocco	0.2922	0.2922	1.3814	1.3814	0.7224	0.7224	0.7987
Spain	2.5521	2.5521	2.6145	2.6145	1.5946	1.5946	2.2537
Tunisia	0.2922	0.2922	1.3814	1.3814	0.7224	0.7224	0.7987
Turkey	1.8195	1.8195	1.5698	1.5698	1.0734	1.0734	1.4875
XMENA	0.2922	0.2922	1.3814	1.3814	0.7224	0.7224	0.7987

Using these parameters, changes in water availability for agriculture have been translated into changes in agricultural productivity, by industry. As water availability depends on the scenario considered, so do the productivity shocks. For example, Table 5 reports the shock parameters associated with the NE scenario.

Table 5 Reduction in agricultural productivity by sectors and region (NE)

	Wheat	Cereals	Rice	Veg&Fruits	Oilseeds	Sugar	Other crops
Egypt	-17.03%	-17.03%	-21.72%	-21.72%	-22.00%	-22.00%	-20.25%
France	-23.54%	-23.54%	-16.28%	-16.28%	-10.61%	-10.61%	-16.81%
Italy	-16.96%	-16.96%	-14.63%	-14.63%	-10.00%	-10.00%	-13.86%
Tunisia	-1.62%	-1.62%	-7.67%	-7.67%	-4.01%	-4.01%	-4.43%
XMENA	-1.12%	-1.12%	-5.27%	-5.27%	-2.76%	-2.76%	-3.05%

On average, the impact on agricultural productivity is very high for Egypt, high for France and Italy, medium for Tunisia and the Rest of Middle East/North Africa.

3.2 *A general equilibrium analysis of changes in agricultural productivity*

Results as those in Table 5 have been inserted in the GTAP CGE model of the world economy (Hertel and Tsigas, 1997) by shocking exogenous productivity parameters in

a simulation exercise, in which a counterfactual equilibrium for the global economy is computed.

Among the many variables produced by the model, we report in Table 6 the estimated percentage variation in national real income. This is a measure of household purchasing power, thereby accounting for the overall impact on welfare.

Table 6 Percentage variations in real national income

	NM	NE	IM	IE
Albania	-0.19	-0.17	-0.08	-0.04
Croatia	-0.05	-0.05	-0.01	-0.01
Cyprus	0.03	-0.02	0.02	-0.002
Egypt	-35.4	-7.24	-20.15	-1.1
France	-1.83	-1.83	-0.04	-0.04
Greece	0.004	-0.01	0.002	0
Italy	-1.77	-1.77	-0.37	-0.37
Morocco	0.41	0.04	0.37	0.01
Spain	0.04	0.03	0.01	0.01
Tunisia	-2.96	-1.42	-0.9	0.03
Turkey	0.01	0.01	0	0
XMENA	-0.41	-0.41	-0.38	-0.37

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.

Egypt is the most hurt country . Under the NM and IM scenarios (EFR water is not available for consumption in any Mediterranean country, with [I] or without [N] improvements in water efficiency), the model estimates a fall in real income as large as 35.41% and 20.16%, respectively (this corresponds to -12.93% and -7.24% for nominal GDP). Reductions in income levels and welfare are also found for France, Italy and Tunisia, which are the other water-constrained countries in our exercise.

There are clear differences among the four scenarios. First, applying the environmental policy constraint on the access to EFR water reserves only for Europe does make a difference for non-European countries, suggesting that countries in Middle East and North Africa 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, especially for northern Mediterranean countries. Notice also that, because of general equilibrium effects, countries that are not directly affected by variations in agricultural productivity are nonetheless influenced, in a positive or negative way.

4 Discussion

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