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Dedicated to all those

who do not believe enough

in their own ability.

Dedicata a tutti coloro

che non credono abbastanza

nelle proprie capacità.

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Saying that the present work would have never been possible without the support of my darling husband, Roberto, is not an overstatement. He always assisted me even when the tougher times got the worst out of me. The first and greatest recognition goes therefore to him. My gratitude is then for all my family and some friends, in particular Anna, Arianna and Piera, who have always encouraged me not to give up.

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Despite the many obstacles and difficulties, which are by nature part of the challenging research world, the Ph.D. "adventure" enriched me more than I expected. As a personal experience, in the first place.

Contents

INTRODUCTION

This dissertation is made up as a collection of papers on environmental economics dealing, in particular, with the economic modeling of natural resources.

All contributions fit into the tradition of the environmental economics literature, which is characterized by a number of notable characteristics. Most issues addressed in this literature revolve around the concept of *market failure* and *negative externality*. Natural resources do not typically possess a formal market in which prices can be formed and used as information signals in the allocation of resources. Overexploitation, unsustainable economic development, lack of efficient coordination among economic agents are all unavoidable consequences. The literature on environmental economics therefore addresses questions like:

- How the value of natural resources should be assessed, in the first place?
- How and how much prices should be adjusted (by means of taxes, subsidies, or quantitative constraints) to account for the social value of natural resources?
- How the system of national accounts should be integrated to consider non-market resources and more comprehensive welfare indexes?
- How to account for the risk of major environmental disasters and non-linearities in complex economic-ecological systems?
- Is economic growth sustainable? And, what do we mean by sustainability?
- As natural resources affect the well-being of future generations, what principles should guide the trade-off between current and future welfare?
- How much renewable resources can be exploited?
- Which is the optimal economic exploitation of natural resources?
- What are the consequences of environmental policies and impacts on the

distribution of income and wealth?

- How international coordination in environmental policies can be obtained and enforced?
- Are environmental and non-environmental policies consistent?
- How and how much environmental policies can foster technological innovation?
- How numerical models can inform effective economic policies?
- How uncertainty can be properly accounted for in theoretical and applied models?
- How numerical models stemming from different approaches and traditions can successfully be integrated?

Clearly, all questions above are extremely difficult to answer, and they may hardly be addressed without introducing value judgments, as well as alternative approaches and models. A number of typical techniques and model "workhorses" can be found in the literature, though.

Regarding the valuation of natural resources, a number of alternative methods are available. Some of them are based on stated preferences, like contingent valuation, choice modeling and experimental estimation. Other methods, such as hedonic preferences, infer preferences from observed market behavior.

The issue of extending economic accounts to consider non-market (environmental) resources is known as "green accounting". In a system of green accounts, environmental assets are valued and presented in a coherent framework, alongside "conventional" macroeconomic variables, like consumption, production and income levels.

Issues of intergenerational equity are typically addressed by means of theoretical models of economic growth, which are extended beyond the traditional neoclassical scheme through the inclusion of environmental assets, characterized by their own dynamics.

In this context, a recurrent problem is the choice of a proper discount rate to balance the exploitation of natural assets, for current consumption, and the preservation of natural capital for future generations. According to Heal (1997), such debate arises from confusing issues of intergenerational equity with other problems, related to pursuing an efficient allocation of the capital stock.

In addition to theoretical models, applied numerical models are highly utilized in this field, primarily for the purpose of environmental policy assessment. Variables and parameters are estimated using real world data, and simulation exercises are conducted to gauge the consequences of environmental policies and phenomena, like the climate change. Most of the chapters in this dissertation refer to applied environmental modeling.

A popular class of applied models is the one of Integrated Assessment Models (IAM), which integrate physical and socio-economic modeling. The socio-economic module inside IAMs is very often based on a Computable General Equilibrium (CGE) framework, which follows a Walrasian approach to account for market interdependencies.

Game theory is also extensively used in environmental economics. A typical issue addressed by means of game-theoretical models is the one of coalition formation in international environmental agreements.

DISSERTATION OUTLINE

This dissertation explores the use and development of computable models for environmental policy assessment. It is aimed at improving methodologies, extending the range of applications and elaborating on the theoretical underpinnings of the models.

Chapters 1, 2, 3 and 4 all deal with the economics of water resources. Most of them make use of computable general equilibrium models to assess the effects of future water availability on the economy of the Mediterranean. Chapter 2 addresses methodological issues arising in the estimation of "virtual water" flows, whereas Chapter 5 explores some aspects of sustainable economic growth in a theoretical setting.

In particular, Chapter 1 builds and illustrates four scenarios, assessing future water availability in the Mediterranean and its macroeconomic implications. The scenarios are constructed by considering forecasts of economic and demographic growth, as well as climate change and environmental policies. It is found that some northern Mediterranean countries will face insufficient water supply for agricultural sectors, because of climate change and reduced precipitation, whereas other southern Mediterranean countries will face similar problems mainly caused, however, by strong economic and demographic development. This chapter is a preliminary, reduced version of a paper, still under development, coauthored with Prof. Luis Garrote, Prof. Ana Iglesias and Prof. Roberto Roson.

Chapter 2 discusses some methodological issues associated with the estimation of virtual water flows, which refer to the volume of water used in the production of a commodity or service, and virtually exchanged through conventional trade. In this paper, we argue that conventional methods for the computation of virtual water flows may bring about biased estimates, thereby limiting the usefulness of the virtual water concept as a tool for informing water policy. We propose a new approach, accounting for both direct and indirect water consumption, that is the one associated with the use of intermediate factors. Furthermore, we distinguish between *green* (soil moisture) and *blue* (surface) water resources, which is important because green and blue water have different opportunity-costs. This chapter was published as: Antonelli, M., Roson, R.

and Sartori, M. (2012), "Systemic Input-Output Computation of Green and Blue Virtual Water Flows with an Illustration for the Mediterranean", *Water Resources Management*, vol.26, pp.4133-4146.

Chapter 3 analyzes current and future virtual water trade patterns in the Mediterranean. The future scenario is obtained by means of a computable general equilibrium model, where the effects of reduced agricultural productivity, induced by lower water availability, are simulated. The analysis highlights a future reduction of intra-Mediterranean virtual water trade and an increase of virtual imports from central and northern Europe, as well as from the rest of the world. A first (quite different) version of this paper was published as: Roson, R. and Sartori, M. (2010), "Water Scarcity and Virtual Water Trade in the Mediterranean", Ca' Foscari University of Venice, Dept. of Economics, Research Paper Series n. 08/10. That paper was also presented at two international conferences, the 13th Annual Conference on Global Economic Analysis and the EcoMod2011 Conference. A recent version of the paper has been submitted for publication.

Chapter 4 considers the consequences, in terms of water demand and economic performance, of climate change-induced variations in tourism flows, for a number of southern European economies. It is found that additional tourists from abroad would increase income and welfare in a hosting country, but they would also induce a change in the productive structure, with a decline in agriculture and manufacturing, partially compensated by an expansion of service industries. The reduction in agricultural production would entail a lower demand for water, possibly counteracting the additional request coming from the tourism sector. A first version of this chapter was published as: Roson, R. and Sartori, M. (2012), "Climate Change, Tourism and Water Resources in the Mediterranean: a General Equilibrium Analysis", IEFE Working Paper Series, Bocconi University, vol. 51. The paper was also presented at two international conferences, the 15th Annual Conference on Global Economic

Analysis and the EcoMod2012 Conference. The paper has been submitted for publication.

Chapter 5 follows a rather different approach, in examining the implications of alternative assumptions on discounting in a theoretical model of economic growth, in which one natural resource (which could possibly be interpreted as water quality level) affects the inter-temporal utility of a representative consumer. The chapter builds upon Smulders (2007), who analyses a model of economic growth with renewable resource dynamics, to study how society's discount rate and the inter-temporal optimization process affect the long-run stock of an environmental resource. A draft version of this paper was presented at the first Environmental Economics Workshop, June 2012, held at the University of Bologna. The paper has been submitted for publication.

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Heal, G. (1997), "Discounting and Climate Change", *Climatic Change*, vol. 37, pp. 335-343.

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1.

TRADE-OFFS IN WATER POLICY: SYSTEM-WIDE EFFECTS OF WATER AVAILABILITY IN THE MEDITERRANEAN ECONOMIES

A SCENARIO ANALYSIS BY 2050

by

Roberto Roson

and

Martina Sartori

1.1. 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 (Iglesias *et al.*, 2011). 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). It is likely that the stress imposed by climate change on agriculture and water intensifies the regional disparities, conflicts over alternative uses of resources and the overall economy of Mediterranean countries (Alcamo *et al.*, 2007).

Knowledge, empirical evidence and modeling tools for assessing the effects of future water availability on agriculture are lacking. This paper aims to advance the understanding of the impacts of climate change on the water balance and on the social and economic factors affecting water security in the Mediterranean region. We develop simple estimates of water availability for agriculture, given a climate change scenario and a set of assumptions about water allocation among users. We subsequently estimate the relationship between water availability and productivity for a range of crops, examining how potential changes in water resources may affect industry production volumes, prices, income and wellbeing in the Mediterranean countries.

Our modeling strategy follows a logical sequence:

1. *From climate scenario to water runoff*. We select a specific scenario from a Regional Circulation Model (RCM) to get estimates of precipitation and temperature, which are used to calculate future water runoff.
2. *From water runoff to water availability*. We evaluate the stock of water resources on the basis of the relationship between water availability and water runoff.
3. *From total water availability to water available for agriculture*. We subtract municipal

and industrial water demand, to assess how much water would be left for agriculture.

4. *From water inputs to agricultural productivity*. We assess how changes in irrigation and water supply may affect crop yields.
5. *From agricultural productivity to system-wide economic effects*. We insert exogenous variations in agricultural productivity into a global general equilibrium model (CGE), to simulate how the changing water availability could entail variations in production volumes, prices, trade flows and welfare.

The rest of the paper is devoted to illustrate the steps above in more detail and to present our findings. It is structured as follows: the next section describes how estimates of agricultural productivity for the Mediterranean, due to changing water availability, have been obtained; Section 1.3 provides a general equilibrium analysis of the implied economic impacts and a final section gives some concluding remarks.

1.2. Assessment of future water availability and its impact on agricultural productivity in the Mediterranean

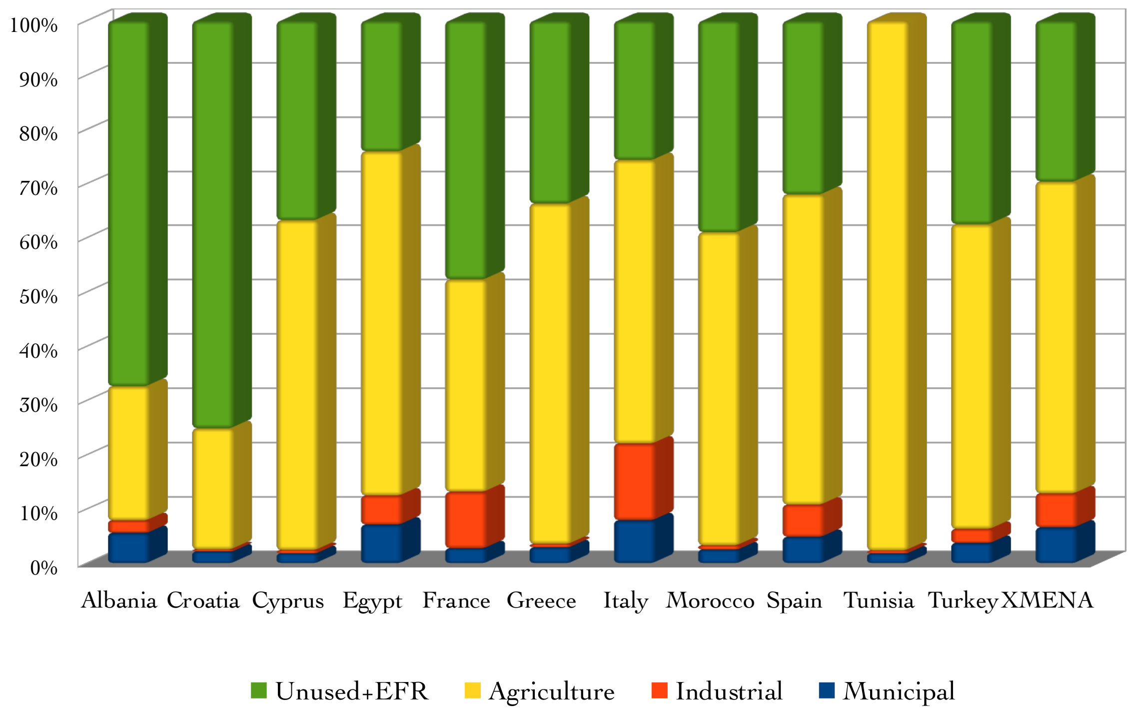
Quite naturally, estimates of agricultural productivity are surrounded by multiple uncertainties. Lack of information, structural model weaknesses, uncertain policy response and degree of adaptation are all factors making the evaluation of future agricultural productivity highly debatable. For these 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. 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.

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 year. Among the supply sources we consider *blue* water, which is surface water stored in lake, rivers, reservoirs, etc., and *green* water, which is embedded into the soil moisture (rainfed). 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).

Three uses of water are appraised: agricultural, municipal and industrial. Green water can only be used by agriculture, where it is supplemented by blue water[1] through irrigation or other means. By construction, we do not allow water consumption to exceed water supply. Any difference between total blue water availability 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 database[2]. Figure 1.1 shows the composition of water demand among different usage classes for the Mediterranean countries considered in this study.[3]

1 It is assumed that blue water covers no less than 10% of agricultural water demand.
2 See: http://www.fao.org/nr/water/aquastat/main/index.stm.
3 XMENA stands for "Rest of Middle East and North Africa".

Figure 1.1. Composition of water consumption in the baseline (2000-2005).



To assess future climate conditions, we use data from the European research project WASSERMed[4] (Congedi *et al.*, 2012), which in turn have been obtained from a set of Regional and Global Circulation Models[5]. Figure 1.2 shows the annual total precipitation for the two years 2000 and 2050, alongside variations in average temperature during the same period of time, for all countries in the Mediterranean.

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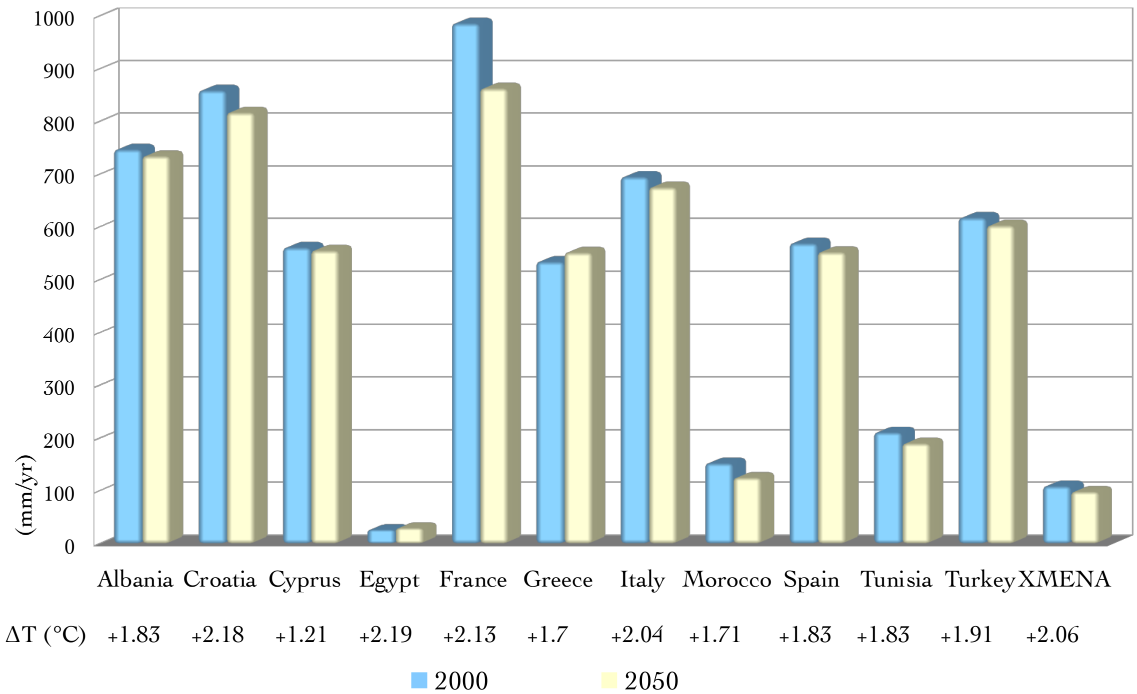
4 WASSERMed (Water Availability and Security in Southern Europe and the Mediterranean Region) is a research project funded by the European Commission in the 7th Framework Program (contract no. 244255). For more information: http://www.wassermed.eu .

5 Estimates used here derive from the output of the Hadley Centre model HadCM3Q0 (resolution: 3,75° x 2,5°).

Figure 1.2. Precipitation 2000-2050 and temperature change.



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[6]. This formula is:

6 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.

$$R = P * \exp(-PET / P) \tag{1.1}$$

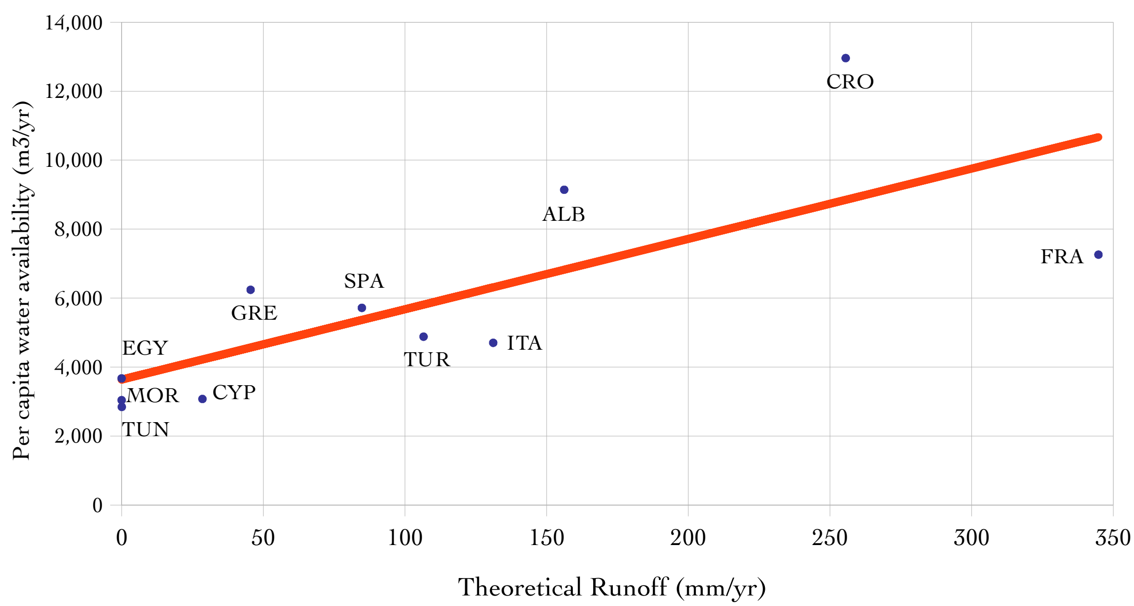
where R stands for runoff, P is annual precipitation in mm and PET is potential evapotranspiration, computed as a function of temperature T (Kelvin degrees):

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

The potential runoff in each country is compared with total per-capita water availability in Figure 1.3. 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 a linear function:

$$TWA = 3638 + 20.4 R \tag{1.3}$$

Figure 1.3. 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 (1.3) to assess how changes in temperature and precipitation could affect water supply in each country. Table 1.1 presents the theoretical runoff computed at the years 2000 and 2050, and the associated variation in estimated total water availability. This amounts to move from one point to another along the red regression line in Figure 1.3.

Table 1.1. Variations in theoretical runoff and water availability, by country.

	T. R-O 2000	T. R-O 2050	Change in TWA
Albania	156.20	125.99	-6.74%
Croatia	255.54	193.20	-9.81%
Cyprus	28.53	22.46	-4.03%
Egypt	0.00	0.00	0.00%
France	344.75	222.45	-34.36%
Greece	45.52	98.61	-1.74%
Italy	131.14	98.61	-14.11%
Morocco	0.00	0.00	0.00%
Spain	84.80	62.82	-7.84%
Tunisia	0.07	0.01	-0.04%
Turkey	106.56	81.18	-10.61%
XMENA	0.00	0.00	0.05%

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[7].

On the demand side, the various components have been projected using different assumptions and methodologies. 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, of about 10%[8]. 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 account for improved access to sanitation and freshwater.

Industrial consumption is assumed to increase at a rate equal to 1/3 of the national Gross Domestic Product. GDP forecasts have been derived from the World Bank Statistics[9]. The lower rate for industrial water consumption is assumed to approximate the changing composition of the national income, with a lower share for

7 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. Furthermore, the relationship (1.1) was estimated on the basis of standard, average conditions. 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.

8 Depending on the country, from +7% for Cyprus to +13% for France.

9 http://www.data.bank.org

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 means the share of blue water resources that should be set aside for effective protection of the environment. These values are displayed in Table 1.2.

Table 1.2. EFR shares.

Albania	30%	Italy	30%
Croatia	30%	Morocco	20%
Cyprus	25%	Spain	35%
Egypt	15%	Tunisia	25%
France	35%	Turkey	25%
Greece	25%	XMENA	15%

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 (including 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.

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 1.3 presents our estimates of reductions in water available to agriculture in the four scenarios, for all countries and in 2050.

Table 1.3. 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	-	-	-	-
XMENA	-10%	-10%	-10%	-10%

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 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 10% of its total water consumption. In Tunisia, water resources are overexploited already in the baseline (see Figure 1.1); any further increase in water demand would not be sustainable.

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, expressing the percentage change in annual yield when the water input is varied by 1% (keeping all other production factors unchanged) has been estimated (Antonelli *et al.*, 2012).

The methodology for the estimation of water productivity parameters is based on results from dynamic process-based crop growth models, specified and validated for sites in the main agro-climatic regions of some selected countries. The validated site crop models are useful for simulating the range of conditions under which crops are grown, and to provide means to estimate water elasticities when experimental field data are not available. However, crop models estimate the water response under hypotheses of perfect efficiency in water delivering.

To get more realistic parameter values for the countries under consideration, which are large geographical regions and for which total annual productions are regarded, we take into account limitations in infrastructure, technology and management of the water distribution systems. We conduct a qualitative analysis by ranking the Mediterranean countries in terms of estimated water efficiency (low, medium, high) in the present and in the future, considering a number of key indicators[10]. Water elasticity parameters used in this study (reported in Table 1.4) have been obtained by scaling down the corresponding values of the crop growth models, with the magnitude of the reduction being smaller for water efficient countries (and vice versa).

10 These are: Infrastructure (pipes, canals), Irrigation technology, Irrigation advisory services, Value of the irrigated production, Land ownership structure. Classification rules: (a) a country has high efficiency when it has either three or more high indicators, or two high indicators and no low indicator; (b) a country las low efficiency when it has either three or more low indicators or two or more low indicators and no high indicator; otherwise (c) a country has medium efficiency. According to these rules we classify four countries with high efficiency (Cyprus, Egypt, France, and Spain); three countries with medium efficiency (Italy, Greece and Turkey); and four countries with low efficiency (Albania, Croatia, Morocco, Tunisia). The regional aggregates are considered with medium efficiency.

Table 1.4. 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 sector and for each scenario. As water availability depends on the scenario considered, so do the productivity shocks. As an illustration, Table 1.5 reports the shock parameters associated with the NE scenario (no improvement in water efficiency, EFR constraint imposed on European countries only).

Table 1.5. Reduction in agricultural productivity by sectors and region (NE scenario).

	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%
Morocco	-0.08%	-0.08%	-0.37%	-0.37%	-0.19%	-0.19%	-0.21%
Tunisia	-1.62%	-1.62%	-7.67%	-7.67%	-4.01%	-4.01%	-4.43%
XMENA	-1.46%	-1.46%	-6.91%	-6.91%	-3.61%	-3.61%	-3.99%

On average, impacts on agricultural productivity in the NE scenario are very high for Egypt, high for France and Italy, medium for Tunisia and the Rest of Middle East and North Africa, low for Morocco. The most sensitive crops are oil seeds, sugar, rice, vegetables and fruits in Egypt, wheat and cereals in France and Italy, rice, vegetable and fruits in Tunisia and in the Rest of Middle East and North Africa.

1.3. A GENERAL EQUILIBRIUM ANALYSIS OF CHANGES IN AGRICULTURAL PRODUCTIVITY

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 can be analyzed 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 account for the circular flow of income and inter-sectoral linkages inside the whole economic system.

Results in Table 1.5 (as well as in Tables A2.1, A2.2 and A2.3 presented in Appendix A2) have been inserted into a CGE model of the world economy (Hertel and Tsigas, 1997; a short description of the model can be found in Appendix A1) to shock 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 1.6 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 1.6. Percentage variations in real national income for each scenario.

	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 country which is hurt the most. 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[11]. Reductions in income levels and welfare are also found for France, Italy and Tunisia, which are the other water-

11 This corresponds to -12.93% and -7.24% for nominal GDP.

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.

1.4. CONCLUSIONS

In this paper, we have presented an analysis of climate change impacts on water and agricultural productivity in the Mediterranean. To our knowledge, this is the only available study providing a quantitative assessment of the phenomenon, which simultaneously considers, for the broad Mediterranean region, estimates of water availability, differentiated crop responses and system-wide effects of variations in agricultural productivity.

This is not a forecasting exercise and it is clear that every step we made could be criticized in terms of realism and robustness of assumptions. Furthermore, we have considered constant production volumes in agriculture, because our primary aim is assessing the sustainability of agricultural production when water resources get scarcer, possibly because of climate change.

Therefore, despite the quantitative nature of our modeling exercise, the key messages are qualitative. We found that several Mediterranean countries will likely face water shortages with significant implications in terms of agricultural productivity, income and welfare. The water gap will be driven by increased temperature and decreased precipitation in Northern Mediterranean countries, by growing non-agricultural water needs in Southern countries. Improvements in water efficiency could help in curbing the negative impacts, yet all gains could be offset by growth in agriculture output, which has not been considered here. We also found that Southern Mediterranean countries will likely find it difficult to put aside precious water resources for purposes of environmental preservation.

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2.

Systemic Input-Output Computation of Green and Blue Virtual Water Flows

with an Illustration for the Mediterranean

by

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2.1. INTRODUCTION

The concept of virtual water has steadily gained prominence as a metaphor to illustrate the relationships between water inputs and industry outputs. The term refers to the volume of water used in the production of a commodity or a service. Accordingly, virtual water trade is the amount of water embedded in internationally traded commodities.

Traditionally, virtual water flows are calculated using the methodology developed by Hoekstra and Hung in 2002. The basic approach is to multiply output or trade flows (ton/yr) by the associated virtual water content (m^3/ton) of the produced or traded commodity. In computing virtual water flows, this accounting method considers only direct, i.e. final, water usage[12], thus ignoring the many indirect, i.e. intermediate, uses of the resource as a fundamental input to production.

Virtual water studies have mainly focused on the water-saving effect brought about by international food trade and on the role it plays in compensating for local water deficits. Few of them, however, have established whether the water used in the production process originates from surface and underground flow (hereby referred to as blue water), or from water stored in the root zone (green water). None, to our knowledge, has applied the Input–Output (IO) methodology to assess the virtual water flows associated with international trade and simultaneously assessed the "color" of the (indirectly) exchanged water. Distinguishing between blue and green water is important, because only the former has a significant opportunity cost and can be controlled (possibly only partially) by water management bodies.

This paper examines the standard virtual water accounting method based on Hoekstra and Hung (2002) and seeks to overcome two of its fundamental shortcomings: (i) the lack of a systemic account of water production factors; and (ii)

12 Only in a few cases, more specifically with regards to livestock products, some intermediate inputs accounted for, thus making the estimates internally inconsistent.

the absence of a distinction between blue and green water resources. These flaws appear to undermine both the reliability of current estimates and the applicability of the concept as a tool for informing water resource management policy. This study is therefore aimed at presenting a comprehensive analysis of virtual water trade that integrates these two different but complementary approaches. Firstly, a systemic quantification of virtual water flows by means of the Input–Output framework is presented. Secondly, the green and blue water components embedded in traded commodities are differentiated.

The implications of the alternative estimation approaches are illustrated here using data referring to 11 Mediterranean-rim economies. The Mediterranean test case is presented with the sole purpose of highlighting how the new methodology can essentially change the results, possibly bringing about different policy implications. The Mediterranean is also chosen as it has been considered by many previous virtual water analyses.

The study is structured as follows: the next section outlines the background of the paper and reviews the relevant literature. The third part describes the methodology which has been deployed and its advantages over conventional approaches. The fourth section presents and discusses the test case results, highlighting the extent to which the improved methodology can make virtual water a more meaningful and useful concept for policy assessments. The final part draws some conclusions.

2.2. BACKGROUND

2.2.1. The concept of virtual water

Virtual water trade is the market-mediated mechanism through which arid and semi-arid countries, like most Mediterranean economies, have indirectly and implicitly coped with water scarcity. The concept of virtual water was identified and made popular by Allan (1993). The exchange of virtual water is implicit in trade: whenever a country imports (exports) food and manufactured commodities from another, a virtual transfer of water occurs (Allan, 1998). Virtual water is an "inherently economic concept", which is consistent with standard international trade theory (Reimer, 2012). Virtual water flows between nations are substantial, accounting for over 1,000 billion cubic metres annually (Hoekstra and Hung, 2002; Chapagain and Hoekstra, 2003; Zimmer and Renault, 2003; Oki *et al.*, 2003). North and South America, Australia, most of Asia and central Africa are major exporters of virtual water. Europe, Japan, the Middle East, North and Southern Africa, Mexico and Indonesia are net virtual water importers.

Commodities are produced and exported by economies, which can undertake production processes in an economically competitive way. Therefore, water-intensive products are likely to be produced in places where water is relatively cheap, although water is not the only production factor and the low price of other factors (e.g., labour, land) may actually be more important to determine the production profile of a country. Water is cheap where it is abundant, but the opposite is not necessarily true: water resources may not be correctly priced and property rights may not be adequately enforced, so that the cost of water could be kept artificially low.

Nonetheless, to the extent that water abundance determines a comparative advantage in water-intensive sectors, countries facing water shortage can achieve some savings by importing high-water goods (e.g., water intensive agricultural products), rather than producing them internally, in exchange for low-water goods and services. As a consequence, while there is no actual water saving in commodity trade, trade does enable very significant advances in food and water security to be achieved. This is to say that although the import of virtual water does not actually bring about real water savings, the capacity to engage in trade provides water scarce countries with water and food security. Virtual water trade is thus a securitizing rather than a "saving" process. However, as virtual water generally moves from regions that achieve high returns to water (especially green water), the result is a saving at the global level when the imports are to economies that achieve poor returns to water.

Two remarks are in order here. First, the virtual water trade mechanism operates smoothly and silently through the markets, so that virtual water trade is not part of any water policy package. Second, what we are discussing here with reference to water applies equally well to any other scarce resource[13]. Indeed, it is well known that the main implication of competitive trade is a more efficient global allocation of resources.

Virtual water is, therefore, a useful metaphor which helps shedding light on the water efficiency gains associated with regional and international trade. In order to enhance its policy relevance, however, it is imperative to refine the current analysis by (i) considering water consumption in its both direct and indirect components; and (ii) distinguishing the different sources of water and their opportunity costs.

2.2.2. Computing virtual water flows using IO accounting

The basic approach for calculating virtual water trade flows was developed by Hoekstra and Hung (2002). Virtual water flows between countries (m^3/year) are calculated by multiplying commodity trade flows (ton/year or $/year) by their associated virtual water content (m^3/ton or m^3/$). The virtual water content of a product, in turn, is the volume of water required to produce the commodity in the exporting country. Therefore:

13 The notion has been used, for instance, to assess the virtual carbon content of imports – i.e. the extent to which carbon is embodied in the international trade of goods and services – (Atkinson *et al.*, 2010). Virtual water has also been linked to of water footprint, which is "the volume of water necessary to produce the good and services consumed by the inhabitants of a country" (Chapagain and Hoekstra, 2004).

$$vwt_i^{rs} = ct_i^{rs} \times w_i^r \quad (2.1)$$

Where vwt is the virtual water trade flow (m^3/year) from the exporting country r to the importing country s as a result of trade in crop i. ct represents the crop trade flow from the exporting country r to the importing country s for crop i and w is the specific unit water demand of crop i in the exporting country (all variables are possibly functions of time). It is assumed that if a crop is exported from a certain country to another, this crop has been grown in the exporting country. This is not always the case, but it is a reasonable approximation.

Input–Output analysis (Leontief, 1951) can be used to get more accurate estimates of virtual water fbws. In a nutshell, IO tables express the value of economic transactions occurring between different sectors of an economy, so that it is possible to account for sectoral interdependencies in the economic system. These affect, for example, how demand in one industry stimulates production not only in that industry, but in all other industries supplying intermediate factors to the former. Over the past few years, a number of scholars have used input–output data and models to analyze regional and national water consumption (Dabo and Hubacek, 2007; Dietzenbacher and Velázquez, 2006; Dietzenbacher and Velázquez, 2007; Feng *et al.*, 2011; Huang *et al.*, 2011; Lenzen and Peters, 2010; Velázquez 2006; Wang *et al.*, 2009; Yu *et al.*, 2010; Zhang *et al.*, 2010, 2011; Zhao *et al.*, 2009, 2010). Whereas these studies focus on one national economy, in this work we propose to extend the application of IO techniques to international trade flows.

In order to understand how the Input-Output analysis can be applied in practice, we consider a matrix A where each element a_{ij} stands for consumption of good i (produced by industry i or not produced, like water w, being a primary resource) necessary to produce one unit of good j (produced by industry j). We shall refer to direct water consumption in industry j as a_{wj}. Direct water requirements do not express the actual usage of water per unit of output, though, as one should account for water employed in the production of intermediate factors, whose amount is $a_{wj} \times a_{ij}$ per unit of output. As production of intermediate factors itself requires intermediate factors, with additional request of water, the computation of global, systemic water input would imply the calculation of an infinite sum which, nonetheless, can be shown to converge to a finite number. For example, for two goods (1 and 2) the unitary water requirement for good 1 is not only a_{w1}, but actually:

$$a_{w1} + a_{21} a_{w2} + a_{12} a_{21} a_{w1} + a_{12} a_{21}^2 a_{w2} + a_{12}^2 a_{21}^2 a_{w1} + \cdots \quad (2.2)$$

It is not necessary to calculate the infinite sum above for all goods, however, as it is possible to easily compute global water input coefficients using a compact matrix notation. Denoting A the square matrix of intermediate input output coefficients in a country a_{ij}, w[14] the (row) vector of a_{wj} coefficients, and v the (row) vector of global (systemic, namely direct plus indirect) unit water requirements, then:

$$v = w(I - A)^{-1} \quad (2.3)$$

In order to calculate systemic virtual water trade, each element in the vector v would replace the corresponding variable w into equation (2.1).

Equation (2.3) can also be used to provide estimates of global water usage for specific water components. For example, to get estimates of systemic unit demand for blue water resources, it is sufficient to reinterpret the vector w in equation (2.3) as sectoral blue water input per unit of output. Furthermore, if it is assumed (as it is done in this paper) that the share of blue water in total water consumption does not vary by industry (though it may vary by country), it is enough to multiply either the

14 It is the same as vector *w* in equation (2.1).

vector v or the vector w by the share of blue water in the total water usage.

2.2.3. Distinguishing green and blue water resources

Not all water is equal. Water resources differ in terms of origin, relative scarcity, mobility, possible allocation and opportunity costs. For policy purposes, it is especially important to distinguish between two different types of water which, for ease of communication, are referred to as blue and green water. The term blue water refers to water stored in lakes, rivers, reservoirs, ponds and aquifers (Rockström *et al.*, 1999). Green water indicates the return flow of water to the atmosphere as evapotranspiration, which includes a productive role in the biosphere – as transpiration, and a non-productive biospheric role – as direct evaporation from the surface of soils, lakes, ponds, and from water intercepted by canopies (Falkenmark, 1995; Yang *et al.*, 2006). The former can be diverted to irrigate crops as a supplement to rainfall; the latter sustains rainfed crop production as well as natural vegetation.

Blue and green water resources differ in many aspects, and their ratio varies substantially over time and space. Green water supply comes from rainfall and is scarce in arid and semi-arid areas. As such it is highly immobile and in general is not explicitly valued by users[15]. Conversely, blue water is mobile: it can be abstracted, pumped, stored, treated, distributed, collected, and recycled. Normally, its supply is costly, because it requires infrastructure. Green water supports human livelihoods through rainfed crop production as well as ecosystems, and faces no major competition from other domestic or industrial uses. Therefore, it has a low opportunity cost compared with the one of blue water. Blue water, instead, is the water with the highest economic potential, as it can perform numerous functions[16].

15 It could be argued that, however, that the price of agricultural land reflects fertility and peculiar climatic conditions, including green water availability.

16 Blue water used in irrigated agriculture yield the lowest economic value among all other options while being associated with significant negative environmental externalities – such as water logging, salinisation, soil degradation (Zehnder *et al.*, 2003).

Holding other factors constant, trading green virtual water is more efficient than trading blue virtual water (Yang *et al.*, 2006; Chapagain *et al.*, 2006). The reason is that the blue water allocated to irrigated agriculture yields the lowest economic value among all alternative uses and it is often associated with significant environmental externalities (Zehnder *et al.*, 2003).

The ratio of irrigated areas or rainfed areas to total crop areas indirectly shows the dependency on blue or green water resources for agricultural production. As calculated by Fader *et al.* (2011), the largest share of the water used in agriculture is green (84%) as well as the virtual water embedded in exports (94%), moving generally from green water- abundant countries to blue-water based countries. Crop production at the global scale is mainly rainfed and the ratio of rainfed or irrigated areas to total crop production have a high geographical correlation with virtual water importers and exporters (Yang *et al.*, 2006). In other words, water-abundant countries rely on green water resources; vice versa, in water- scarce countries the dependency on blue water is generally higher.

The importance of keeping blue and green water distinct in a context of policy assessment should now be clear. By importing goods one country can free up those water inputs that would have been needed to produce the goods domestically. As in water-scarce countries, blue water is generally relatively more abundant than green water, the import of food commodities potentially enables this water to be re-allocated to uses yielding "more value per drop" than irrigated agriculture. In order to understand the significance of international trade in terms of water, it is thus necessary to appraise whether the water that is not used for agricultural production in the importing economies is blue or green.

2.3. A TEST CASE: VIRTUAL WATER TRADE IN THE MEDITERRANEAN

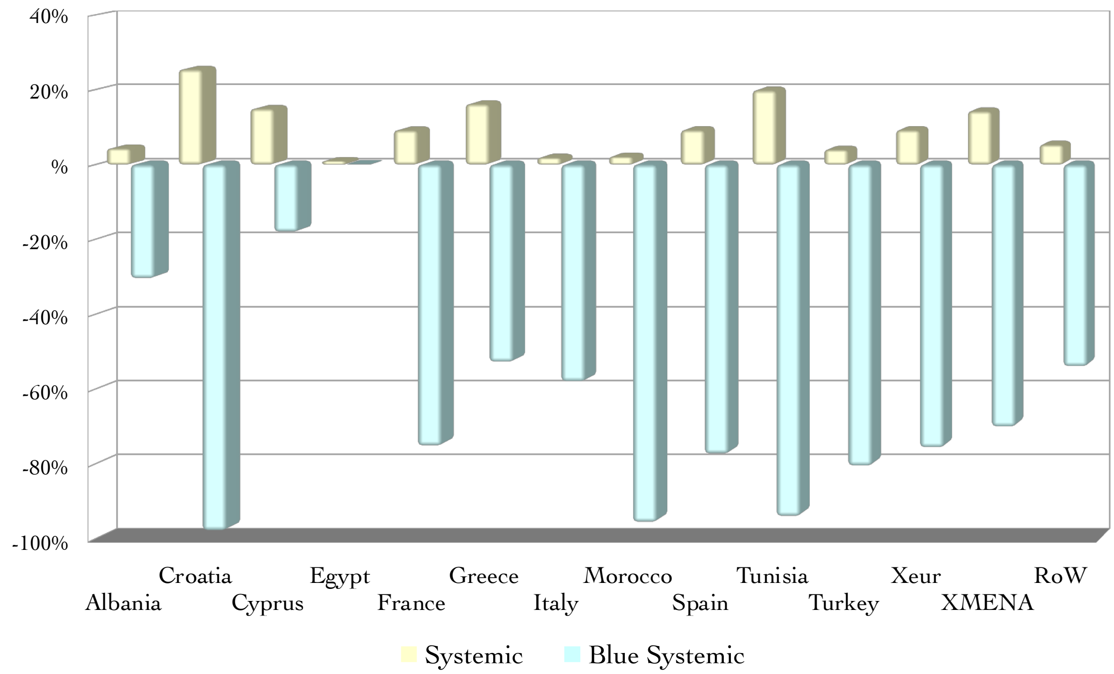
In the previous section, we argued that systemic (rather than only direct) and blue/green (rather than only global) water usage should be considered in virtual water trade analysis. From a practical point of view, however, would the improved estimates of virtual water flows fundamentally change the (qualitative) results, possibly bringing about different policy implications?

To explore this issue, we estimated virtual water trade flows for a set of countries in the Mediterranean, using three alternative methodologies: the standard one (*à la* Hoekstra and Hung), the systemic one (where virtual water coefficients are corrected using input-output matrices), and the systemic one applied only to blue water. The Mediterranean is an especially interesting test case and it has been the subject of several virtual water studies. This should not come as a surprise, as the Mediterranean region is one of the most water-challenged areas in the world. Water issues regard not only the overall limited water supply throughout the region, but also the uneven distribution of the resource. The results of the estimation exercise, as well as a cursory description of the procedure, are presented in Appendix A3. In the following, we focus on some key results, highlighting the implications of using different methods to calculate virtual water variables.

Figure 2.1 presents the percentage variation, with respect to estimates obtained with the standard method, in water requirement per unit of output for the Fruit and Vegetables industry, when (i) the IO-based method is adopted to overall water consumption (light brown bar); (ii) the method is only applied to blue water (light blue bar). The results are shown for 11 Mediterranean countries and three residual macro-regions[17].

17 Xeur = Rest of Europe; XMENA = Rest of Middle East/North Africa; RoW = Rest of the World.

Figure 2.1. % change in water requirements per unit of output (m^3/M$). Fruit and vegetables industry.

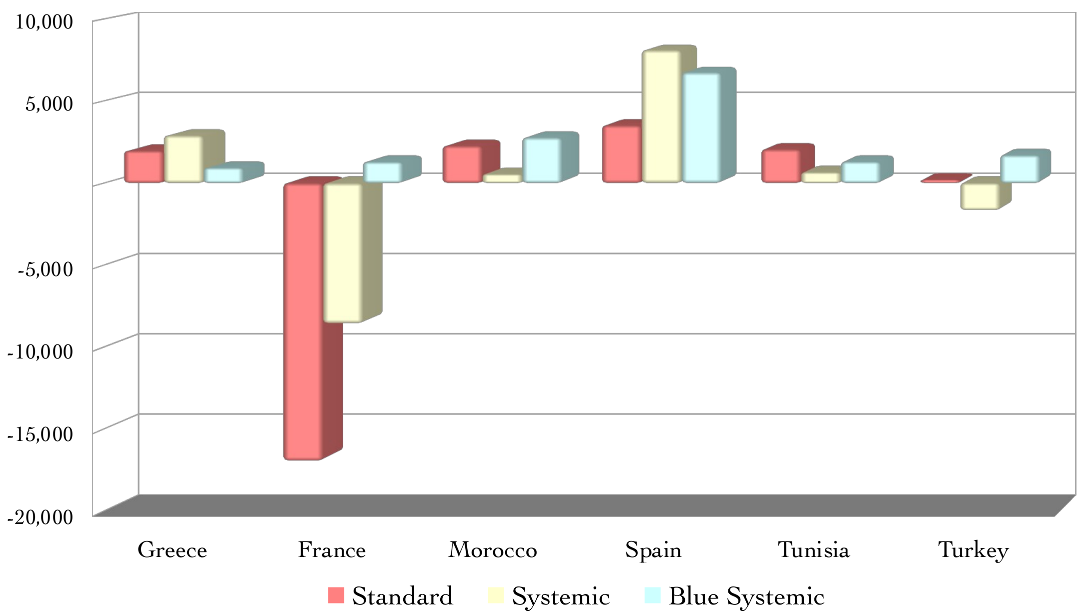


Not surprisingly, systemic (IO) coefficients are always larger than those obtained when the standard method is applied, because indirect water consumption is included. Also, blue (systemic) water coefficients are always smaller, as blue water is only a share of overall water consumption.[18] What is important to notice here is that the ranking among countries in terms of water productivity, or water intensity, may be very different when the focus is on blue water resources and interdependencies between industries are accounted for. For example, countries like Morocco and Tunisia turn out to be much less blue water intensive than Egypt. This means that exporting one dollar of fruits or vegetables from Morocco or Tunisia entails a much lower consumption of precious blue water resources.

18 Actually, the total variation of blue systemic coefficients is due to the overlapping of two counteracting effects: (i) the inclusion of indirect consumption; and (ii) the consideration of the blue water share. The second effect dominates.

Figure 2.2 shows virtual water trade balances (virtual water imports minus virtual water exports), in millions of cubic meters, for some representative countries, estimated using the standard methodology (purple bar), the systemic/IO one (light brown bar), and the blue + systemic one (light blue bar).

Figure 2.2. Virtual water trade balance (Mm^3). Standard, systemic and blue+systemic methods.



The general purpose of computing virtual water trade balances is assessing whether a country is a net virtual water importer or exporter. In this respect, Fig. 2.2 highlights that the results can be dramatically different when a more appropriate methodology to estimate virtual water coefficients is adopted. Indeed:

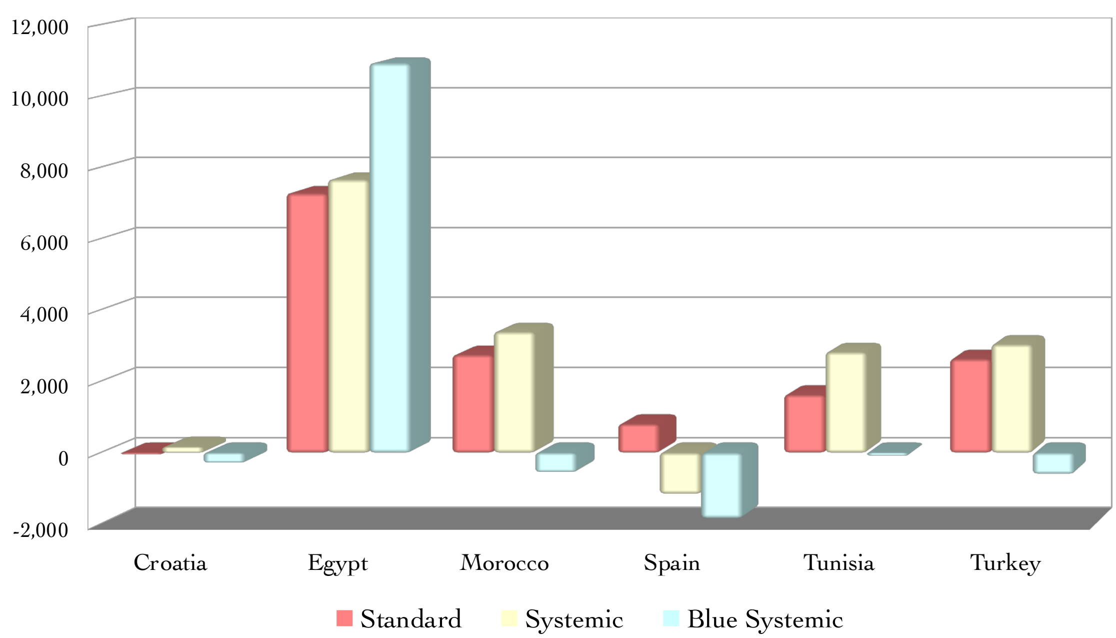
- former net virtual exporters (e.g., Turkey and, more importantly, France) become (blue) virtual water importers;
- significant import volumes remain so if only the blue water component is considered (e.g., Morocco and Tunisia);

- higher virtual inflows of water are estimated when systemic inter-dependencies are considered (e.g., Greece and Spain).

Another interesting exercise is assessing the gains in terms of water resources to water importing countries. This is done by computing how much water (total or blue) would be needed if imports were instead produced domestically, while subtracting from the latter the water consumed to produce exported goods. This new kind of balance expresses how much extra water would be necessary if a country was not involved in international trade, at given (unchanged) levels of domestic consumption.

Figure 2.3 (analogous of Figure 2.2) illustrates some interesting results for a set of representative countries.

Figure 2.3. Potential virtual water "savings" by means of trade (Mm^3).



The findings illustrated in Figure 2.3 confirm that the application of different methodologies for the estimation of virtual water trade flows may lead to strikingly different outcomes:

- depending on which method is used, a country can be a net gainer or loser, in terms of virtual water resources;
- the gains obtained by a country like Egypt are much higher than initially estimated, when blue water and system effects are considered;
- countries like Morocco, Tunisia and Turkey appear to gain from trade, the more so when systemic effects are taken into account. Yet, they are not gaining blue water resources.

We argued above that analyzing systemic virtual water trade, while focusing on blue water, allows to get a more meaningful understanding of the implications of international trade in terms of water. The results of our numerical test support this argument. Furthermore, they suggest that neglecting these effects may lead to biased estimates and erroneous interpretations.

2.4. Conclusions

A general principle of economics states that trade can improve upon the allocation of resources, including water. The concept of virtual water was introduced to better understand what this principle implies in terms of resources management and possibly how this automatic, market-driven mechanism may interact with specific water systems policies.

From this perspective, the fruitfulness of the virtual water concept is obviously dependent on the techniques used to estimate virtual water variables and parameters. In this paper, we argued that a correct estimation of virtual water parameters should consider the indirect consumption of water, due to the use of intermediate production factors, as well as the fact that blue water is what really matters in many circumstances. Indeed, as only blue water can be transferred to alternative uses, the relevance of virtual water trade is linked to the possibility of diverting blue water away from agriculture, where its marginal value is generally low, to other utilizations (drinking, industrial uses, etc.), where the marginal value is higher. By contrast, green water cannot be moved, so "saving" green water is a quite meaningless concept.

To our knowledge, this is the first paper to show that, by combining input-output techniques with blue water accounting, it is possible to get not only more accurate estimates of virtual water flows in international trade, but also to obtain dramatically different results, from a qualitative point of view.

Previous estimates of virtual water flows and trade could have been flawed by their lack of consideration of indirect water usage and by not fully differentiating between blue and green water resources. We showed in the paper that estimates of water requirement per unit of output are generally higher when systemic effects are accounted for, whereas they are lower when only blue water is considered. What really changes the picture, however, it not the fact that estimates are all biased upward or downward, but that the shift does not occur homogeneously among the sectors. Systemic water requirements are higher in those industries that are highly integrated with the rest of the economy, using a lot of intermediate factors, which themselves require water. Therefore, previous studies have underestimated the water needs of those integrated sectors. Similarly, as the ratio between blue and green water consumption is higher in arid countries (relying relatively more on irrigation), previous studies have underestimated the water needs of those countries.

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3.

Virtual Water Trade in the Mediterranean: Today and Tomorrow

by

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and

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3.1. 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.

Availability of water resources affects international trade and the relative competitiveness of countries and industries. In this context, "virtual water" is a useful concept to highlight the link between water consumption and trade (Allan, 1993). 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. An origin/destination trade matrix can therefore be translated in terms of virtual water equivalent flows, allowing one to see whether a country is a net importer or exporter of virtual water, and which are its trade partners.

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, the National Geographic (2010) magazine provided a map of virtual water trade flows in the world. 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").

In this paper, we estimate and analyze the current virtual water trade flows for some countries in the Mediterranean. Following Antonelli, Roson and Sartori (2012) we consider both the direct and the indirect (that is, associated with intermediate factors) water consumption, and we make a distinction between "green" and "blue" water. We compare the current picture of virtual water trade in the Mediterranean with a counterfactual one, where we simulate the effects of reduced water availability.

To this end, we first construct a scenario, accounting for changes in water demand and supply at the year 2050. We then estimate the associated changes in productivity for agricultural industries in some Mediterranean countries. Subsequently, we simulate the effects of changing productivity on international trade by means of a Computable General Equilibrium model of the world economy (Hertel and Tsigas, 1997). The counterfactual trade patterns estimated by the CGE model are then translated in terms of virtual water trade flows, so that an assessment can be made about how reduced water availability would affect the structure of virtual water trade in the Mediterranean.

The paper is organized as follows. In the next section, some estimates of current virtual water trade flows in the Mediterranean are presented and discussed. Section 3.3 illustrates how future changes in water availability, and the related impact on agricultural productivity, have been obtained. Section 3.4 presents the results of the CGE simulation exercise in terms of virtual water trade. A final section provides some concluding remarks.

3.2. Current virtual water trade in the Mediterranean

To estimate current virtual water trade flows, we consider 11 countries and 3 regional economies, obtained through aggregation from the GTAP 8 database[19]. These are: Albania, Croatia, Cyprus, Egypt, France, Greece, Italy, Morocco, Spain, Tunisia, Turkey, Rest of Europe (Xeur), Rest of Middle East and North Africa (XMENA), Rest of the World (RoW). Chapagain and Hoekstra (2004) provide estimates of total water consumption for 164 crops in 208 countries. We aggregate data to the 14 regions and 7 agricultural industries of the GTAP data base, and then we make a comparison between water consumption, by crop and region, and value of production (2004). This creates 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 includes the water indirectly consumed through the utilization of intermediate production factors. Antonelli, Roson and Sartori (2012) show how virtual water coefficients can be estimated, while taking into account the input-output linkages among sectors in the economy (see Chapter 2). We apply this methodology to get the systemic virtual water consumption, per unit of output, for each agricultural product in all regions. These parameters allow to translate trade flows into equivalent virtual water units.

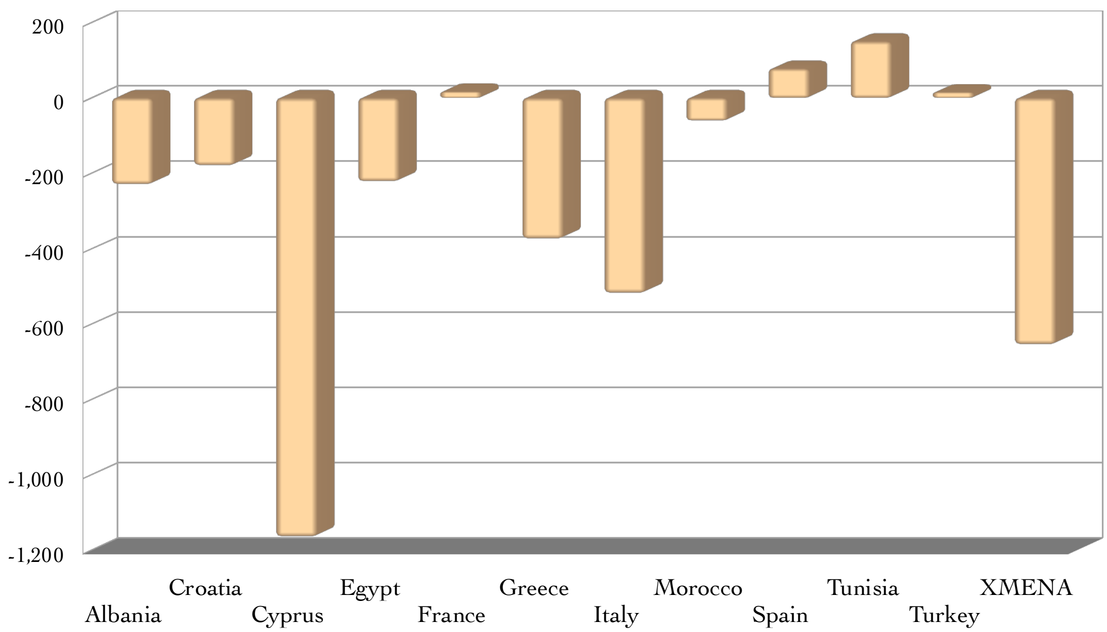
The whole matrix of bilateral virtual water trade flows corresponding to agricultural trade flows in the 2004 GTAP 8 database is displayed in Table A4.1 of Appendix A4. In the following, we illustrate some summary indicators of current virtual water trade in the Mediterranean, to highlight some of its key characteristics.

Figure 3.1 shows the per capita virtual water trade balance, that is the difference between total virtual water exports and imports. It can be interpreted as a measure of trade-related water dependence. Countries were water resources are scarce and

19 See: http://www.gtap.org.

expensive are generally expected to have a comparative disadvantage in water-intensive industries, resulting in net virtual water imports. However, this outcome may not necessarily emerge, because of a number of other effects at work, like market failures (severe in the water sector, where resources may be underpriced and over-exploited) and other factors affecting the overall competitiveness of an industry in the world economy.

Figure 3.1. Per capita net virtual water exports/balance (Mm^3).



We can see that Cyprus is the country which indirectly obtains the largest amount of water through trade in agricultural goods, followed by Rest of Middle East and North Africa, Italy and Greece.

More information about the sources of virtual water trade can be obtained through a decomposition of flows by region of origin and destination, which is provided in Figure 3.2. In this figure, each country and region is associated with a negative and a positive bar. Negative bars express imports and positive bars express exports. Each bar is split in terms of countries of origin and destination, all with a distinctive color. The trade balance displayed in Fig. 3.1 is just the algebraic difference between total exports and total imports in Fig. 3.2.

Figure 3.2. Per capita virtual water trade flows in Mediterranean countries (Mm^3).

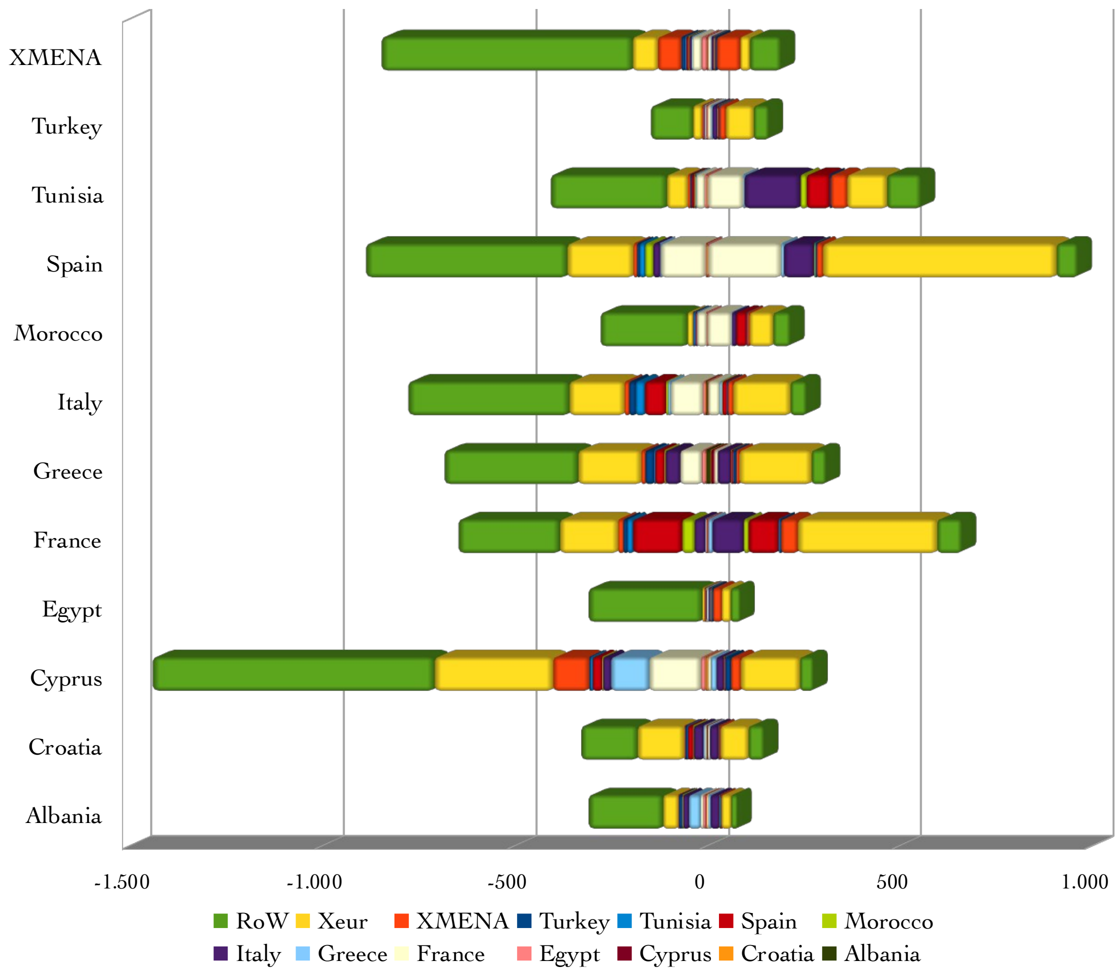
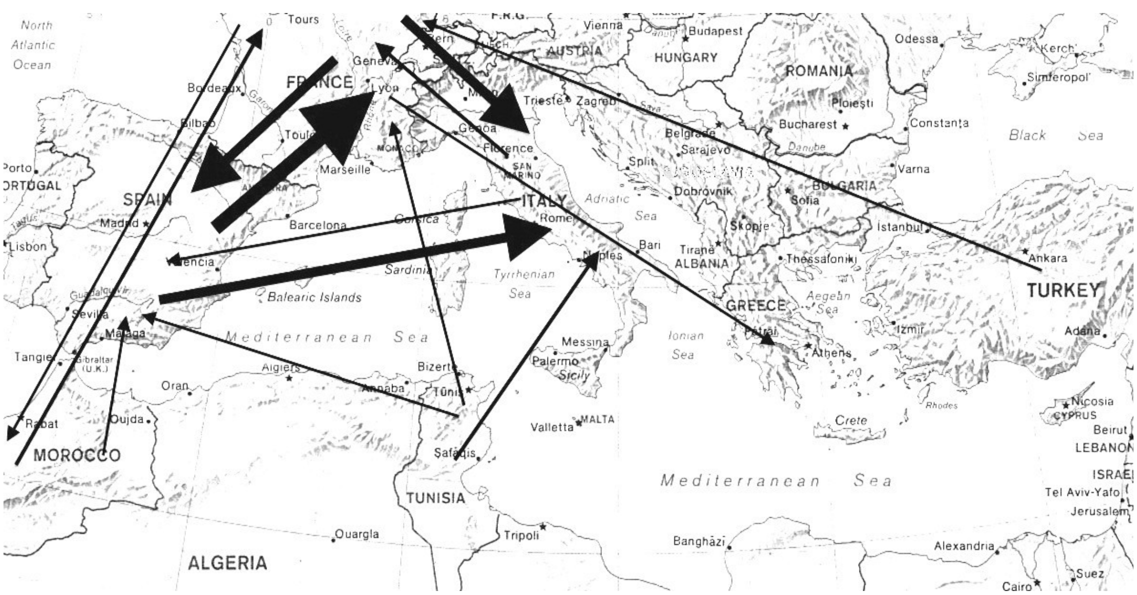


Figure 3.2 highlights some interesting facts. First, some countries (e.g., Cyprus and Rest of Middle East and North Africa) have a polarized trade: they import a lot but

make almost no exports. Other countries, like Spain, are more balanced: they have quite large input and output flows, suggesting that they may play a role as hub in agricultural markets, possibly by importing raw agricultural goods and exporting refined, processed goods. Second, some countries have principal and different trading partners for imports and exports. Spain, but also Morocco and Italy, get the bulk of their virtual water imports from outside Europe and the Mediterranean, exporting mainly towards central and northern Europe.

Figure 3.3 provides a picture of major virtual water flows on a geographical map. It displays only the largest flows, where thickness of the arrow line depends on the flow magnitude[20].

Figure 3.3. Largest flows of virtual water trade in the Mediterranean.



The most significant exchanges of virtual water are found between the largest North-Mediterranean economies. France and Spain are the greatest traders of agricultural

20 Classes are: 500-1,000 Mm^3, 1,000-3,000 Mm^3, 3,000-7,000 Mm^3, >7,000 Mm^3.

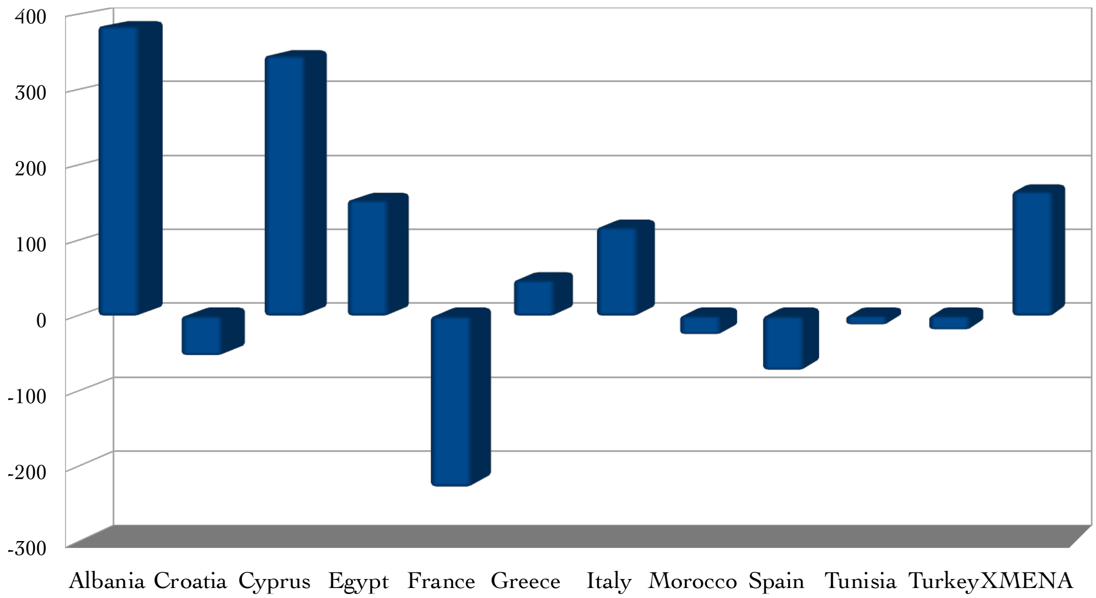
goods. An important role is also played by Italy, which is a substantial importer of agricultural products, and by some North African countries, like Morocco and Tunisia, as well as by Turkey.

Further insights can be obtained by making a distinction between *green* and *blue* water trade flows. Green water is water stored into the soil moisture. Blue water is surface and underground water. The distinction is important because, whereas green water can be used only in agriculture, blue water can be allocated to alternative uses. Therefore, it has a greater economic potential and value. To the extent that virtual water trade is an indirect mean of saving on water resources, savings obtained on precious blue water is what matters the most.

From our estimates it is possible to assess the blue virtual water "savings" achieved by means of trade in agricultural goods. This is done by computing how much blue water would be needed if imports were instead produced domestically, while subtracting from the latter the blue water consumed to produce the exported goods. Therefore, this new balance expresses how much extra blue water would have been necessary if a country would not have been involved in international trade, at given (unchanged) levels of domestic consumption. Results are shown in Figure 3.4.

Much of the countries "save" on blue water by trading agricultural goods. Albania and Cyprus display the most significant savings, followed by Rest of Middle East/North Africa, Egypt, Italy and Greece. France is the only country exhibiting an exploitation of blue water resources, but this comes quite naturally, as blue water is relatively abundant in that country.

Figure 3.4. Per capita *blue* water 'savings' through trade in agricultural goods (Mm^3).



3.3. A Scenario of future water availability for the Mediterranean[21]

Virtual water patterns will change in the future because international trade will. Any factor affecting the world economy, including growth, economic policies, demography and external shocks, has the potential to generate repercussions on virtual water flows.

In this paper, we focus on the prospective effects of varying water availability in the Mediterranean. Drawing upon findings of the European research project WASSERMed[22], we consider a scenario at the year 2050, where supply and demand of water in the different countries are evaluated. Variations in agricultural productivity induced by the changing water availability are subsequently inserted into

21 This scenario is equivalent to the "NE" scenario presented in Chapter 1. Here it is briefly summarized.

22 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.

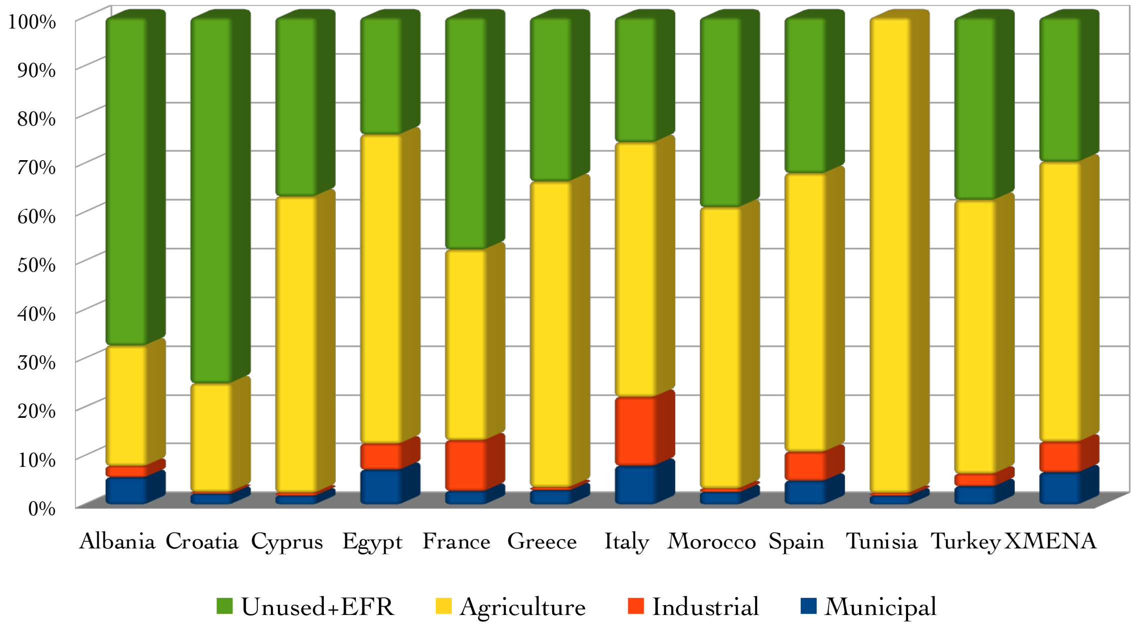
a global CGE model, to simulate the structural adjustment process for the world economy, and its implications in terms of virtual water trade. This section illustrates how the water availability scenario has been constructed.

The starting point is the current water balance for the 14 regional economies in our data set, that is the relationship between water supply (sources) and water demand (uses) at one period in time (e.g., a year). Among the supply sources we distinguish between blue water and green water, supposing that 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).

Three uses of water are appraised: agricultural, municipal and industrial. Green water can only be used in agriculture, where it is supplemented by blue water through irrigation or other means. Any difference between total blue water availability 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 database. Figure 3.5 (equivalent to Fig. 1.1) shows the composition of water demand among different usage classes for the Mediterranean countries[23] considered in this study.

23 Results for the residual non-Mediterranean macro-regions (Rest of Europe and Rest of the World) are not presented.

Figure 3.5. Composition of (blue) water consumption in the baseline (2000-2005)[24].



To assess how much water will be available for agriculture in 2050, values for all supply and demand components have been projected to the future. On the supply side, total water availability has been estimated starting from data about future climate conditions, produced in WASSERMed from a set of Regional and Global Circulation Models (Congedi *et al.*, 2012). 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. Climate scenario affects the future total water availability by means of changes in precipitation and temperature. Elaborating on these data[25], we predict a significant drop in water supply for France (-34%), Italy (-14%), Turkey (-11%), Croatia (-10%), Spain (-8%), whereas countries

24 It is equivalent to Figure 1.1 of Chapter 1.

25 We considered that changes in precipitation do not automatically translate into changes in total water availability. For the detailed procedure, see Section 1.2 of Chapter 1.

in southern Mediterranean would be much less affected, because their water resources are relatively more independent from local climate conditions.

On the demand side, the various components have been projected using different assumptions and methodologies. 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, of about 10%.

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, to reflect improved access to sanitation and freshwater.

Industrial consumption is assumed to increase at a rate equal to 1/3 of the national income growth. GDP forecasts have been derived from World Bank Statistics[26]. The lower rate for industrial water consumption is intended to account for 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,

26 http://www.data.bank.org

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 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[27] 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. In our scenario, we assume that non-EU countries do not comply 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. 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. Table 3.1 presents our estimates of reductions in water available for agriculture in 2050, only for affected regions.

Table 3.1. Reductions in water available for agriculture in 2050.

Egypt	-12%
France	-15%
Italy	-19%
Morocco	-0.5%
Tunisia	-11%
XMENA	-10%

27 The group includes Croatia and Turkey as accession countries.

Six economies will suffer insufficient water resources, at the year 2050, to sustain current production levels in agriculture. For France and Italy, the drop in water resources is due to the lower precipitation and higher temperature, with a larger impact in Italy, where relatively more blue water is used for agriculture. The other four regional economies will also lack water for agriculture, but for different reasons. In Egypt and Morocco the lesser water availability for agriculture will be due to non-agricultural water uses, which are expected to grow at a significant rate. In these regions, 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. In Tunisia water resources are overexploited already in the baseline (see Figure 3.5): any further increase in water demand would not be sustainable. The Middle East and North Africa 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 10% of its total water consumption.

We analyze how reductions in water availability could affect agricultural productivity. To this end, it is important to take into account that (i) each country has its own mix of agricultural products, and (ii) crops may differ in terms of sensitivity to water shortages. As in the GTAP data base, 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 has been estimated[28], accounting for both the physical characteristics of the crop and the overall efficiency of the water delivering system. Using these parameters, changes in water availability for agriculture have been translated into changes in agricultural productivity by sector, as reported in Table 3.2.

28 For details, see Section 1.2 and Table 1.3 of Chapter 1.

Table 3.2. Reduction in agricultural productivity by sectors and by region.

	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%
Morocco	-0.08%	-0.08%	-0.37%	-0.37%	-0.19%	-0.19%	-0.21%
Tunisia	-1.62%	-1.62%	-7.67%	-7.67%	-4.01%	-4.01%	-4.43%
XMENA	-1.46%	-1.46%	-6.91%	-6.91%	-3.61%	-3.61%	-3.99%

On average, the crops most affected by the productivity reduction are rice and vegetable and fruits, followed by wheat and cereals, oilseeds and sugar. The impact on agricultural productivity is very high for Egypt (-20%), high for France (17%) and Italy (14%), medium for Tunisia (4.5%) and the Rest of Middle East and North Africa (4%), very low for Morocco (0.2%).

3.4. Future virtual water trade in the Mediterranean

Estimates of Table 3.2 have been used to shock exogenous productivity parameters in a Computable General Equilibrium model of the world economy (Hertel and Tsigas, 1997; a short description of the model can be found in Appendix A1). 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 account for the circular flow of income and inter-sectoral linkages inside the whole economic system.

A simulation exercise entails comparing two equilibria for the global economy, in which all markets clear, before and after the variation of some exogenous parameters (in our case, multi-factor productivity in a set of agricultural industries). The model output includes all the main macroeconomic variables, like nominal and real GDP, consumption and production levels, relative prices for products and primary factors.

To summarize the overall macroeconomic impact of the simulated variation in agricultural productivity, Table 3.3 reports the estimated percentage variations for the national real income (which is a measure of aggregate welfare) for all regions in our set.

Table 3.3. Estimated variations in real national income.

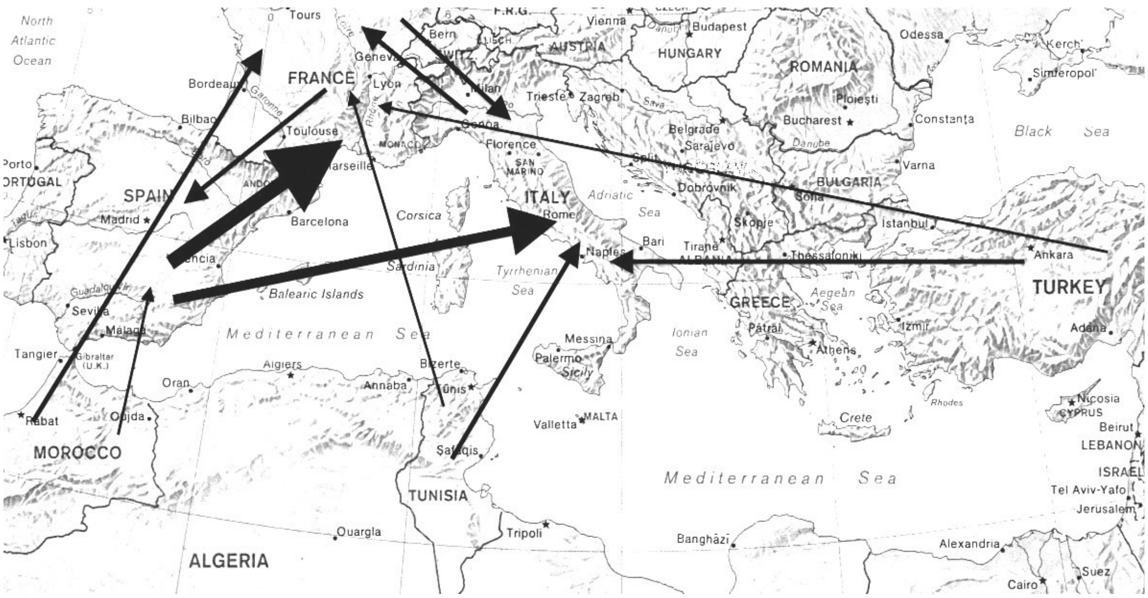
	Var. %		Var. %
Albania	-0.17	Morocco	0.04
Croatia	-0.05	Spain	0.03
Cyprus	-0.02	Tunisia	-1.42
Egypt	-7.24	Turkey	0.01
France	-1.83	Rest of Europe	-0.03
Greece	-0.01	Rest of MENA	-0.41
Italy	-1.77	RoW	-0.003

Not surprisingly, lower productivity in agriculture, induced by reduced water availability, generates negative consequences in terms of national income for most Mediterranean countries. The magnitude of the loss depends on the amount of the productivity shock, but also on the share of agricultural activities in the economy. Egypt is the country which is hurt the most, as the model estimates a fall of 7.24% for real income. Significant reductions of GDP and welfare are also estimated for France, Italy and Tunisia, which are the other water-constrained countries in our exercise. Three countries get (slight) benefits: Morocco, Spain and Turkey. This is not because of improvements in productivity (which is unchanged there) but because of enhanced relative competitiveness vis-à-vis trading partners and competitors (a second-order general equilibrium effect).

The output of the CGE computer simulation comprises counterfactual estimates of trade flows. Using the same procedure applied for actual trade flows, illustrated in

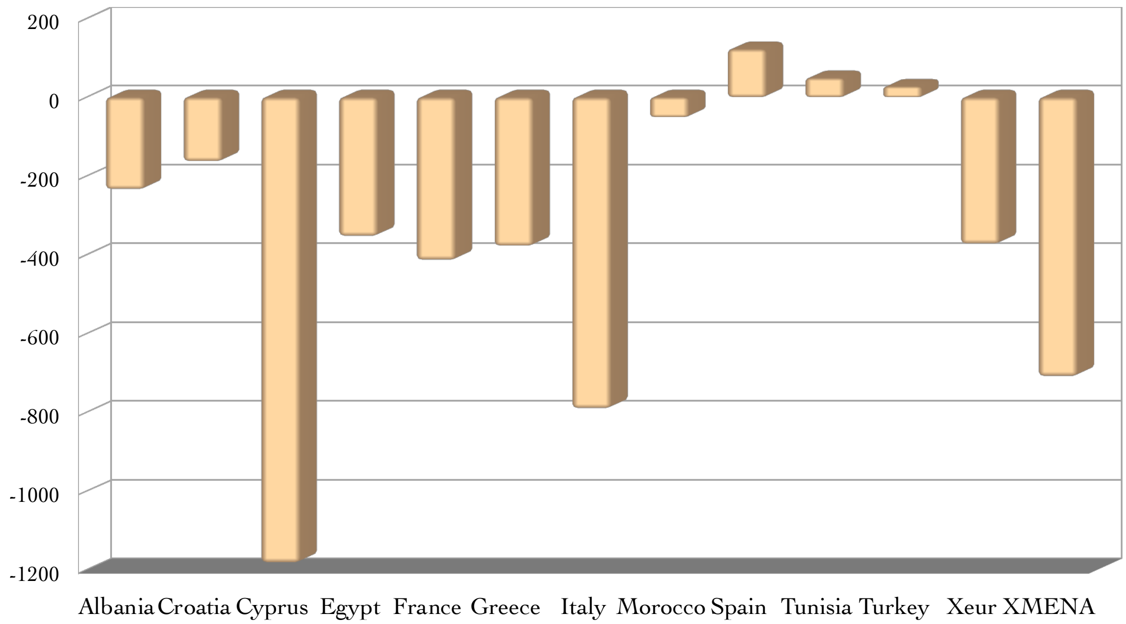
Section 3.2, it is possible to estimate virtual water flows for the scenario under consideration. Figure 3.6 is analogous of Figure 3.2 and displays the most significant flows of virtual water between Mediterranean countries.

Figure 3.6. Largest flows of virtual water trade in the counterfactual scenario (Mm^3).



The most notable difference between Figures 3.2 and 3.6 is that the amount of virtual water flowing from France towards Italy, Spain and, to a lesser extent, Morocco decreases significantly. On the other hand, imports of virtual water by France increase somewhat. The reason is easily found by looking at Figure 3.7 (corresponding to Figure 3.1 in Section 3.2), presenting estimates of the virtual water trade balance.

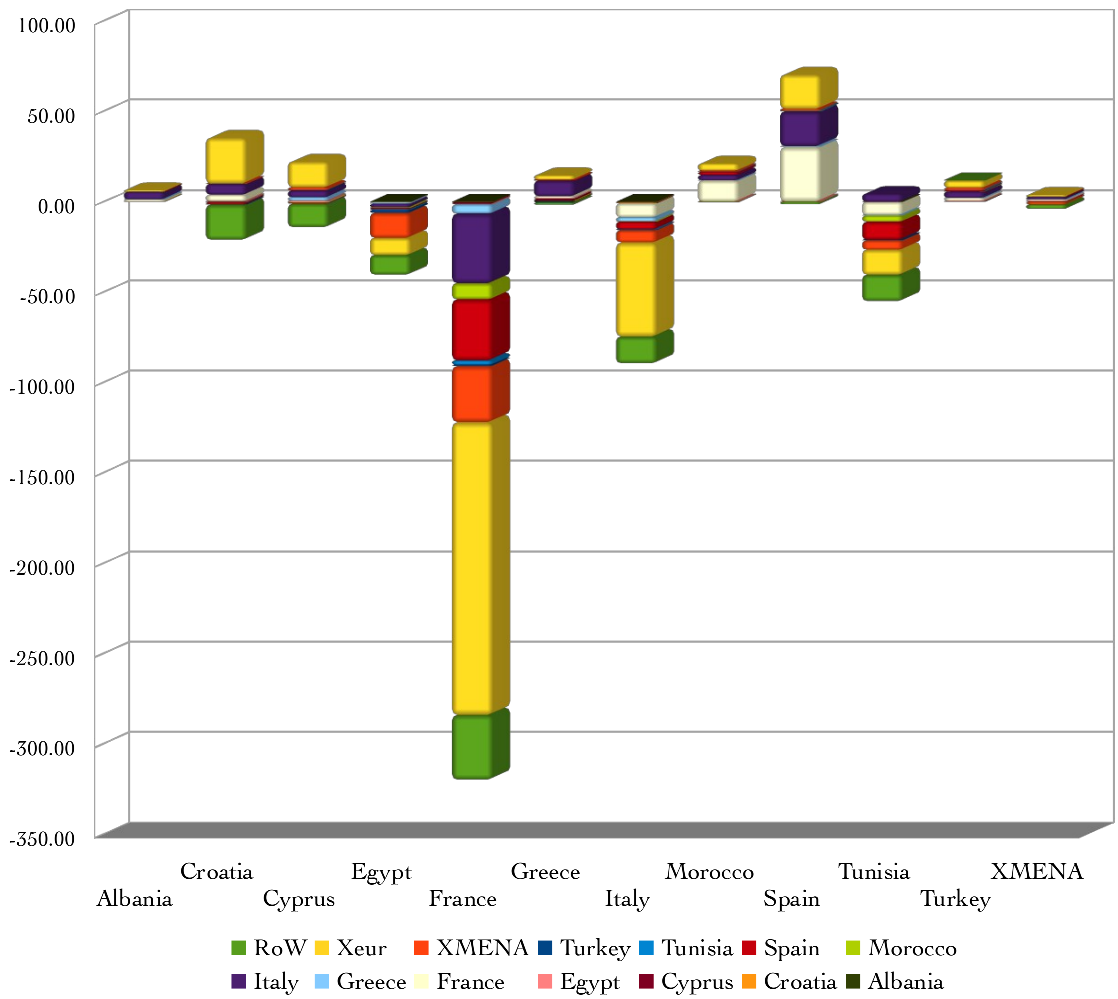
Figure 3.7. Per capita net virtual water exports (balance) in the counterfactual scenario (Mm^3).



In the current baseline (Fig. 3.1), the French virtual water trade balance was slightly positive. In the counterfactual scenario (Fig. 3.7) the balance gets negative, because the agricultural sector in France becomes much less competitive. Italy and Tunisia also deteriorate their virtual water trade balance, with less water flowing towards Spain and Italy, respectively. On the other hand, Morocco and Turkey grow in terms of virtual water exports.

Figure 3.8 shows *from where* the additional water imports come from, or *to where* additional water exports are directed. As such, this figure does not completely correspond to Figure 3.2. We can see that France and Italy get most of the extra water imports from central and northern Europe. On the other hand, Spain increases its virtual trade exports towards the latter two countries.

Figure 3.8. Variation in per capita virtual water flows (Mm^3) for each Mediterranean economy.



3.5. Concluding remarks

This paper has provided some estimates of virtual water trade patterns in the Mediterranean. Virtual water trade follows conventional trade in goods (in this case agricultural products), whereas no water is physically exchanged. As international trade is a powerful mechanism for improving the allocation of economic resources, including water, the virtual water paradigm is just one way of looking at the potential benefits of international trade from a "water perspective".

The Mediterranean is an area where water is scarce and unevenly distributed. Potential water demand exceeds supply in many Mediterranean countries, and problems are likely to be exacerbated in the future, because of climate change and reduced precipitation.

In this work, two cases have been considered: the current virtual water trade structure, related to trade in agricultural goods, and a future scenario, simulated by means of a computable general equilibrium model, where reduced agricultural productivity, induced by lower water availability, is taken into account.

Analysis of current virtual water flows reveals that most countries are net importers of virtual water, thereby realizing sizable "savings", particularly of precious blue water resources. Much of the intra-Mediterranean virtual water trade occurs between the largest northern economies (Spain, France, Italy) but, in per capita terms, the country which gets the largest amount of virtual water from abroad is Cyprus.

This picture will likely change in the time ahead, because of the evolution of the world economy, as well as of international trade, which will ultimately be reflected in varying virtual water flows. A simulation exercise has been performed in this paper, where we abstract from the many possible factors affecting future trade patterns, focusing instead only on the possible consequences of reduced water availability in the Mediterranean.

We found that both northern and southern countries will be affected by water shortages, although for different reasons. In the north, increased temperature and reduced precipitation will lessen water stocks. In the south, the driving factors will be demographic and economic development. Implications of this scenario in terms of virtual water entail reduction of intra-Mediterranean trade and increases in virtual imports from central and northern Europe, as well as from the rest of the world.

Acknowledgments

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4.

Climate Change, Tourism and Water Resources in the Mediterranean: a General Equilibrium Analysis

by

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and

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4.1. Introduction

Among the many impacts that climate change can have on the economy, the impact on tourism activities is one of the most important, especially in some regions. Climate conditions are obviously crucial in determining tourism destination choices, so any change in climate conditions will have consequences in terms of number of incoming/outgoing tourists, tourism revenues, consumption patterns, income and welfare.

Several papers have investigated the relationship between climate conditions and tourist destination choices. Clearly, climate has several dimensions and, on the other hand, the ideal climate profile depends on the nature of the recreational activities to be performed. For example, high temperatures and low precipitations may be bad for winter tourism (e.g., at alpine ski resorts), but good for summer tourism (e.g., at the beaches).

To account for the multifaceted aspects of climate, a popular approach is based on a composite index of "climate suitability" for recreational activities (Mieczkowski, 1985). The most diffused and known index is the Tourism Climate Index (TCI), measuring the appropriateness of climate conditions for outdoor activities, which are especially relevant for summer tourism. Other indices have been recently proposed[29] (e.g., de Freitas, Scott and McBoyle, 2008), but they are currently not as diffused as the TCI.

The TCI consists of five sub-indices, describing daytime thermal comfort, daily thermal comfort, precipitation, hours of sunshine, and wind speed. The TCI is a wighted average of the five sub-indices, where the highest weight is given to daytime comfort, to reflect the fact that tourists are generally most active during the day.

29 A critical limitation of the TCI is that it is as an "expert-based" index. In most existing climate indices for tourism the rating schemes for individual climate variables and the weighting of climate variables in the index are based on the subjective opinion of the researchers and are not empirically tested.

Values are normalized, so that the maximum TCI score is 100. Mieczkowski proposed a classification of TCI scores, with values in excess of 60 corresponding to "good" conditions, scores exceeding 70 representing "very good" climatic conditions, levels of over 80 corresponding to "excellent" conditions, and scores of 90 or more standing for "ideal" circumstances.

One reason why the TCI is popular in the tourism economics literature is because it has proved to be a good predictive variable in many empirical studies of tourism demand. TCI is usually a statistically significant variable in econometric analyses of tourism flows. On the other hand, the monthly distribution of the TCI closely matches the monthly distribution of tourist arrivals/nights, at least in those destinations where beach holidays are dominant, like the Balearics (Amelung and Viner, 2006).

A recent literature has adopted the TCI for a tourism-oriented assessment of future climate change scenarios. Global and Regional Circulation Models (GCM/RCM) are employed to simulate future climate conditions, under a number of alternative assumptions. Estimated values for climate variables are then post-processed, to build future TCI indices. A comparison between current and future TCIs allows to qualitatively assess the changing relative attractiveness of tourism destinations, as well as the varying seasonality. Studies of this kind are: Amelung and Viner (ibid.), for the Mediterranean; Amelung and Moreno (2009), Perch-Nielsen, Amelung and Knutti (2010), for Europe.

To our knowledge, only Hein, Metzger and Moreno (2009) go further by "converting" future TCI values into estimates of tourism flows, for five regions in Spain and three other regions in Europe. On the other hand, a few other studies provide quantitative estimates of the impact of climate change on future tourism flows. For example, Hamilton, Maddison and Tol (2005) describe the Hamburg Tourism Model, which is a large econometric model, used to predict bi-lateral tourism flows as functions of socio-economic variables and average temperatures. That model is used to estimate arrivals and departures through changes in population, per capita income and climate change.

There is a fundamental difference between these two latter studies. Hein, Metzger and Moreno (ibid.) focus on one region at a time, as we shall do later in this paper. A major disadvantage of this approach is that "push" and "pull" factors are not simultaneously considered. For example, suppose that an improvement in the TCI index for some region in Spain is detected. The model should then predict an increase in the arrivals of tourists. However, if most of the tourists are coming from a country where the TCI has improved more than it has in Spain, total arrivals may well decrease. Hamilton, Maddison and Tol (ibid.) avoid this problem, but at a price. The price is due to the fact that their estimates are based on average yearly temperatures, rather than more accurate monthly TCIs.[30]

Results from the Hamburg Tourism Model have fed other simulation exercises, aimed at assessing the global, system-wide effects of changing relative competitiveness in the national tourism industries. Berritella *et al.* (2006) and Bigano, Roson and Tol (2008) consider these effects by means of a static Computable General Equilibrium (CGE) model of the world economy. Eboli, Parrado and Roson (2010), Roson and van der Mensbrugghe (2012), Galeotti and Roson (2012) conduct similar exercises, but with dynamic CGE models, while tourism impacts are considered alongside other economic impacts of climate change.

In this paper, we get back to the single region, TCI-based analysis, but we insert the estimates of changing tourism flows into a general equilibrium model, to assess the broader consequences of climate change impacts on the economic structure. In addition, we include in the CGE model parameters of water consumption by industry, in order to evaluate the effects of varying tourist patterns on water resources.

30 Bigano *et al.* (2006) defend this choice, by noting that: (i) temperature is the only climate variable for which there are reliable data and future projections with a large spatial coverage, (ii) many climate parameters are strongly correlated to temperature.

Exploring the nexus between tourism activities and water is especially important in an area, like the Mediterranean, where the tourism industry often competes with other sectors for scarce water resources. A recent paper by Gössling *et al*. (2012) provides a systematic overview of the tourism/water issue. The authors point out that "the understanding of tourism's indirect water requirements, including the production of food, building materials and energy, remains inadequately understood, but is likely to be more substantial than direct water use".

This paper adds to the literature by considering both direct and indirect water use by tourists, as it takes into account input-output linkages of the tourism industry inside the economic structure. Furthermore, general equilibrium conditions reveal interesting second-order effects of increasing tourism attractiveness. More foreign tourists visiting a country imply an inflow of foreign currency, generating a real valuation and a loss of competitiveness for non-tourism industries in the international markets. In terms of water consumption, it is especially important to consider the role played by the agriculture industry, because agriculture is by far the largest user of water resources. As long as an expansion of the tourism industry is associated with a contraction of the agriculture industry, the net effect could be a (rather unexpected) reduction of total water consumption. We detected this kind of phenomenon in much of the Mediterranean countries considered in our numerical simulation exercise. To the best of our knowledge, this is the first paper highlighting the effect.

The rest of the paper is organized as follows. Section 4.2 illustrates how recent estimates of monthly TCIs for a set of Mediterranean countries, which have been produced in the European research project WASSERMed[31], are used to predict future tourism flows. The findings have been used to set up a simulation exercise with a multi-regional computable general equilibrium (CGE) model. Results of the

31 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 .

simulation exercise are presented in Section 4.3. Implications for water demand are considered in Section 4.4, whereas Section 4.5 provides some concluding remarks.

4.2. Changing climate conditions and tourism flows in the Mediterranean

We consider here eight Mediterranean countries: Spain, France, Italy, Malta, Slovenia, Croatia, Greece and Cyprus.[32] Table 4.1 shows the total number of nights spent by tourists in each country, followed by the monthly distribution, where each number represents the percentage of total nights associated with a specific month.

Table 4.1. Total nights and monthly distribution 2009 (source: EUROSTAT, 2010).

	Nights (M)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ott	Nov	Dec
Greece	61.1	1.6	1.7	2.2	4	9.7	14.8	19.6	21.9	14.5	6.2	2	2
Spain	349.4	4.6	5	6	7.5	8.3	9.9	14	16.4	10.4	8	5.1	4.9
France	294.7	3.9	4	4.6	5.4	8.3	9.2	19.7	22.6	8.6	5.4	3.9	4.3
Italy	357.9	4.1	4.2	4.4	5.7	7.7	11.6	18.1	21.5	10.5	5.4	3	3.8
Cyprus	12.9	2.6	2.7	4.1	6.4	10.2	12.4	14.2	16.1	13	11.3	4.5	2.6
Slovenia	8.1	6.1	6.2	5.7	7.1	7.5	9.3	14.9	16.8	9	7	4.9	5.4
Croatia	37.5	0.9	0.8	1.2	3.6	7.3	14.2	26.2	28.2	12.2	3.5	1	0.8
Malta	6.9	4.8	5.6	6.3	7.9	8.4	9.6	12.9	13.9	10.6	9.4	5.8	4.6

Kampragou *et al.* (2012) have processed the output[33] of the regional climate model RACMO2 (driven by the global GCM model ECHAM5-r3) to obtain the TCI index for a set of Mediterranean countries, including those considered here. The TCI is calculated on the basis of rates assigned to sub-indices, referring to precipitation, temperature, humidity, sunshine duration and wind speed. An increase in temperature

32 Our choice has been dictated by data availability.
33 These data have been produced by the European research project ENSEMBLES.

causes a relative increase in TCI values, which explain why (i) the highest value for the TCI index is found in Greece in July (August in the future), and (ii) the global warming generally brings about an increase in the TCI.

Table 4.2. Estimates of TCI at present (1991-2010) and future (2036-2065) time.

	TCI PRESENT											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ott	Nov	Dec
Greece	58.23	61.85	67.16	73.62	86.35	94.38	95.01	94.91	91.22	76.08	64.03	58.20
Spain	55.26	60.09	63.63	70.21	78.58	91.18	93.25	93.01	86.51	70.81	59.74	56.04
France	51.35	55.44	61.65	66.58	73.58	85.97	89.79	87.08	77.02	62.36	55.12	51.23
Italy	55.83	59.95	63.93	71.05	80.54	89.90	92.11	91.86	85.93	71.53	60.42	55.80
Cyprus	64.14	68.07	72.21	79.79	91.36	94.29	94.29	94.43	94.29	90.07	78.71	64.57
Slovenia	51.15	56.38	59.90	67.15	74.68	86.83	91.18	89.23	77.45	62.98	54.88	51.33
Croatia	53.36	57.12	63.72	70.23	81.06	91.90	94.35	94.00	85.42	67.89	57.74	53.18
Malta	61.00	63.00	67.00	73.00	77.00	89.00	94.00	94.00	94.00	89.00	74.00	62.00

	TCI FUTURE											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ott	Nov	Dec
Greece	59.16	63.82	68.73	76.35	90.36	94.99	95.09	95.15	93.76	81.47	64.94	59.84
Spain	56.31	60.29	64.91	72.75	83.75	92.67	94.11	94.22	90.50	74.32	61.62	57.85
France	52.00	56.81	61.32	66.53	76.08	88.08	92.05	91.74	81.58	64.79	56.10	51.79
Italy	56.29	61.38	65.13	72.54	83.85	91.76	93.13	92.92	88.59	74.47	61.92	57.42
Cyprus	66.57	70.07	75.86	85.14	94.14	94.21	93.07	91.43	94.43	91.64	83.36	67.71
Slovenia	52.10	57.00	61.38	66.88	77.95	90.50	94.03	92.25	82.23	63.65	55.95	53.08
Croatia	54.18	60.22	64.20	71.20	85.18	93.94	94.80	94.77	89.02	70.25	59.15	54.05
Malta	65.00	69.00	71.00	72.00	82.00	94.00	94.00	94.00	94.00	90.00	79.00	64.00

Amelung and Moreno (2009) investigate the relationship between TCI values and arrivals of tourists in Mallorca. They provide a simple regression analysis, from where it is found that a 1% increase in the TCI would trigger an increase in the number of nights/arrivals of about 21.87%. Assuming this elasticity value for the whole Mediterranean[34], considering the baseline data of Table 4.1 together with the estimated variations in the TCI reported in Table 4.2, it is possible to get an estimate of changes in tourists' nights per country and month, as illustrated in Table 4.3.

Table 4.3. Estimated variation in future tourism flows (monthly and yearly average).

	AVG	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ott	Nov	Dec
Greece	0.40%	0.35%	0.70%	0.51%	0.81%	1.02%	0.14%	0.02%	0.06%	0.61%	1.55%	0.31%	0.61%
Spain	0.60%	0.41%	0.07%	0.44%	0.79%	1.44%	0.36%	0.20%	0.28%	1.01%	1.08%	0.69%	0.71%
France	0.70%	0.28%	0.54%	-0.11%	-0.02%	0.75%	0.54%	0.55%	1.17%	1.30%	0.85%	0.39%	0.24%
Italy	0.45%	0.18%	0.52%	0.41%	0.46%	0.90%	0.45%	0.24%	0.25%	0.68%	0.90%	0.54%	0.64%
Cyprus	0.23%	0.83%	0.64%	1.10%	1.47%	0.67%	-0.02%	-0.28%	-0.69%	0.03%	0.38%	1.29%	1.06%
Slovenia	0.65%	0.41%	0.24%	0.54%	-0.09%	0.96%	0.93%	0.68%	0.74%	1.35%	0.23%	0.43%	0.75%
Croatia	0.40%	0.34%	1.18%	0.17%	0.30%	1.11%	0.49%	0.10%	0.18%	0.92%	0.76%	0.54%	0.36%
Malta	0.62%	1.43%	2.08%	1.31%	-0.30%	1.42%	1.23%	0.00%	0.00%	0.00%	0.25%	1.48%	0.71%

It can be readily seen that tourism flows are generally expected to increase, with only a few exceptions (e.g., Cyprus in July and August, Malta in April). The AVG column shows the yearly increase, which is a weighted average of monthly variations, with weights given by Table 4.1[35]. The largest improvements in climate conditions and tourism flows are expected to occur in Malta (February, November, January and May), Cyprus (April), Spain (May), Greece (October).

EUROSTAT (2008) provides information, at the country level, on the "tourism balance", which can be regarded as the difference between tourism expenditure by foreigners in a country and expenditure by nationals traveling abroad. This balance is positive for all countries in our set, meaning that they are net exporters of tourism

34 We explored an alternative methodology, by conducting a panel regression of tourist nights with present values of TCI, finding a much smaller elasticity value (2.83). We preferred not to use this estimate, as the nights refer to months in the year 2009, whereas the TCIs are 20-years averages.

35 Therefore, changes in the seasonal distribution of tourism flows have not been considered.

services.

When a country becomes more attractive as a touristic destination, we can expect to see more incoming tourists and less outgoing tourists. However, we have here not enough information about national tourists traveling abroad. Therefore, in order to roughly calculate the change in net receipts which could be obtained in the future, we have just applied the yearly average of Table 4.3 to the surplus of the tourism balance in 2006 (2005 for Greece).

Table 4.4. Changes in net receipts (M€ 2006).

	Surplus 06	Increase
Greece (05)	8,591	34.26
Spain	27,445	164.23
France	12,065	83.87
Italy	11,969	54.24
Cyprus	1,133	2.55
Slovenia	652	4.23
Croatia	5,692	22.88
Malta	355	2.22

Results shown in Table 4.4 are estimates of additional income spent by foreign tourists in each country, as a consequence of the higher attractiveness induced by the climatic change. They are the starting point for an analysis of the systemic effects induced on the whole economic structure, presented in the following section.

4.3. Macroeconomic implications

The economic impact of an increase in foreign tourists is characterized by two main effects: (a) more income, earned abroad, is spent in the hosting country, (b) the pattern of final consumption changes, with more demand concentrating on services, which include hotels, restaurants, transports, etc. The additional demand for domestic services pushes upwards the price of internal resources like labour, capital and land. All domestic products, as a consequence, become relatively more expensive than foreign products, causing some substitution of domestic goods with imports in the production and consumption processes. This loss of competitiveness deteriorates the balance of trade and causes a change in the whole structure of the economic system.

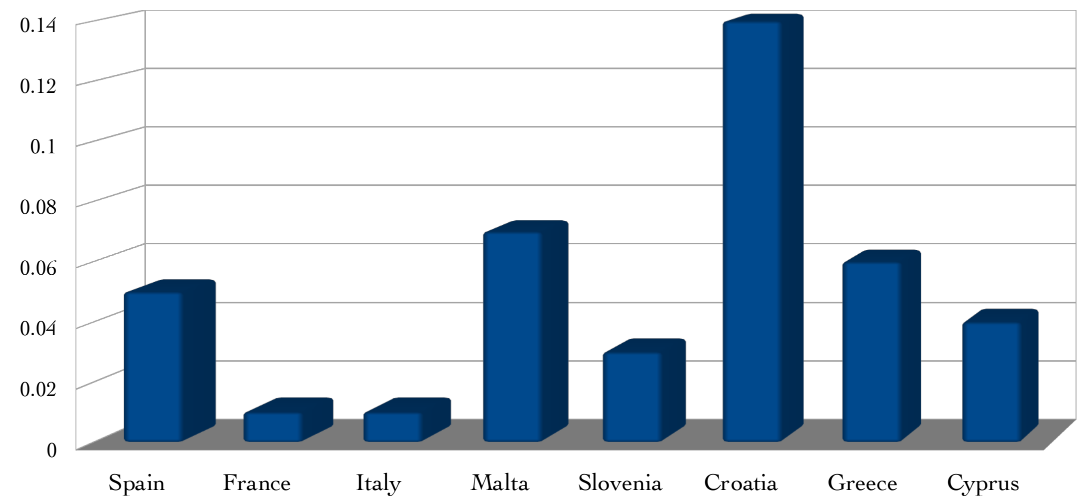
In order to effectively assess these system-wide effects, we carry out an analysis with a Computable General Equilibrium model. The model is an adaptation of the standard GTAP model described in Hertel and Tsigas (1997)[36]. A CGE model is a very large non-linear system, including market clearing conditions and accounting identities, tracing the circular flow of income inside an economic system. The model is typically calibrated using national accounting data, and simulation exercises are performed by shocking exogenous variables and parameters.

We have used the CGE model to simulate the effects of more incoming tourists in the Mediterranean countries considered in the previous section. The exercise is implemented by increasing international income transfers (with values as displayed in Table 4.4), while simultaneously shifting, by the same amounts, the demand for services produced in each of the eight Mediterranean countries. A counter-factual equilibrium is then computed by the model, in which all markets clear and all agents comply with their budget constraints (receipts equal expenditures).

Figure 4.1 shows the estimated percentage change in national income, which depends on the magnitude of the shock, as well as on the share of the tourism industry in the overall domestic production. Higher income levels allow to expand consumption by households, thereby raising welfare.

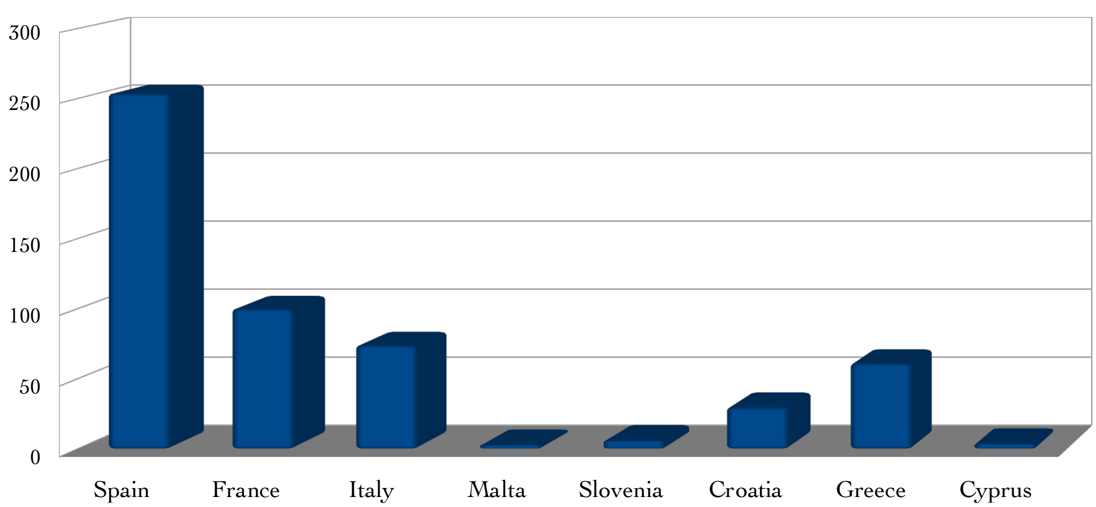
36 A short description of the model can be found in Appendix A1. Extensive documentation on the GTAP model is available at http://www.gtap.org .

Figure 4.1. Percentage variations in national income.



The Equivalent Variation (EV) is a money-metric measure of welfare effects, indicating what change in initial income would have had the same impact on welfare, at constant prices. Figure 4.2 shows the estimated EV for the countries at hand, measured in millions of U.S. Dollars (2004).

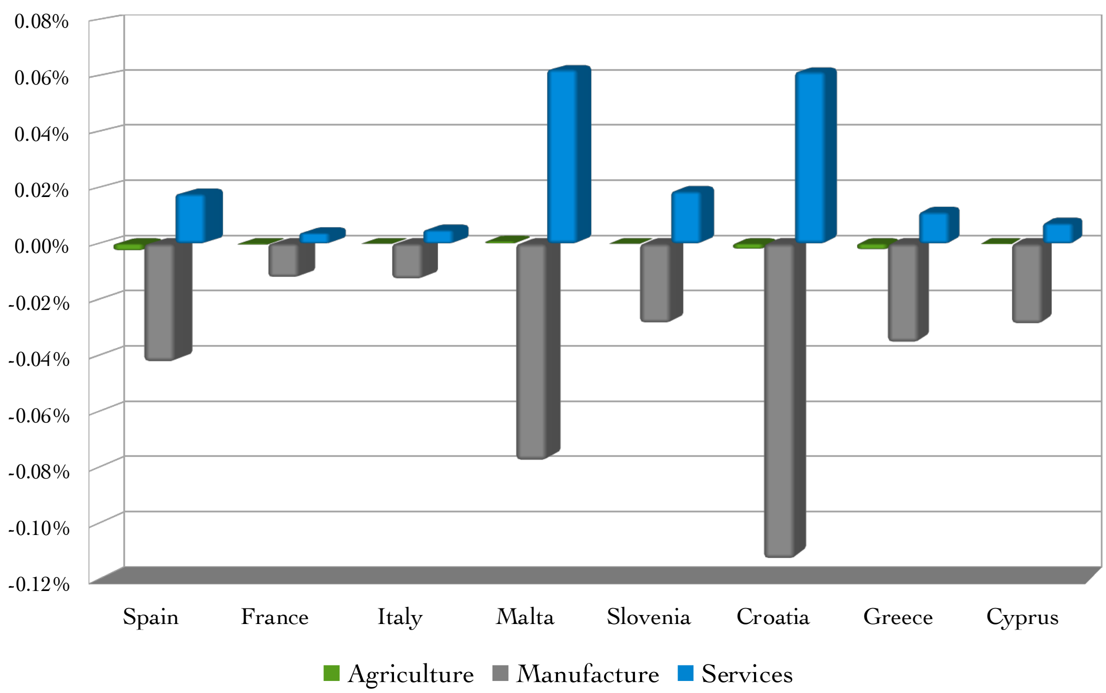
Figure 4.2. Percentage variations in equivalent variations (MUS$, 2004).



Our findings indicate that the increased attractiveness of northern Mediterranean countries expand welfare in a way which is equivalent to receiving money, from a minimum of 2.85 (Malta) to a maximum of 253.65 (Spain) millions of dollars.

Not everybody gains in this game, though. As stated above, the additional demand from foreign tourists creates an inflationary pressure, which amounts to an appreciation of the real exchange rate, affecting the terms of trade, the trade balance and the firms' competitiveness on the foreign markets. Figure 4.3 displays the estimated change in the production volume of three aggregate sectors (Agriculture, Manufacturing and Services) in the Mediterranean countries.

Figure 4.3. Sectoral production volumes by country.



As one can see, the expansion in the service industries comes at the expense of the other two sectors, particularly Manufacturing. This is an example of a phenomenon, which is known in the literature as "the Dutch disease"[37], whose meaning is that higher competitiveness in the tourism industry brings about lower competitiveness elsewhere. The whole productive structure of a country changes, with possible consequences in terms of distribution of income and wealth.

4.4. Implications for water resources

It is often feared that an expansion of tourism in areas like the Mediterranean, which are already water stressed (particularly during the summer), may exacerbate the water management problems, especially by creating conflicts for access to water resources between agriculture and tourism activities.

Savvides et al. (2001) estimate that one night stay by one tourist generates a (direct) demand for 0.465 cubic meters of water[38]. Assuming this value for the whole Mediterranean, one can easily covert results like those in Table 3.3 in terms of additional demand for water, coming from the tourism sector. However, we showed in the previous section that the expansion of tourism is associated with a decline in agriculture and manufacturing.

The reduction in agricultural production is especially relevant here, because agriculture covers about 2/3 of total water usage in the region. Therefore, even a modest decline in agriculture could more than compensate the increased tourists' demand. It should be noted, however, that not all water savings obtained in

37 The Dutch disease (Corden and Neary, 1982) is a concept that explains the apparent relationship between the increase in exploitation of natural resources and a decline in the manufacturing sector. The mechanism is that an increase in revenues from natural resources (or inflows of foreign aid) will make a given nation's currency stronger compared to that of other nations, resulting in the nation's other exports becoming more expensive for other countries to buy, making the manufacturing sector less competitive. While it most often refers to natural resource discovery, it can also refer to any development that results in a large inflow of foreign currency, like an increase in tourism receipts.

38 This estimate refer to Cyprus. Gössling et al. (2012) summarize other estimates which, for the Mediterranean, are in the range 0.25-0.88 cubic meters. On global average, it has been suggested that an international tourist consumes 0.222 cubic meters per day (Gössling, 2005), but evidence from more recent studies suggests this estimate should be considered conservative.

agriculture could be redirected to support water consumption by tourists. Much of the water used in agriculture is "green water" (Antonelli, Roson and Sartori, 2012), which is water embedded into the soil moisture, typically linked to rainfed agriculture. Water used for irrigation, which could potentially be transferred to other uses, is termed instead "blue water". Possible conflicts over the utilization of water resources only refer to blue water resources.

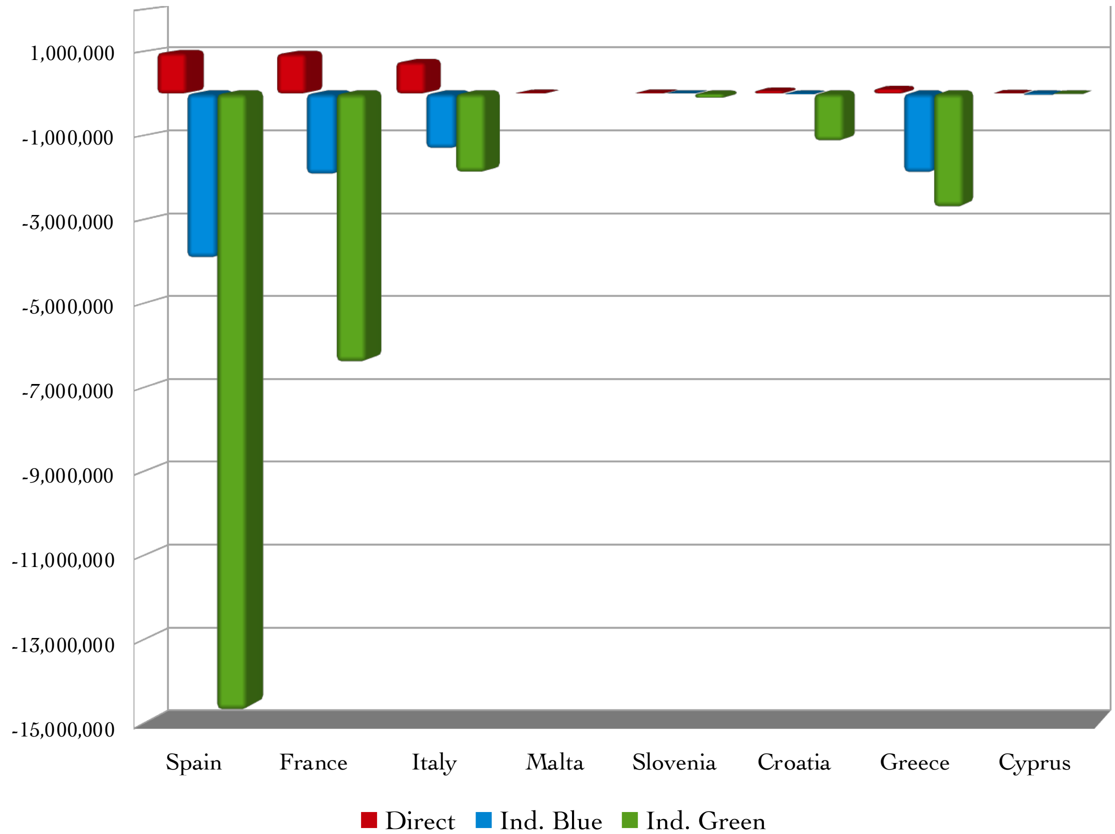
The green/blue water composition of agricultural water demand is very variable in the countries under consideration. Almost all water used in Croatia is green water; therefore, agriculture is not significantly subtracting water resources to tourism in that country. The opposite occurs in Cyprus, where about 71% of all water usage in agriculture is blue water.

Roson and Sartori (2010), using data from Chapagain and Hoekstra (2004), estimate water consumption per unit value of production in a set of agriculture industries. These data can be used to roughly calculate the change in water demand associated with changes in industrial outputs. The result, which refers to the indirect effect on water demand associated with the expansion of tourism, can therefore be compared with the direct consumption of water by tourists, as shown in Table 4.5 and graphically displayed in Figure 4.4.

Table 4.5. Changes in water consumption (m^3/year) by country.

	Spain	France	Italy	Malta	Slovenia	Croatia	Greece	Cyprus
Ind. Green	-14,649,234	-6,372,604	-1,857,608	0	-100,970	-1,113,174	-2,683,715	-14,571
Ind. Blue	-3,894,100	-1,903,505	-1,290,880	0	-2,061	-22,718	-1,864,954	-35,673
Direct	973,189	951,613	754,171	19,980	24,398	70,010	113,524	13,520
Global Balance	-17,570,145	-7,324,496	-2,394,317	19,980	-78,633	-1,065,881	-4,435,145	-36,723

Figure 4.4. Variations in water demand by country (m^3/year).



We see that the net effect of higher demand from tourism and lower demand from agriculture is net savings in water usage for all countries, with the exception of Malta, where the decline in agricultural production is negligible. Even the difference between tourism demand and blue water consumption by agriculture turns out to be positive for most countries under consideration, suggesting that the expansion of tourism activities is not likely to create conflicts for access to water resources.

This is a somewhat surprising and non trivial finding of our analysis. It has been obtained here because the change in water demand has been assessed into a general equilibrium framework, in which systemic and second-order effects can be detected.

4.5. Discussion and concluding remarks

Results like those presented above are subject to a number of caveats. A great deal of uncertainty affects, in particular: (a) estimates of future climate conditions, especially for variables different from temperature, (b) the relationship between climate and tourist demand, and its interaction with socio-economic variables (Gössling and Hall, 2006). Furthermore, as we followed here a single region approach, we were not able to consider the impact of climate change on the global tourism industry. For example, most climate models predict that climate will significantly improve at high latitudes, where much of the origin countries of Mediterranean tourists are found. We have not considered here domestic tourists, nor possible increases of tourists moving from the Mediterranean to northern European countries.

Nonetheless, we believe that a quantitative analysis like the one presented above is not without scope. First, it provides an order of magnitude for the impact of climate change on tourism and the national economy. Second, it allows to assess systemic and second-order effects, which are especially relevant here and, moreover, appear to be sufficiently robust to alternative model specifications. In other words, the value added of this study does not lie in specific figures obtained by numerical computations, but on the broader picture emerging from the overall exercise.

We found that stronger tourism attractiveness results in higher national income, consumption levels and welfare. However, distributional effects are felt through the contraction of production and competitiveness in those industries not directly linked to tourism.

This generates some interesting and unexpected consequences in terms of water consumption. The increase in tourists' arrivals and stays implies a higher demand for water from the tourism industry but, at the same time, the reduction of production volumes in agriculture, implied by the worsening of the terms of trade, brings about a global reduction in water demand. Even if attention is confined to “blue water”, that is the water used for irrigation and potentially transferable to alternative uses, net water savings remain positive in most Mediterranean countries.

To our knowledge, this is the first study in which, by assessing higher tourism attractiveness into a general equilibrium framework, this kind of effect is detected and highlighted.

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5.

TIME PREFERENCE AND ENVIRONMENTAL RESOURCES WHEN THE ENVIRONMENT IS A LUXURY GOOD

by

Martina Sartori

5.1. INTRODUCTION

This paper elaborates on Smulders (2007). Following Musu (1994), Smulders explores a model of economic growth combined with a standard renewable resource model to study how society's discount rate and the inter-temporal optimization process affect the long-run environmental stock. He compares a GGR - Green Golden Rule (Phelps, 1961; Chichilnisky *et al.*, 1995) and an inter-temporal optimization problem *à la* Ramsey (OPR). In both regimes, the environment plays a double role, being a productive asset as well as a direct source of utility. His main result is that a sufficiently high discount rate may bring about a level of environmental quality/quantity which is higher in the OPR than in the GGR, despite the fact that GGR amounts to maximize the steady state utility[39].

This result is especially interesting, as it is known that the choice of a (explicit or implicit) discount rate is a critical aspect in balancing the trade-off between the exploitation of natural assets for current consumption and the preservation of the natural capital for future generations. Indeed, a high discount rate means lower weights associated with future utility levels.

In this context, it is important to remember that the environment acts not only as a pure productive asset, but also as a consumption good. When the environment enters the utility function, the future stock of environmental resources may increase, even if a high discount rate works to the opposite direction. This kind of effect has often been overlooked in the environmental economics and growth literature, with only a few notable exceptions, including the contribution by Smulders.

In this work, we start from Smulders' model framework, introducing a time-varying preference parameter for environmental amenities in the utility function. Our aim is to study how the steady state level of the environmental resource may vary when environmental preferences change over time, in particular, when the marginal utility

39 Similar results are obtained by other studies. For a review see Smulders (ibid.).

of the environment increases with income. We introduce this "luxury good nature" of the environment into the model by replacing the Cobb-Douglas (CD) specification for the instantaneous utility function with a LES - Linear Expenditure System (Stone, 1954). We find that an initial low preference for the environment does not prevent reaching the same long-run level of environmental resource as in Smulders (ibid.). We also provide a qualitative and quantitative analysis of the transient model dynamics.

The structure of the paper is as follows. Section 5.2 describes the environmental growth model. Section 5.3 assesses the two behavioral regimes considered by Smulders (GGR and OPR), while taking into account the transient model dynamics. Section 5.4 modifies the model framework by introducing an income dependent preference parameter for the environment in the utility function, and provides a sensitivity analysis of the model results. A final section draws some conclusions.

5.2. THE MODEL

A one-sector neoclassical growth model is combined with a standard renewable resource model[40]. Production of final goods Y is given by a simple Cobb-Douglas specification:

$$Y = N^{\chi} K^{\beta} P^{\omega} \tag{5.1}$$

where: N is the level of environmental resource stock, which can be interpreted as a mix of quality and quantity, and K is conventional physical capital comprising all kinds of reproducible productive assets, like physical capital, knowledge (or human) capital, and infrastructure; P is the environmental resource use, or harvest, or pressure; β and ω are the positive production elasticities of capital and environmental resource use respectively.

40 In what follows, the time subscripts are suppressed for notational convenience.

Capital accumulation is driven by the standard accumulation rule:

$$\dot{K} = Y - C - \delta K \quad (5.2)$$

where C is consumption. Natural capital dynamics is determined by[41]:

$$\dot{N} = E(N) - P \quad (5.3)$$

where $E(N)$ is a function expressing the absorption capacity of the environment, that is the amount of regenerated environmental resource stock per period (a regeneration rate).

For $E(N)$ we posit, as it is standard for renewable environmental resources, that $E(0) = E(\bar{N}) = 0$ and $E_{NN} < 0$. As long as $P < E(N)$ ($P > E(N)$), the stock of environmental resources increases (decreases) over time. A constant level of environmental resource use that does not exceed absorption capacity ($P = E(N)$) is so that $\dot{N} = 0$.

Denoting by s the fraction of income saved, consumption equals:

$$C = (1 - s) Y \quad (5.4)$$

and capital accumulation in (5.2) can be written as:

$$\dot{K} = sY - \delta K \quad (5.5)$$

Substituting (5.1) into (5.5), and solving for K, when $\dot{K} = 0$, we obtain the long run level of capital stock:

41 For a review of alternative specifications, see Ludwig *et al*. (1997).

$$(K)_\infty = [sN_\infty^\chi P_\infty^\omega/(\delta)]^{1/(1-\beta)} \tag{5.6}$$

where the subscript ∞ is used to denote long-run values.

Furthermore, in the steady state, the stock of environmental resources does not change over time, therefore:

$$P_\infty = E(N_\infty) \tag{5.7}$$

Substituting (5.6) and (5.7) into the production function gives the following expression for the long run level of income:

$$(Y)_\infty = [s/(\delta)]^{\beta/(1-\beta)}[E(N_\infty)^\omega N_\infty^\chi]^{1/(1-\beta)} \tag{5.8}$$

This expression indicates a long run relationship between environmental resources and income. For a discussion see Smulders (ibid.).

Following the traditional approach of a Ramsey-based model, inter-temporal preferences can be framed as an integral of instantaneous utility, like:

$$W = \frac{\sigma}{\sigma-1}\int_0^\infty (CN^\varphi)^{\frac{\sigma-1}{\sigma}} e^{(-\theta t)}\,dt \tag{5.9}$$

where (CN^φ) stands for the instantaneous utility; θ is the utility discount rate; φ is a parameter affecting the marginal rate of substitution between consumption and environment (the higher φ, the more the consumer is willing to give up consumption in exchange for environmental resources – it is a sort of "subjective price", determining the subjective evaluation of the environmental resources); σ is the inter-temporal elasticity of substitution. Notice that both consumption and environmental resources affects utility. In addition, the environment has a production value and contributes directly as well as indirectly to welfare and consumption.

5.3. INVESTMENT BEHAVIOR

An optimal consumption rule is obtained through the inter-temporal optimization of (5.9). Different investment profiles and different steady state are obtained according to the value assigned to the relevant parameters. Among them, the discount rate is particularly interesting. For example, when the discount rate is zero or almost zero, the utility obtained far distance into the future is highly weighted by the consumer, in the limit only the steady state utility level matters. In this case, inter-temporal optimization boils down to utility maximization in the steady state. In traditional growth theory, when utility is only affected by consumption, a rule is identified: maximizing consumption (therefore welfare) in the long run. This rule has been termed "Golden Rule" (Phelps, 1961). In this context, however, instantaneous utility depends both on consumption and on the amount of the environmental resource stock. Maximization of the steady state utility brings about a modified golden rule, which has been called "Green Golden Rule" - GGR (Chichilnisky *et al.*, 1995).

The GGR is obtained by maximizing instantaneous utility which, using (5.4) and (5.8), can be expressed as:

$$\max_{s,N}(1-s)\{[s/(\delta)]^{\beta/(1-\beta)}[E(N_\infty)^\omega N_\infty^\chi]^{1/(1-\beta)}\}N^\varphi \tag{5.10}$$

First order conditions for (5.10) are given by:

$$s_{GGR}=\beta \tag{5.11}$$

$$\frac{-E_N N}{E(N)} = \chi + \varphi(1-\beta) \tag{5.12}$$

Equation (5.12) determines an implicit relationship between φ and N. The exact relationship depends on the functional form of $E(N)$. For example, for:

$$E(N) = \xi(1-N^{\eta})N \quad ^{42} \tag{5.13}$$

N can be directly expressed as a function of φ:

$$N_{GGR} = \left(1 + \frac{\eta\omega}{\omega + \chi + \varphi(1-\beta)}\right)^{-\frac{1}{\eta}} \tag{5.14}$$

It is easy to observe that N_{GGR} is a monotonically increasing function of φ, which has a trivial interpretation: the higher the level of the marginal rate of substitution between consumption and environment, the higher the level of N.

The steady state can be reached following various time paths. In order to illustrate the short run dynamics of a system satisfying the conditions above, we assign a value to the relevant parameters[43]. As in the Solow model, we first assume that the saving rate is constant over time (and equal to β). Regarding the environmental variables, N and P are the two sides of the same coin: while N is a *stock* variable identifying the stock of environmental resources, P is the corresponding *flow* variable, which represents the environmental resource harvest. Recalling (5.3), the level of P in each period is essential in determining the evolution of N.

The dynamics of harvesting in the GGR is not defined in Smulders (ibid.). We therefore assume that P is a constant fraction z of the level of environmental

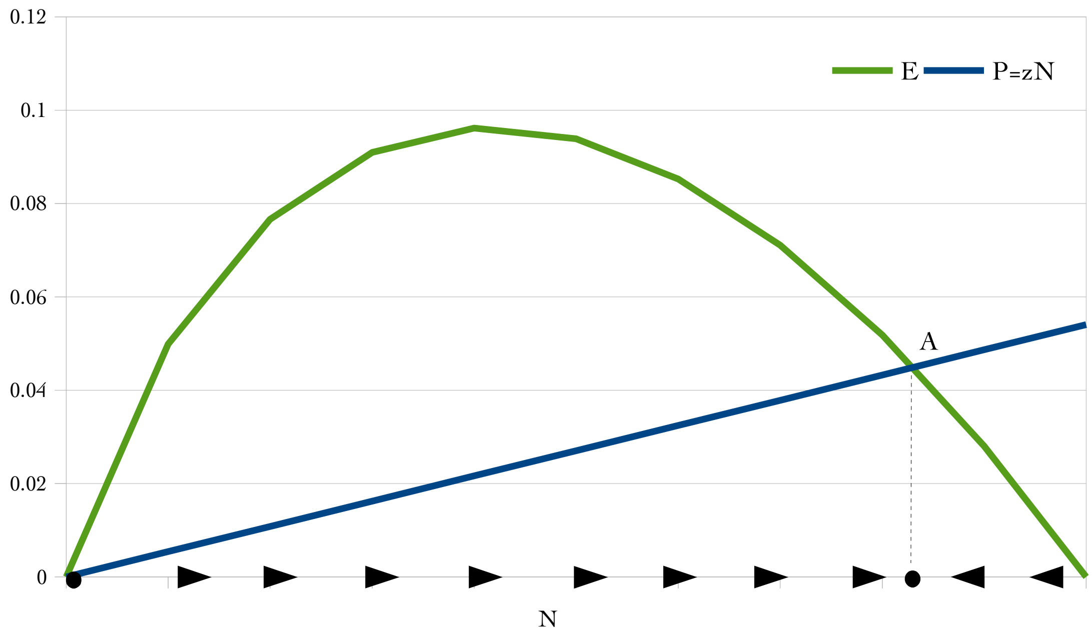
---

42 Where $\xi>0$, $\eta>0$ and $0 \leq N \leq 1$.

43 $K_0 = 0.5$; $N_0 = 1$; s= 0.4; β=0.4; δ=0.05; ω=0.4; χ=0.5; ϕ=2; η=0.3 and ξ=1.

stock, that is $P = zN$, where $z = P_{GGR}/N_{GGR}$. In addition, we assume that $N_0 = 1$. In this case, as illustrated in Figure 5.1, the system possesses two equilibria: an unstable equilibrium in (0, 0) and a stable equilibrium, labeled A, in (P_{GGR}, N_{GGR}).

Figure 5.1. Evolution of absorption capacity function $E(N)$ and harvesting function $P(N)$.



We consider now how the marginal rate of substitution between consumption and environment φ affects the system dynamic. Figures 5.2, 5.3, 5.4 and 5.5 illustrate the time paths of consumption levels, capital stocks, pollution and environmental resource stock for different levels of φ . We can notice that lower levels of φ increase consumption levels, capital accumulation and environmental harvesting, deteriorating the long-run environmental resource stock.

Figure 5.2. Consumption path (C_{GGR}) for different levels of φ. GGR.

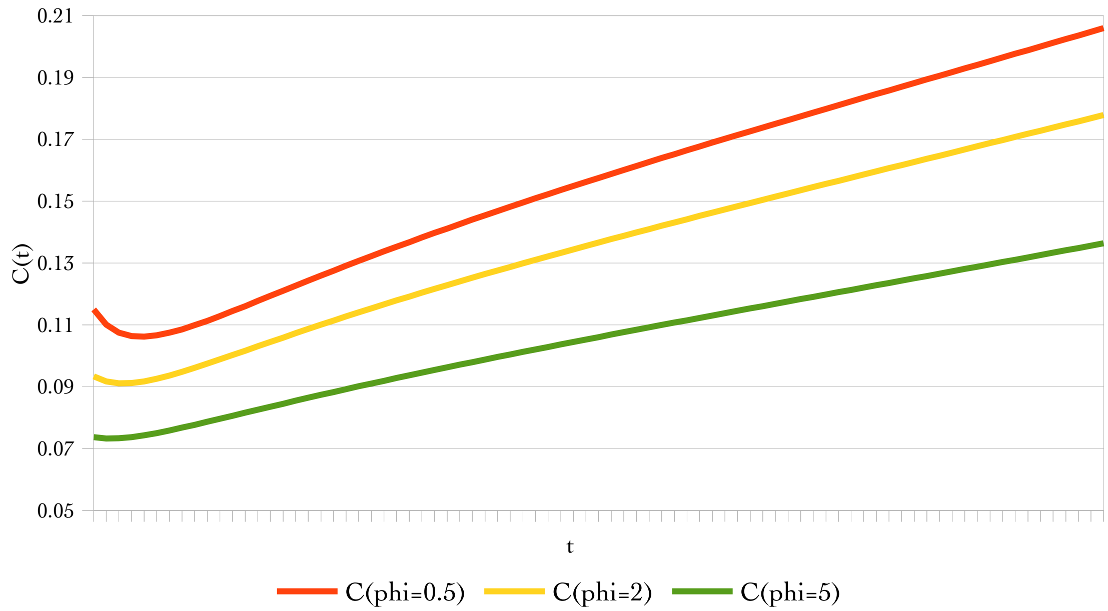


Figure 5.3. Capital path (K_{GGR}) for different level of φ. GGR.

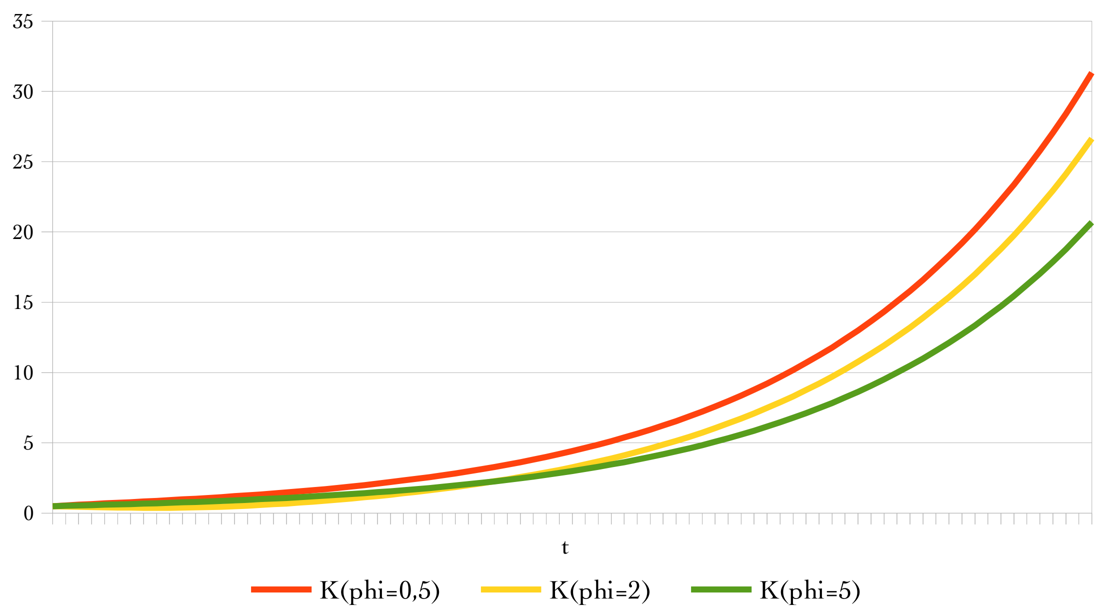


Figure 5.4. Harvesting path (P_{GGR}) for different level of φ. GGR.

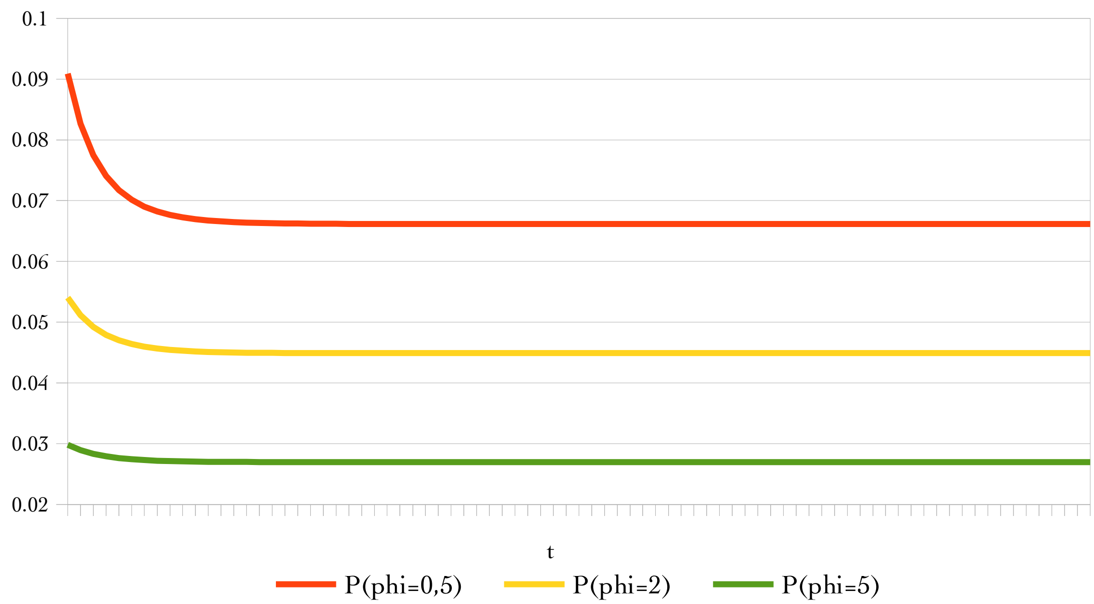
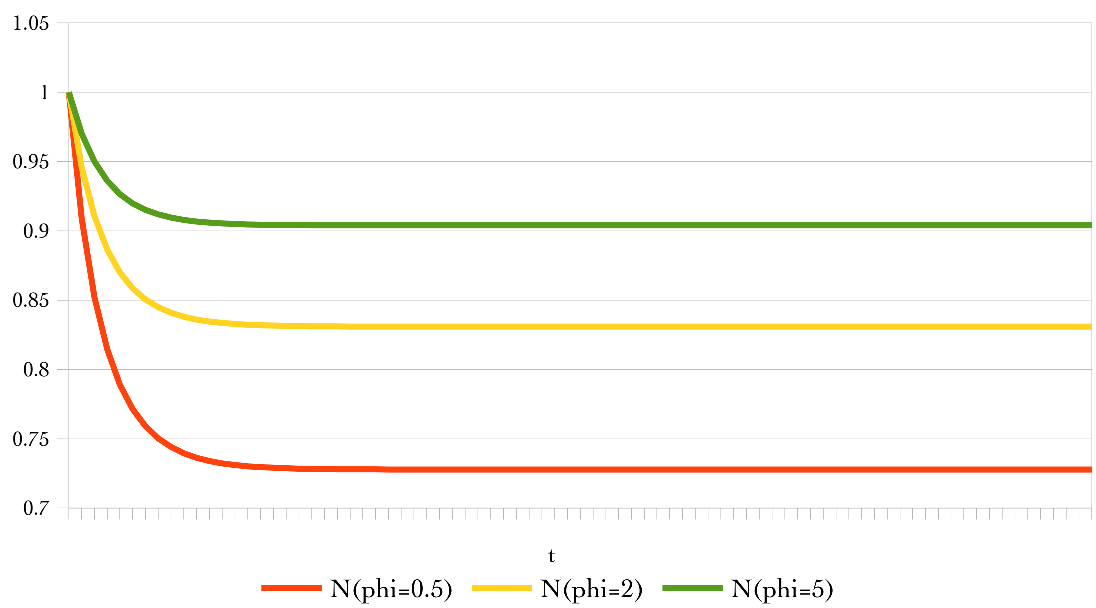


Figure 5.5. Environmental resources path (N_{GGR}) for different level of ϕ. GGR.



The case above refers to a maximization behavior, where only the long-run utility matters, which amounts to a discount factor equal (or very close) to zero. A more general case is provided by the inter-temporal optimization problem *à la* Ramsey (OPR), where the discount factor may be different from zero. That problem is associate with the following Hamiltonian:

$$H^o = (1-1/\sigma)^{-1}(CN^{\varphi})^{1-1/\sigma} + \mu[Y - \delta K - C] + \nu[E(N) - P] \tag{5.15}$$

where C and P are the control variables, K and N are the state variables and μ and ν are the co-state variables or shadow prices of the capital stock and the environmental resource stock. The first order conditions are:

$$\partial H^o / \partial C = C^{-1/\sigma} N^{\varphi(1-1/\sigma)} - \mu = 0 \tag{5.16}$$

$$\partial H^o / \partial P = \mu \omega Y / P - \nu = 0 \tag{5.17}$$

$$\partial H^o / \partial K = \mu \beta Y / K - \mu \delta = \mu \theta - \dot{\mu} \tag{5.18}$$

$$\partial H^o / \partial N = \varphi C^{1-1/\sigma} N^{\varphi(1-1/\sigma)-1} + \mu \chi Y / N + \nu E_N = \nu \theta - \dot{\nu} \tag{5.19}$$

By solving the system of FOCs (Smulders, ibid.), the steady state values for the saving rate and the environmental resource stock are found:

$$s_{OPR} = \beta\left(\frac{\delta}{\theta + \delta}\right) \tag{5.20}$$

$$(\theta - E_N)\frac{N}{E(N)}\omega = \chi + \varphi(1 - s_{OPR}) \tag{5.21}$$

Equation (5.11) is a special case of equation (5.20) where θ equals zero. Higher levels of the discount rate imply lower levels of the saving rate; the more impatient the consumer is, the less he or she is willing to save for future consumption.

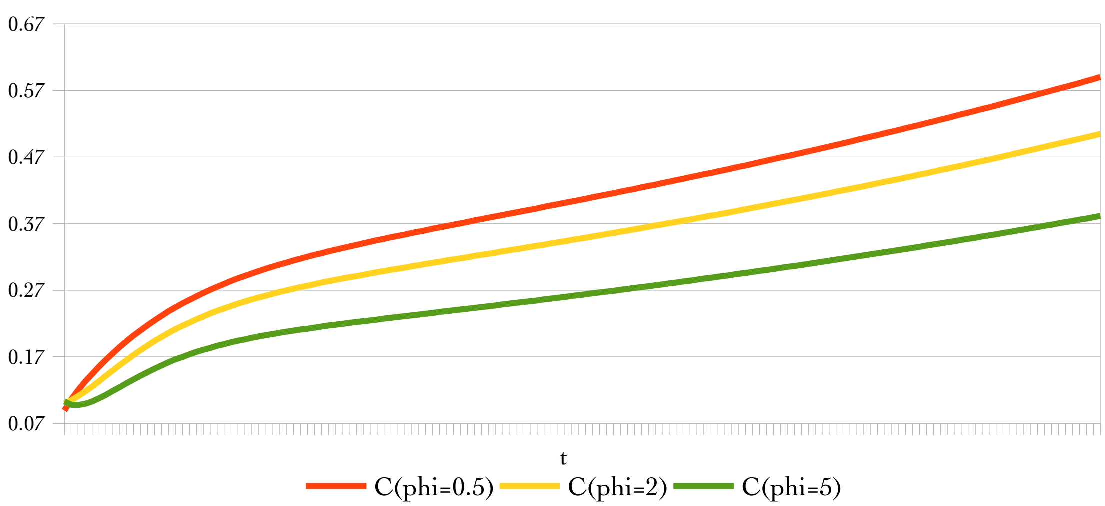
Analogously, equation (5.21) corresponds to equation (5.12). Substituting (5.13) into (5.21), we again obtain a relationship between N and φ :

$$N_{OPR}=\left[\frac{\left(1+\frac{\chi+\varphi(1-s)}{\omega}\right)-[\theta+(1/\sigma-1)g]1/\xi}{\left(1+\frac{\chi+\varphi(1-s)}{\omega}\right)+\eta}\right]^{(1/\eta)} \tag{5.22}$$

It is easy to demonstrate that, even in this case, N_{OPR} is monotonically increasing in φ .

Consumption levels, capital stock, environmental harvesting and environmental resource paths are fully specified by the system dynamics[44]. Figures 5.6, 5.7, 5.8, and 5.9 illustrate the time path of these variables for varying values of the parameter φ .

Figure 5.6. Consumption path (C_{OPR}) for different level of φ. OPR.



44 The parameters are set at the same levels of the previous example. In addition, θ=0.01 and σ=2.

Figure 5.7. Capital stock harvesting path (K_{OPR}) for different level of φ.

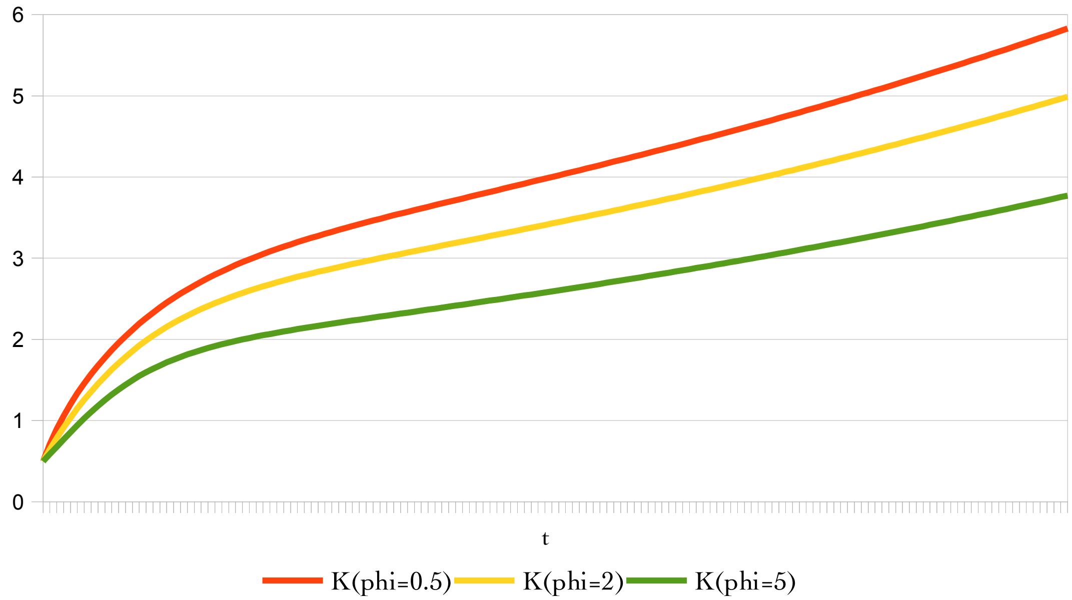


Figure 5.8. Harvesting path (P_{OPR})for different level of φ. OPR.

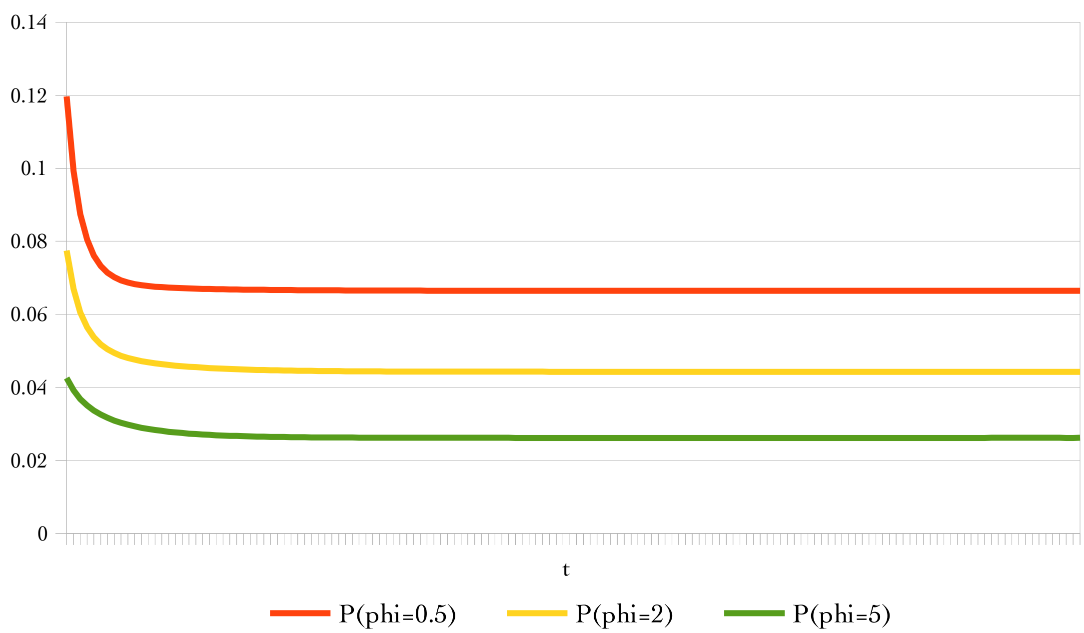
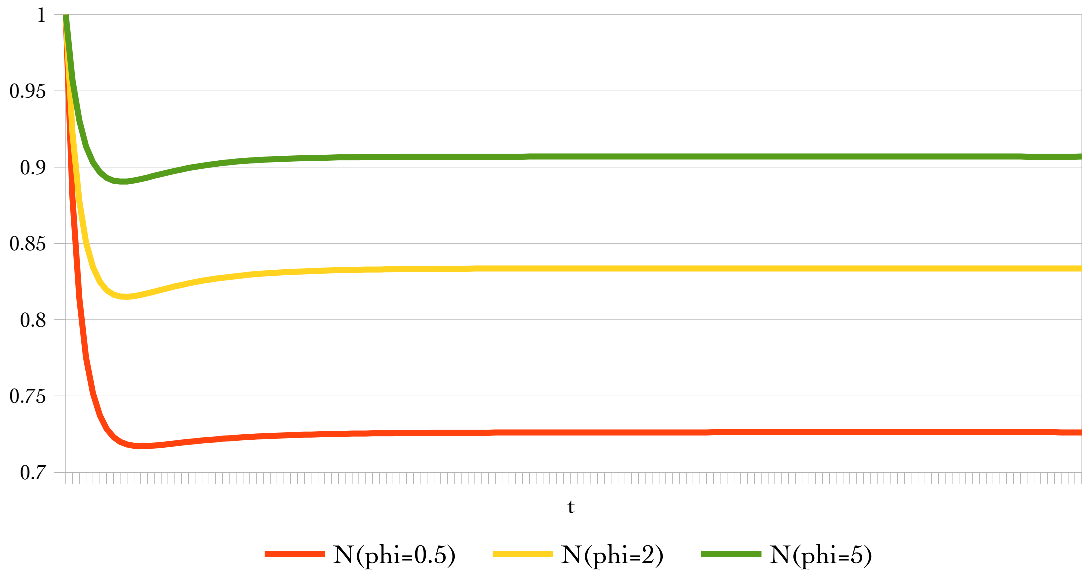


Figure 5.9. Environmental resource path (N_{OPR}) for different level of φ. OPR.



Comparing the two cases, since the GGR corresponds to a situation where the discount factor is zero, implying that future utility is highly weighted, the steady state level of environmental resources would be higher. However, as the environment enters directly the utility function, this result is not granted. Indeed, Smulders states the following proposition:

Proposition 1 (Smulders, ibid.): In the steady state, when $\theta > 0$, the environmental resource stock level is higher in the OPR than in the GGR if and only if:

$$\varphi \beta \frac{E(N_{GGR})}{N_{GGR}} > \omega(\theta + \delta) \tag{5.23}$$

Notice that condition (5.23) holds if: φ and β are sufficiently high, ω and δ are sufficiently low. However, the higher the discount rate, the more difficult it is to satisfy the condition.

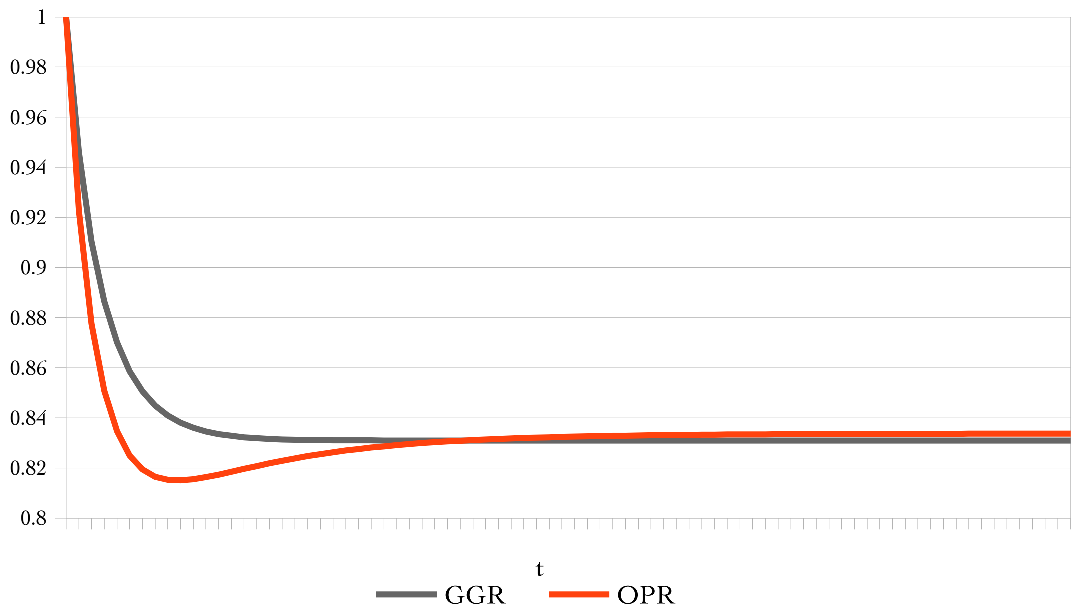
A vast empirical literature exists on the valuation of environmental resources (for a review, see Venkatachalam, 2004). This literature may provide useful insights about the magnitude of key parameters in condition (5.23), as well as on their variations over time.

If the environment does not enter the utility function ($\varphi=0$), condition (5.23) can never be satisfied. On the other hand, a positive φ implies that the environment is no longer a pure productive asset, but also acts as a consumption good, stimulating the household to invest in the environment. A low δ is needed to shift investment in man-made capital towards investment in the environment. A low marginal productivity of environmental resources, ω , reduces the incentive of conveying those resources into production processes, thereby making it more convenient to save them for consumptive needs. The marginal productivity of capital, β , makes it the physical capital relatively more productive than the environment, which has a similar effect of a low ω .

As condition (5.23) depends on all these parameters, a higher discount rate may still bring about a higher environmental stock if its effect is compensated by other parameters. For example, Smulders underlines that condition (5.23) might hold, even with a high θ , in the presence of a sufficiently high φ .

In the short run, however, it may well be the case that the GGR case displays higher levels of environmental resources, as shown in Figure 5.10. Starting from the same initial conditions (e.g., $N_0=1$ in both cases), the absence of impatience ($\theta=0$) guarantees an initial higher level of N_{GGR} . After some time, the situation reverses and makes N_{OPR} to increase and to leapfrog N_{GGR} .

Figure 5.10. Environmental resource dynamics (N_{GGR} and N_{OPR}) under different investment rules.



5.4. THE CASE OF VARIABLE ENVIRONMENTAL VALUATION

While the discount factor can be assumed to be relatively constant over time, at least for well-behaved optimization problems, there is no reason to believe that the marginal rate of substitution between consumption and the environment does not vary over time.

Indeed, several studies suggest that the marginal rate of substitution between consumption and the environment may be a parameter variable over time and dependent on income. For instance, a U-shaped empirical relationship has been found between income pollution levels, known as the Environmental Kuznets Curve (Grossman and Krueger, 1995). A number of arguments has been put forward to justify this empirical regularity, including the fact that the demand for environmental quality/quantity may increase more than proportionally than per capita income (Barbier, 1997; Flores and Carson, 1997). This amounts to say that the income elasticity of demand for the environment is greater than one; in other words, the environment is a "luxury good". The luxury good nature of the environment may be due to a complementarity with tourism services, whose consumption are known to increase more than proportionally than income (Kara, *et al*. 2003, and Garín-Muñoz, 2006).

In the previous section we noticed that a key parameter affecting the long run level of environmental resources is the marginal utility of the environment. In Smulders (ibid.), this is determined by a constant parameter (φ). However, to the extent that the environment is a luxury good, the latter would increase as income rises. A natural question then emerges: how the results discussed above would be affected by the assumption of the environment being a luxury good?

A simple way to introduce the luxury good hypothesis is to replace into the model the CD specification for the instantaneous utility function with a LES, as in the following case:

$$U(C,N)=(C-c_0)(N^{\varphi}) \tag{5.24}$$

where c_0 and φ are positive parameters.

The parameter φ has the same meaning as in the CD function, whereas c_0 affects the marginal utility of consumption. Notice that consumption C generates utility only for the part exceeding c_0 . For this reason, some authors have proposed the interpretation of c_0 as a predetermined subsistence consumption level. In a LES demand system, the allocation of the household income can be thought as a two-stage process. First of all, the consumer has to fulfill his or her subsistence consumption, c_0 . Only the residual income, $Y-c_0$, is then allocated between consumption goods, with constant budget shares.

As income rises, the residual part of it becomes relatively larger. Therefore, total consumption $C+c_0$ increases less than proportionally, whereas the environment would do the opposite. The LES system converges asymptotically to a CD structure. Therefore, since the Smulders condition (5.23) must only hold in the long run, if it is satisfied under a CD specification, it will also be satisfied under the LES.

In the LES case, the Hamiltonian function has to be modified in the following way:

$$H^o=(1-1/\sigma)^{-1}((C-c_0)N^{\varphi})^{1-1/\sigma}+\mu[Y-\delta K-C]+\nu[E(N)-P] \tag{5.25}$$

which generates these FOCs:

$$\partial H^o/\partial C=C^{-1/\sigma}N^{\varphi(1-1/\sigma)}-\mu=0 \tag{5.26}$$

$$\partial H^o/\partial P=\mu\omega Y/P-\nu=0 \tag{5.27}$$

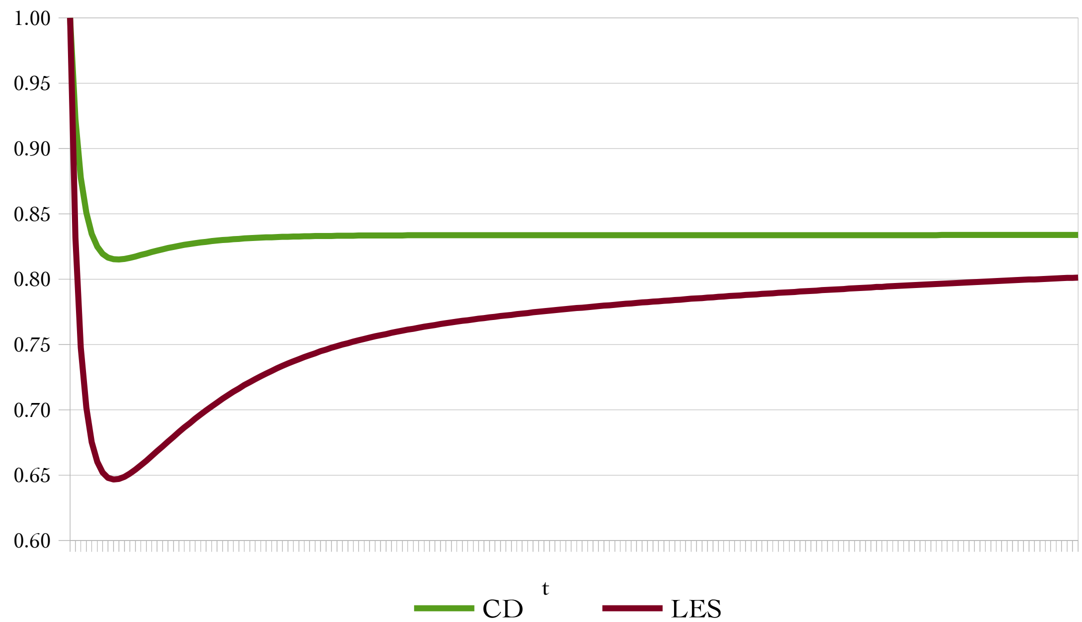
$$\partial H^o/\partial K=\mu\beta Y/K-\mu\delta=\mu\theta-\dot{\mu} \tag{5.28}$$

$$\partial H^o/\partial N=\varphi(C-c_0)^{1-1/\sigma}N^{\varphi(1-1/\sigma)-1}+\mu\chi Y/N+\nu E_N=\nu\theta-\dot{\nu} \tag{5.29}$$

The presence of the parameter c_0 brings about a different short run dynamics. Indeed, condition (5.29) is the only equation that changes. This condition represents the impact of a marginal unit of environmental resource on consumer utility, at any period t . The presence of c_0 lowers the marginal utility obtained from an extra unit of the environment. This makes the environment a less attractive asset than capital, bringing about higher environmental pressure, more consumption and lower environmental stock. This kind of effect vanishes over time for rising income levels.

A possible interpretation is the following: an initial lower preference for the environment does not prevent reaching a high level of environmental resource in the long run. Figure 5.11 illustrates this feature, by showing the time paths for the environmental resource under the two alternative specifications.

Figure 5.11. Environmental resource dynamics under the two specifications at hand.



We can notice that, in the LES formulation, the level of environmental resources is significantly lower at early stages of economic development. However, the gap between the two cases progressively narrows over time, as they both reach the steady state values as in (5.22) in the long run.

5.4.1. A sensitivity analysis to changes in the subjective environmental valuation

The dynamics of the environmental stock variable depends on the interplay between some parameters, which are relevant in determining the model results. In the previous section, we noticed that the presence of the parameter c_0 reduces the marginal utility obtained from an extra unit of the environment, lowering the short-run environmental stock. This kind of effect, however, vanishes over time, for rising income levels.

In order to assess how the environmental resource path is affected by different values of the exponent of the natural stock variable in the utility function, φ, a sensitivity analysis has been carried out. The model has been tested for increasing level of φ ($\varphi=0$, $\varphi=0.2$, $\varphi=1$ and $\varphi=2$). Figures 5.12, 5.13, 5.14 and 5.15, analogous to Figure 5.11, show the time paths for the environmental resource under the two alternative specifications. Notice that a positive relationship between φ and the long-run level of environmental resources exists, which does not depend on the utility function specification.

Figure 5.12. Time path of N (φ=0).

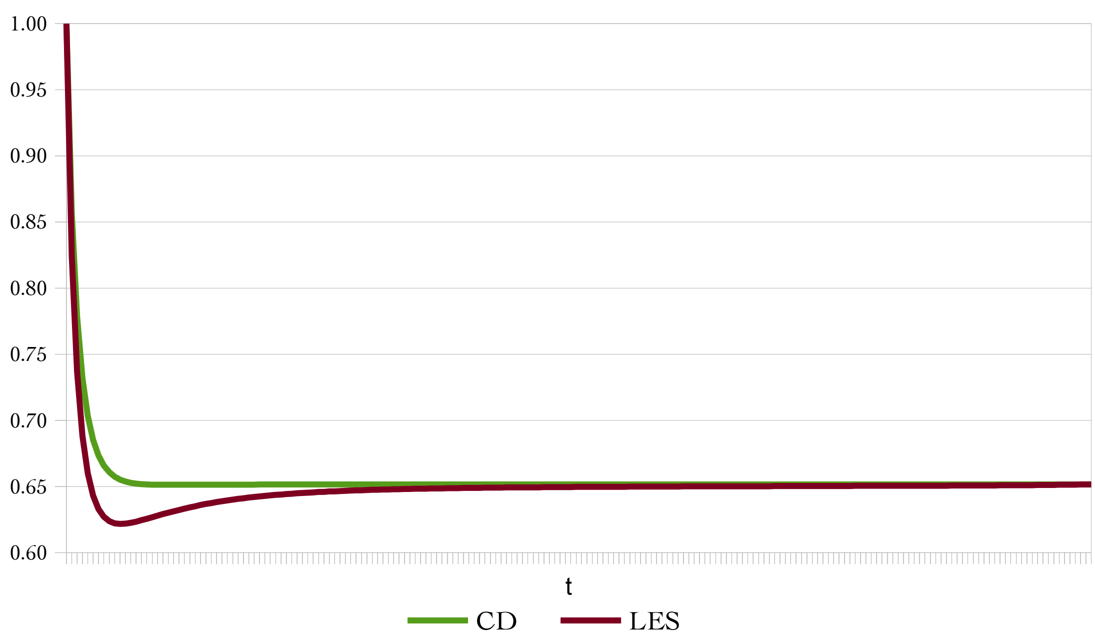


Figure 5.13. Time path of N (φ=0.2).

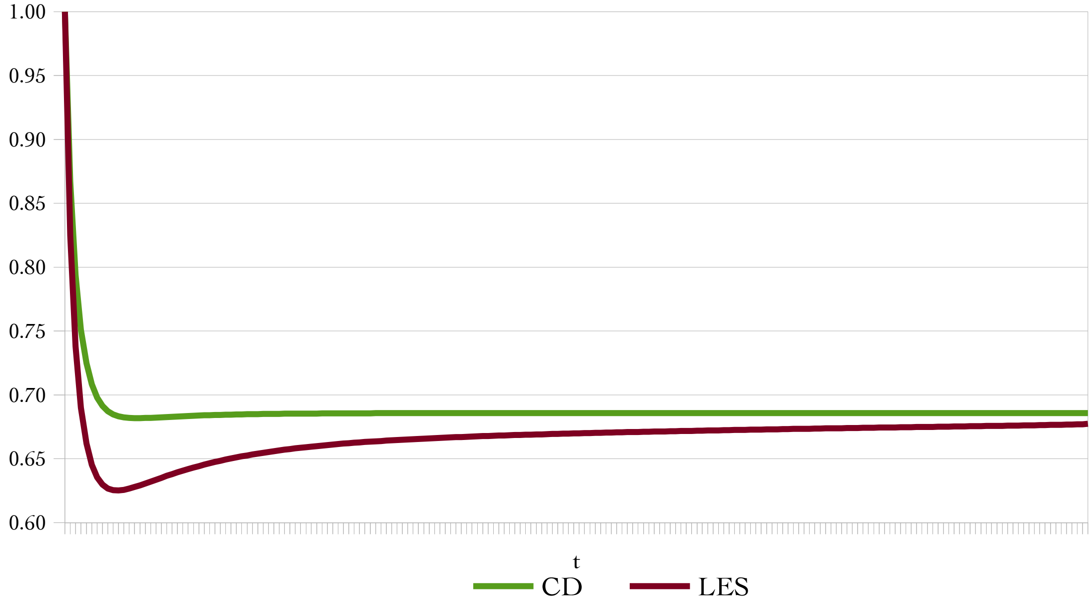


Figure 5.14. Time path of N (φ=1).

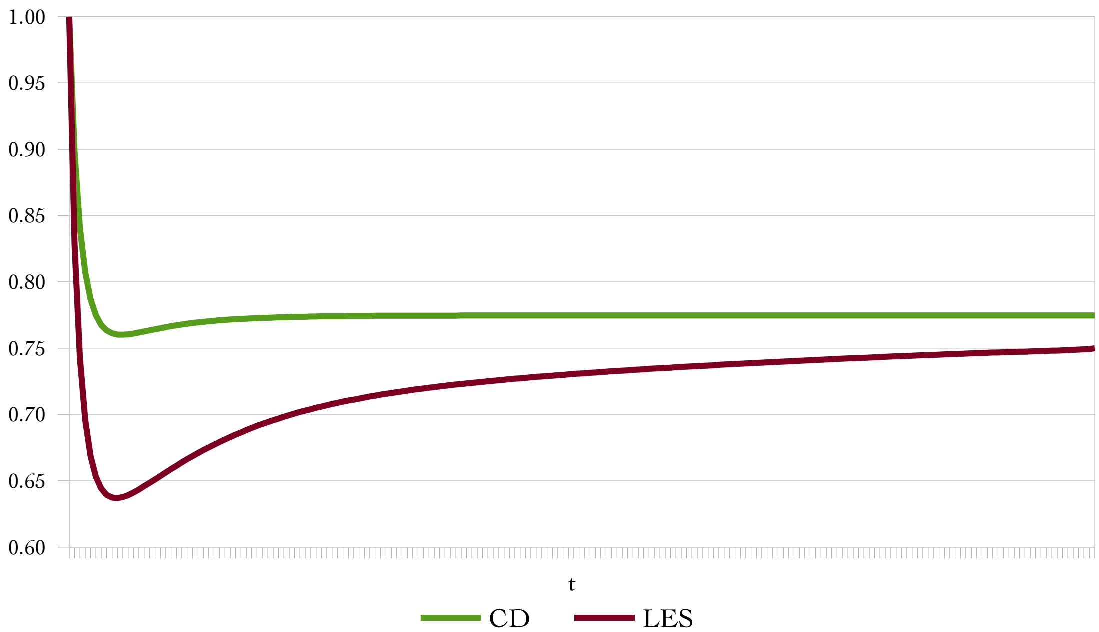
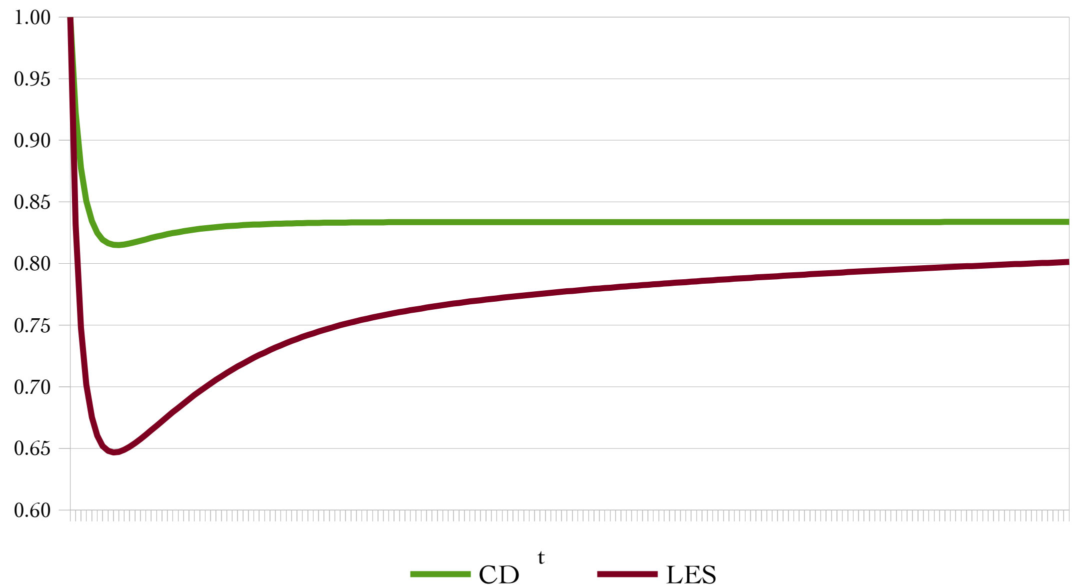


Figure 5.15. Time path of N (φ=2).



Furthermore, both the shape of the different curves and their distance are influenced by values of the parameter. In order to better compare the various instances, Table 5.1 presents some indicators, describing salient characteristics of the cases at hand.

Table 5.1. Sensitivity analysis: key indicators.

	$\varphi=0$	$\varphi=0.2$	$\varphi=1$	$\varphi=2$
Short-run lowest N value in CD-case	0.65	0.68	0.76	0.81
Period of minimum level	21	14	11	10
Short-run lowest N value in LES-case	0.62	0.63	0.64	0.65
Period of minimum level	11	11	10	9
Max distance between CD-LES	0.044	0.063	0.13	0.17
Period of max distance	4	6	8	9
Distance CD-LES at period 100	0.002	0.015	0.043	0.054

For increasing values of the parameter φ , notice that:

- the short-run minimum level of environmental resources increases, under both utility specifications;
- the short-run minimum level of environmental resources is reached sooner, under both utility specifications;
- the maximum short-run distance between the two model specifications is greater;
- the maximum short-run distance between the two model specifications is reached at a later time.

This amounts to say that, as φ increases, the short-run gap between the two cases increases and the convergence process is slower. This is due to the negative relationship between φ and the parameter c_0 , which emerges from the marginal instantaneous utility of the environment:

$$\partial U / \partial N = \varphi (C - c_0) N^{\varphi - 1} \tag{5.30}$$

A higher φ amplifies the short-run negative impact of c_0 on the marginal utility of the environment. This makes the environment a relatively less attractive asset than capital, bringing about more consumption levels and lower environmental stock in the short run. As φ and c_0 enter multiplicatively in the marginal utility (5.30), the two effects reinforce each other.

5.5. CONCLUSIONS

Smulders points out that the discount rate is not the only factor affecting the long run level of environmental resources, despite the fact that a higher discount rate will necessarily harm the environment in the future. However, the latter is actually determined by the interplay between several parameters, including the relative preference for the environment as an amenity good in the utility function.

Although Smulders' analysis focuses on the long run results, in this paper we have considered the transient short run dynamics of the system. Even when Smulders' condition for larger environmental stock is satisfied, we observed that: (i) the GGR regime may still exhibit higher environmental resource levels in the short run; (ii) the LES specification initially reduces optimal levels for the environmental capital, yet it does not affect the steady state.

When subsistence consumption and primary needs are constraints in utility maximization, consumers' choices may initially put the environment at a disadvantage, bringing about a temporary decline in environmental quality/quantity. This effect is, however, bound to vanish as a consequence of economic growth. Therefore, our results suggest that the quality of the environment may significantly improve in developing countries, despite the fact that the level of economic development does not currently allow for an effective preservation of the environment.

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The author expresses her gratitude to her supervisors, Prof. Dr. Marzio Galeotti and Prof. Dr. Roberto Roson, who helped me in the drafting of this paper. She also thanks the Professors who participated in the internal examination panel (Prof. Dr. Emanuele Bacchiocchi, Prof. Dr. Alberto Bucci and Prof. Dr. Michele Santoni) for the many useful suggestions and comments.

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APPENDIX

A1. 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 A1.1 a graphical representation of income flows in the model (from Brockmeier, 2001).

Equation and identities in the model include the following conditions:

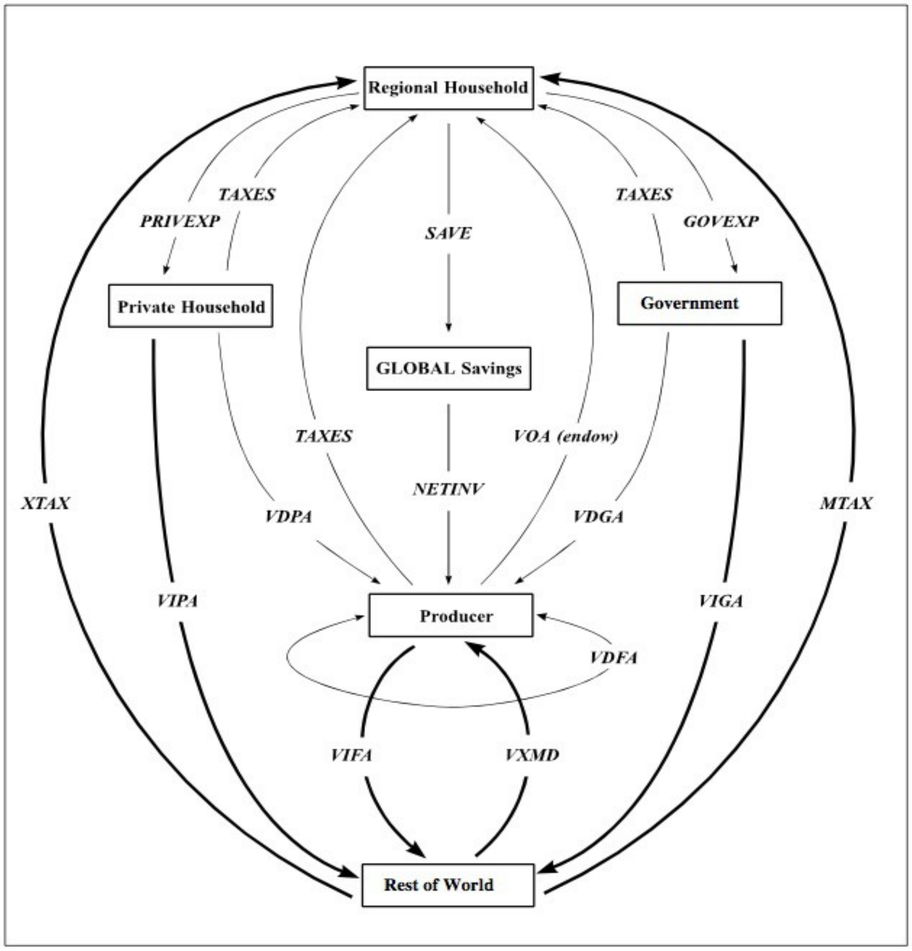
- production of industry *i* in region *r* equals intermediate domestic consumption, final demand (private consumption, public consumption, demand for investment goods) and exports to all other regions;
- endowments of primary factors (e.g., labour, capital) matches demand from domestic industries;
-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

Figure A1.1. Income flows in the GTAP Model.



A2. Additional results from chapter 1

Tables A2.1, A2.2 and A2.3 report the shock parameters associated with the NM, the IM and the IE scenarios, respectively.

Table A2.1. Reduction in agricultural productivity, by sector and by region (NM scenario).

	Wheat	Cereals	Rice	Veg&Fruits	Oilseeds	Sugar	Other crops
Egypt	-46.47%	-46.47%	-59.27%	-59.27%	-60.03%	-60.03%	-55.26%
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%
Morocco	-0.64%	-0.64%	-3.01%	-3.01%	-1.57%	-1.57%	-1.74%
Tunisia	-2.99%	-2.99%	-14.15%	-14.15%	-7.4%	-7.4%	-8.18%
XMENA	-1.46%	-1.46%	-6.91%	-6.91%	-3.61%	-3.61%	-3.99%

Table A2.2. Reduction in agricultural productivity, by sector and by region (IM scenario).

	Wheat	Cereals	Rice	Veg&Fruits	Oilseeds	Sugar	Other crops
Egypt	-35.74%	-35.74%	-45.58%	-45.58%	-46.17%	-46.17%	-42.49%
France	-0.57%	-0.57%	-0.39%	-0.39%	-0.26%	-0.26%	-0.41%
Italy	-3.89%	-3.89%	-3.36%	-3.36%	-2.30%	-2.30%	-3.18%
Morocco	-0.49%	-0.49%	-2.32%	-2.32%	-1.22%	-1.22%	-1.34%
Tunisia	-0.94%	-0.94%	-4.46%	-4.46%	-2.33%	-2.22%	-2.58%
XMENA	-1.46%	-1.46%	-6.91%	-6.91%	-3.61%	-3.61%	-3.99%

Table A2.3. Reduction in agricultural productivity, by sector and by region (IE scenario).

	Wheat	Cereals	Rice	Veg&Fruits	Oilseeds	Sugar	Other crops
Egypt	-3.02%	-3.02%	-3.85%	-3.85%	-3.90%	-3.90%	-3.59%
France	-0.57%	-0.57%	-0.39%	-0.39%	-0.26%	-0.26%	-0.41%
Italy	-3.89%	-3.89%	-3.36%	-3.36%	-2.30%	-2.30%	-3.18%
XMENA	-1.46%	-1.46%	-6.91%	-6.91%	-3.61%	-3.61%	-3.99%

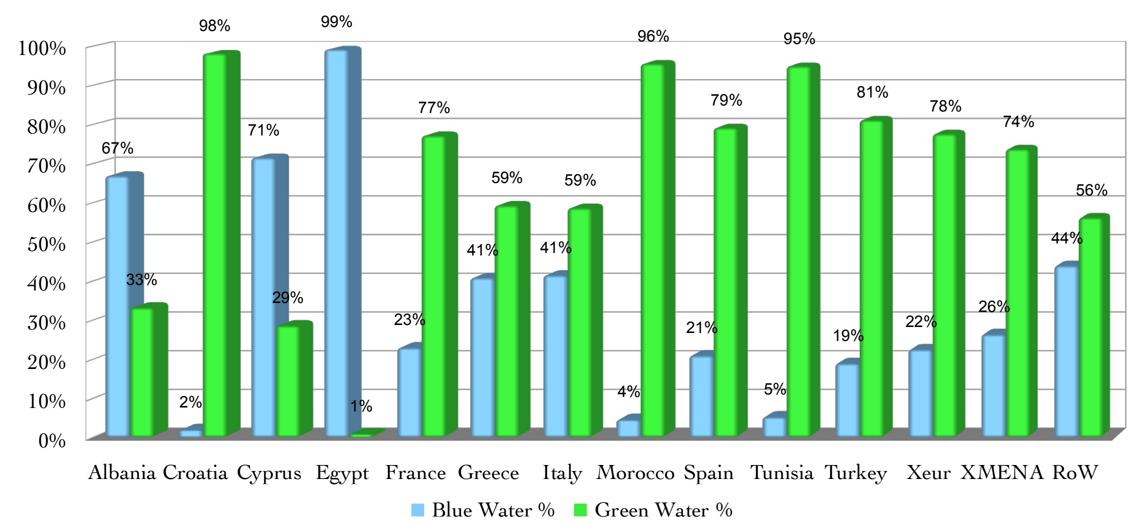
A3. Additional results from chapter 2

Data for 14 Mediterranean economies was obtained through aggregation from the 7.1 Global Trade Analysis Project (GTAP) database (see http://www.gtap.org). The following countries are considered: 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. Seven agricultural industries are taken into account: Cereals, Rice, Sugar, Oilseeds, Vegetable and Fruits, Wheat, Other Crops.

Water requirements per crop were derived from Chapagain and Hoekstra (2004), and expressed as water required for one million of dollars value of industry output in agricultural sectors. Green water consumption, by country, has been estimated by the eco-hydrological model LPJmL. Blue water consumption has been estimated by multiplying total blue water availability (in each region) by the percentage of irrigated land over total agricultural area (source: http://faostat.fao.org).

Figure A3.1 shows, for each country/region, the estimated green and blue water shares.

Figure A3.1. Shares of blue and green water used in agricultural industries.



Figures A3.2, A3.3, A3.4, A3.5 and A3.6 are analogous to Fig. 2.1 and present the percentage variation, with respect to estimates obtained with the standard method, in water requirement per unit of output (m^3/M$) for all other agricultural industries.

Figure A3.2. % change in water requirements per unit of output (m^3/M$). Rice industry.

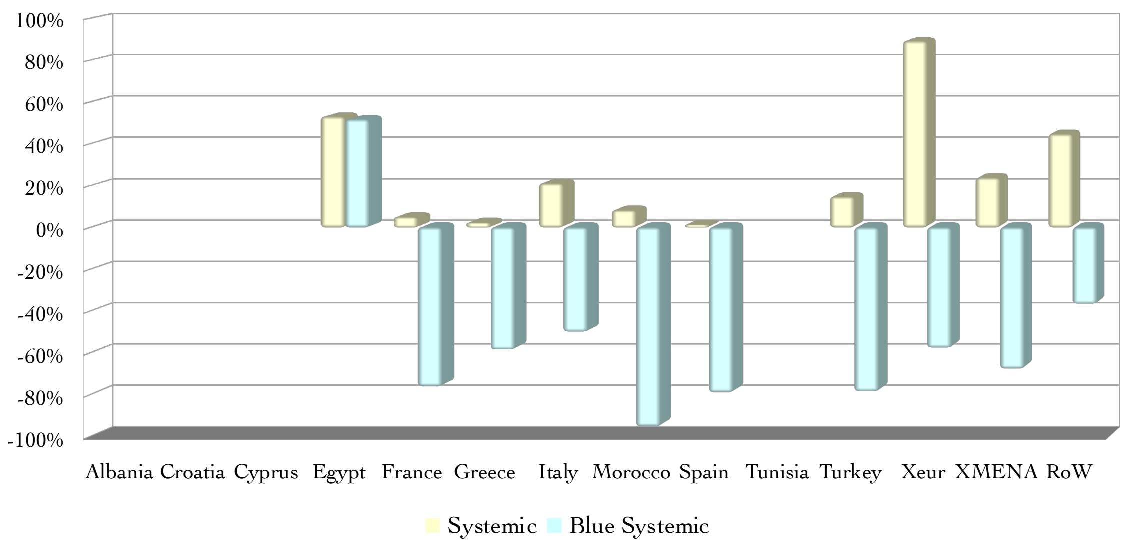


Figure A3.3. % change in water requirements per unit of output (m^3/M$). Wheat industry.

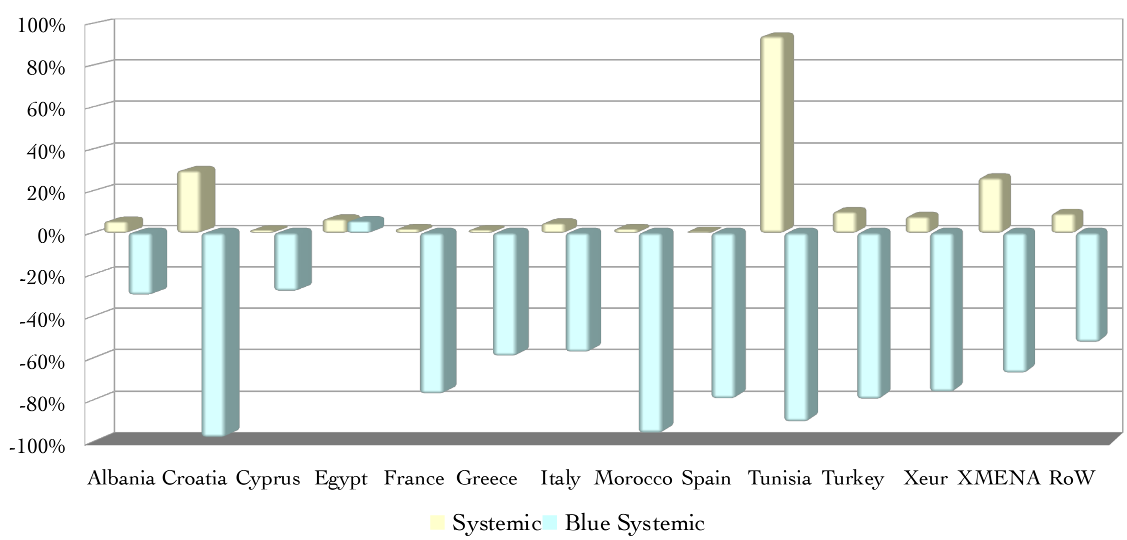


Figure A3.4. % change in water requirements per unit of output (m^3/M$). Cereals industry.

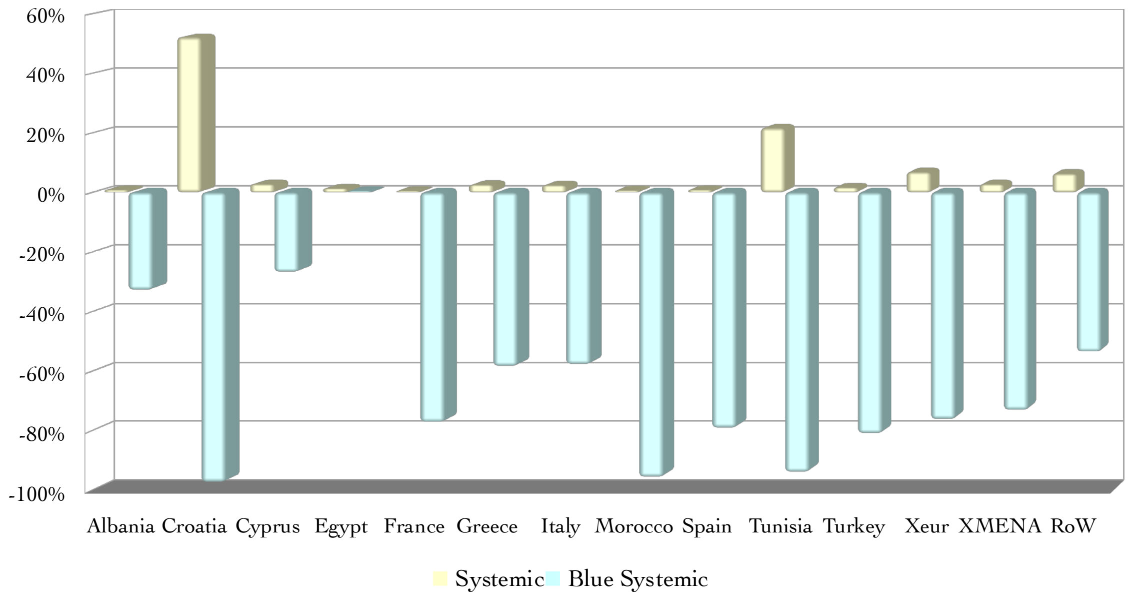


Figure A3.5. % change in water requirements per unit of output (m^3/M$). Oilseeds industry.

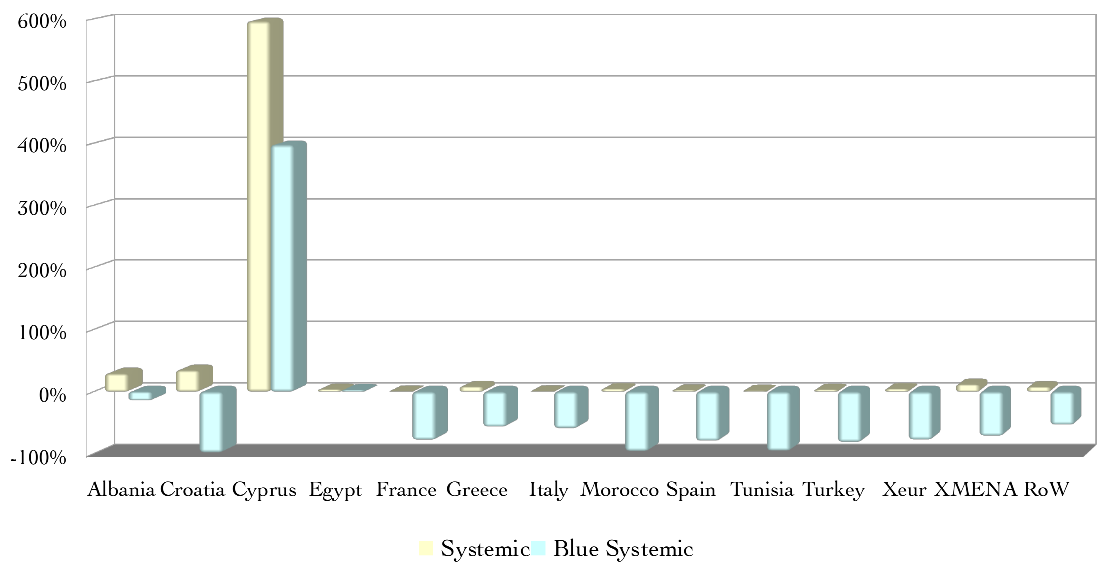


Figure A3.6. % change in water requirements per unit of output (m^3/M$). Sugar industry.

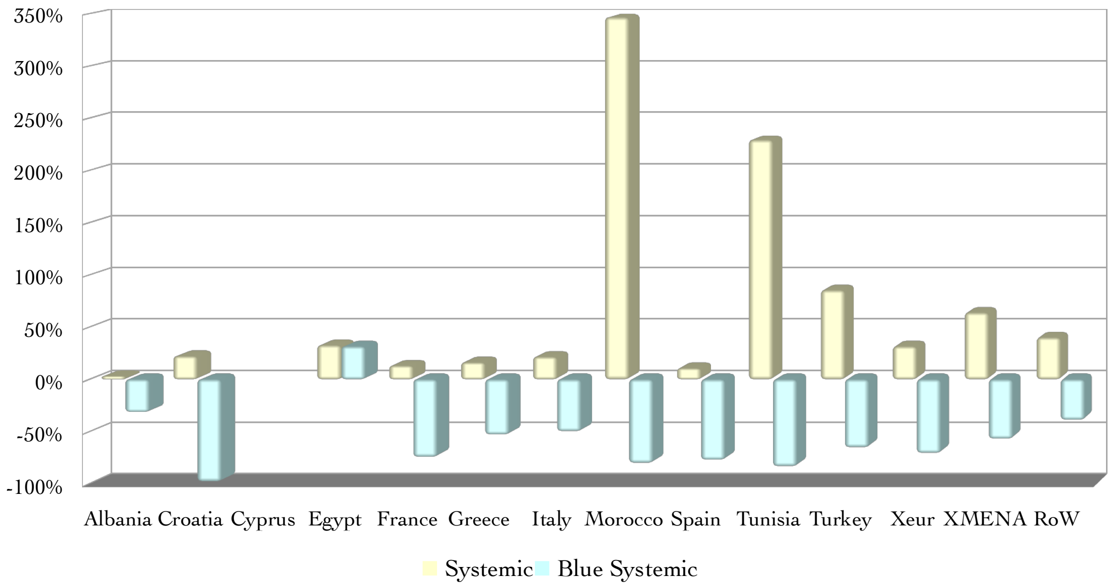


Table A3.1 displays virtual water trade flows, computed using the systemic method applied only to blue water, for all pairs of countries/regions.

Table A3.1. Bilateral blue virtual water trade flows (Mm^3, systemic+blue method).

	Albania	Croatia	Cyprus	Egypt	France	Greece	Italy	Morocco	Spain	Tunisia	Turkey	Xeur	XMENA	RoW	Tot. Exp.
Albania	0,00	0,55	0,07	0,24	6,97	7,25	62,44	0,08	2,88	0,04	5,50	42,35	1,17	27,61	134
Croatia	0,19	0,00	0,07	0,08	0,47	0,11	132,52	0,93	10,25	0,28	5,32	8,57	0,23	4,75	17
Cyprus	0,1	0,6	0,00	0,63	3,45	6,71	12,02	0,04	2,37	0,03	9,06	67,13	16,53	20,11	132
Egypt	22,59	5,01	9,40	0,00	123,44	117,55	413,81	42,24	123,79	52,71	169,94	1624,63	1.585,05	1756,29	6040
France	6,49	3,74	25,21	12,55	0,00	146,21	5.264,37	901,28	4.731,69	260,75	112,	4991,52	726,52	928,25	9420
Greece	45,78	8,81	33,21	7,83	36,34	0,00	398,14	2,37	62,88	5,10	74,98	953,39	34,79	172,36	1514
Italy	16,07	38,5	5,7	6,41	587,22	140,27	0,00	11,96	607,78	18,62	79,29	2801,27	289,49	904,9	5087
Morocco	0,05	0,29	0,08	0,7	93,3	1,15	353,33	0,00	943,44	24,58	12,22	91,5	7,51	67,1	322
Spain	0,63	8,88	2,92	2,44	1011,8	39,06	2.179,05	76,60	0,00	48,96	69,92	3229,49	112,51	335,81	5239
Tunisia	0,04	0,16	0,12	0,24	24,65	0,74	734,20	78,28	300,42	0,00	15,27	29,36	14,05	25,59	153
Turkey	5,68	4,88	0,44	14,03	102,37	45,74	921,78	23,55	269,79	35,38	0,00	911,42	199,97	518,06	2039
Xeur	26,92	120,04	53,22	69,34	1847,02	380,65	6.729,49	368,31	5.776,60	450,96	1.480,95	0,00	1613,15	4129,16	12136
XMENA	0,45	1,72	12,11	44,26	143,58	21,89	599,67	31,06	275,16	57,54	237,03	473,23	0,00	1636,06	2603
RoW	238,67	289,7	239,02	7984,81	6723,2	1525,93	22.770,10	6.167,49	20.103,10	2.673,43	6.867,50	61351,96	29189,35	0,00	133233
Tot. Imp.	364	483	382	8144	10704	2433	14404	3087	11993	1444	3738	76576	33790	10526	

A4. Additional results from Chapter 3

Table A4.1 displays the baseline virtual water trade flows, for all pairs of countries/regions.

Table A4.1. Baseline virtual water trade flows (Mm^3).

	Albania	Croatia	Cyprus	Egypt	France	Greece	Italy	Morocco	Spain	Tunisia	Turkey	XMENA	XEur	RoW	Tot. Exp.
Albania	0.0	1.0	0.1	0.4	12.9	13.4	77.4	0.1	3.6	0.1	6.9	2.2	78.5	51.5	248.2
Croatia	7.4	0.0	2.8	3.2	18.5	4.4	103.9	0.7	7.5	0.2	3.9	9.3	341.1	188.1	691.0
Cyprus	0.1	1.1	0.0	1.1	5.9	11.0	15.7	0.0	2.8	0.0	11.0	19.9	120.8	27.6	217.1
Egypt	22.0	4.9	9.1	0.0	120.3	114.7	399.9	40.8	119.6	50.9	164.4	1545.9	1584.4	1711.8	5888.9
France	22.4	17.0	105.4	78.5	0.0	592.8	4847.4	719.9	4656.4	215.1	111.9	2600.1	21473.3	3800.5	39240.8
Greece	95.9	18.0	78.1	19.3	82.3	0.0	373.3	2.2	58.3	5.1	73.9	81.1	1997.9	398.8	3284.1
Italy	47.6	118.4	16.3	17.0	1684.3	409.3	0.0	13.2	721.5	20.5	86.6	764.9	8595.7	2402.4	14897.7
Morocco	1.0	5.8	1.6	13.9	1893.0	22.8	317.0	0.0	847.8	22.1	10.9	150.0	1846.1	1342.1	6474.1
Spain	3.6	65.5	19.5	15.1	7599.3	260.9	3158.4	104.6	0.0	58.8	78.3	633.9	24254.1	2199.5	38451.5
Tunisia	1.3	5.5	4.2	8.2	871.6	26.3	1380.1	149.4	569.1	0.0	27.0	403.3	975.8	837.3	5259.1
Turkey	28.2	26.3	2.3	79.8	555.9	242.0	957.8	22.2	260.0	36.9	0.0	1020.1	4835.3	2641.4	10708.2
XMENA	2.6	9.5	74.0	226.8	836.0	112.8	693.4	37.8	368.1	60.6	294.3	6694.8	2707.7	8846.3	20964.7
XEur	124.1	564.4	241.2	340.9	8945.6	1737.4	8234.2	411.3	6856.3	513.3	1516.3	7077.4	62861.7	19109.8	118533.7
RoW	607.0	681.9	574.4	20061.9	15608.5	3687.7	24074.3	6755.5	20876.7	2853.7	7301.3	71166.7	143929.1	763887.2	1082066.1
Tot. Imp.	963.2	1519.5	1129.1	20866.1	38234.1	7235.6	44632.6	8257.8	35347.9	3837.2	9686.5	92169.7	275601.7	807444.4	

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