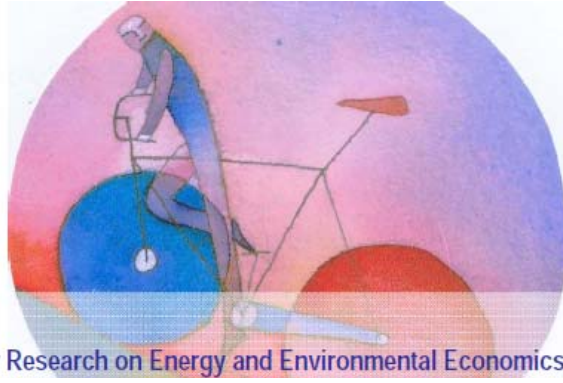


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Climate Change, Tourism and Water Resources in the Mediterranean: a General Equilibrium Analysis

Roberto Roson*
Martina Sartori§

Abstract

This paper presents and discusses some quantitative results obtained in assessing the economic impact of variations in tourism flows, induced by climate change, for some Mediterranean countries. Estimates by a regional climate model are used to build a Tourism Climate Index, which indicates the suitability of climate, in certain locations, for general outdoor activities. As climate change is expected to affect a number of variables like temperature, wind and precipitations, it will have consequences on the degree of attractiveness of touristic destinations. We estimate the macroeconomic consequences of changing tourism flows by means of a computable general equilibrium model. We found that more incoming tourists will increase income and welfare, but this phenomenon will also induce a change in the productive structure, with a decline in agriculture and manufacturing, partially compensated by an expansion of service industries. We found that, in most countries, the decline in agriculture entails a lower demand for water, counteracting the additional demand for water coming from tourists and bringing about a lower water consumption overall.

Keywords: Climate Change, Computable General Equilibrium, Tourism, Water, Tourism Climate Index.

JEL Codes: C68, Q26, Q54, R13.

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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 proposed¹ (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 weighted 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. 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

¹ 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.

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 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 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.²

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 Mensbrugge (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.

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 2 illustrates how recent estimates of monthly TCIs for a set of Mediterranean countries, which have been produced in the European research project

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

WASSERMed³, 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 simulation exercise are presented in Section 3. Implications for water demand are considered in Section 4, whereas Section 5 provides some concluding remarks.

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.⁴ Table 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.

COUNTRY	Nights (M)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	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

Table 1. Total nights and monthly distribution 2009 (source: EUROSTAT, 2010)

Kampragou et al. (2012) have processed the output⁵ 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 causes a relative increase in TCI values, which explain why (a) the highest value for the TCI index is found in Greece in July (August in the future), and (b) the global warming generally brings about an increase in the TCI.

3 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>.

4 Our choice has been dictated by data availability.

5 These data have been produced by the European research project ENSEMBLES.

Table 2. Estimates of TCI at present (1991-2010) and future (2036-2065) time

TCI PRESENT												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	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	Oct	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 Mediterranean⁶, considering the baseline data of Table 1 together with the estimated variations in the TCI reported in Table 2, it is possible to get an estimate of changes in tourists' nights per country and month, as illustrated in Table 3.

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 1⁷. 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).

Table 3. Estimated variation in future tourism flows (monthly and yearly average)

	AVG	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	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%

⁶ 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.

⁷ Therefore, changes in the seasonal distribution of tourism flows have not been considered.

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 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 3 to the surplus of the tourism balance in 2006 (2005 for Greece).

Table 4. Changes in net receipts (M€ 2006)

	Surplus 06	Increase
Greece (05)	8591	34.26
Spain	27445	164.23
France	12065	83.87
Italy	11969	54.24
Cyprus	1133	2.55
Slovenia	652	4.23
Croatia	5692	22.88
Malta	355	2.22

Results shown in Table 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.

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)⁸. 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), while simultaneously shifting, by the same

⁸ Extensive documentation on the GTAP model is available at <http://www.gtap.org>.

amounts, the demand for services produced in each of the eight Mediterranean countries. A counterfactual equilibrium is then computed by the model, in which all markets clear and all agents comply with their budget constraints (receipts equal expenditures).

Figure 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.

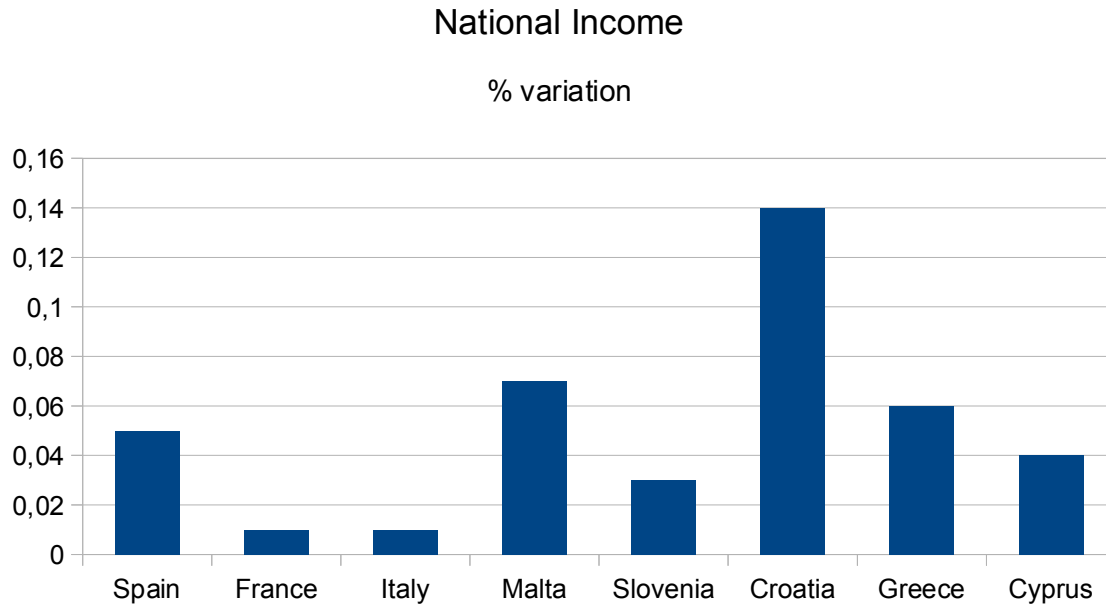


Figure 1

Higher income levels allow to expand consumption by households, thereby raising welfare. 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 2 shows the estimated EV for the countries at hand, measured in millions of U.S. Dollars (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.

Equivalent Variation

MUS\$(2004)

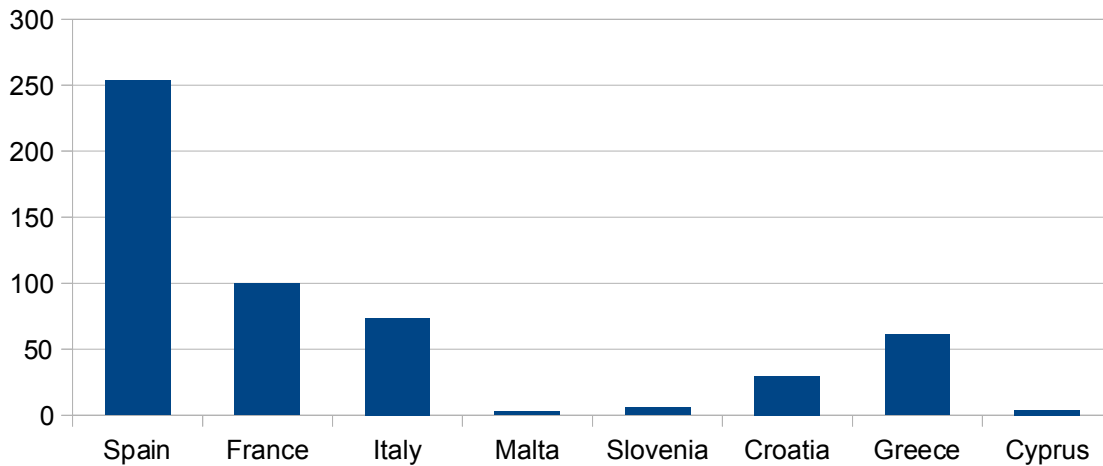


Figure 2

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 3 displays the estimated change in the production volume of three aggregate sectors (Agriculture, Manufacturing and Services) in the Mediterranean countries.

Sectoral Production Volumes

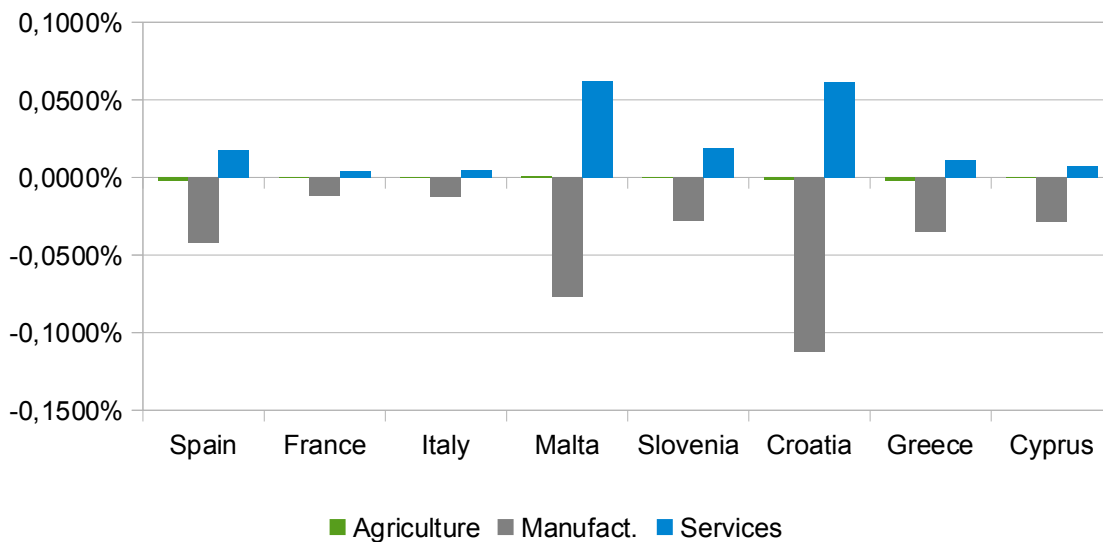


Figure 3

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”⁹, 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. 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 water¹⁰. Assuming this value for the whole Mediterranean, one can easily convert results like those in Table 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 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 5 and graphically displayed in Figure 4.

9 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.

10 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.

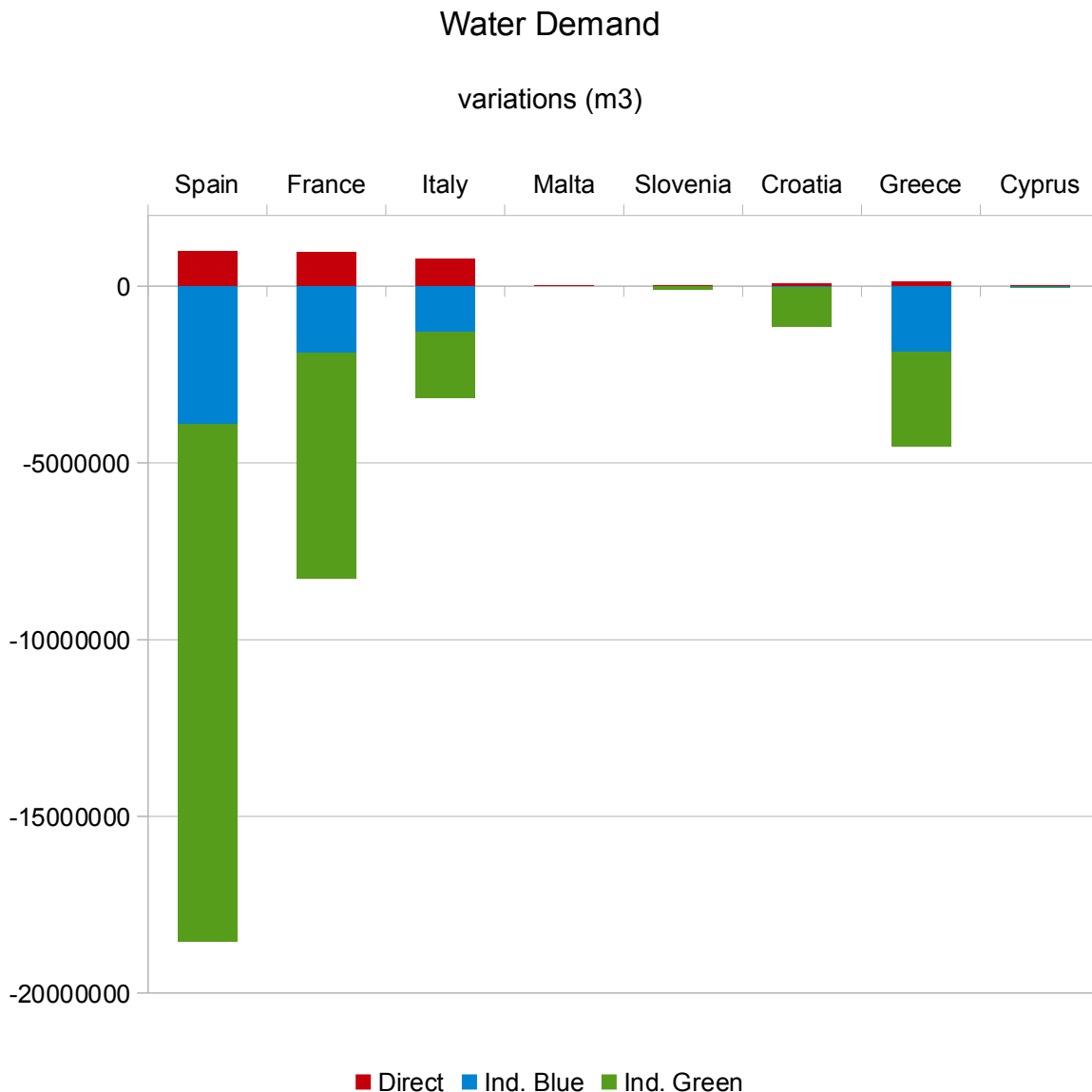
Table 5. Changes in water consumption (m³/year)

	Spain	France	Italy	Malta	Slovenia	Croatia	Greece	Cyprus
Ind. Green	-14649234	-6372604	-1857608	0	-100970	-1113174	-2683715	-14571
Ind. Blue	-3894100	-1903505	-1290880	0	-2061	-22718	-1864954	-35673
Direct	973189	951613	754171	19980	24398	70010	113524	13520
Global Balance	-17570145	-7324496	-2394317	19980	-78633	-1065881	-4435145	-36723
Blue Balance	-2920911	-951892	-536709	19980	22337	47292	-1751431	-22153

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.

Figure 4



4. 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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Appendix

A brief description of the GTAP model

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

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

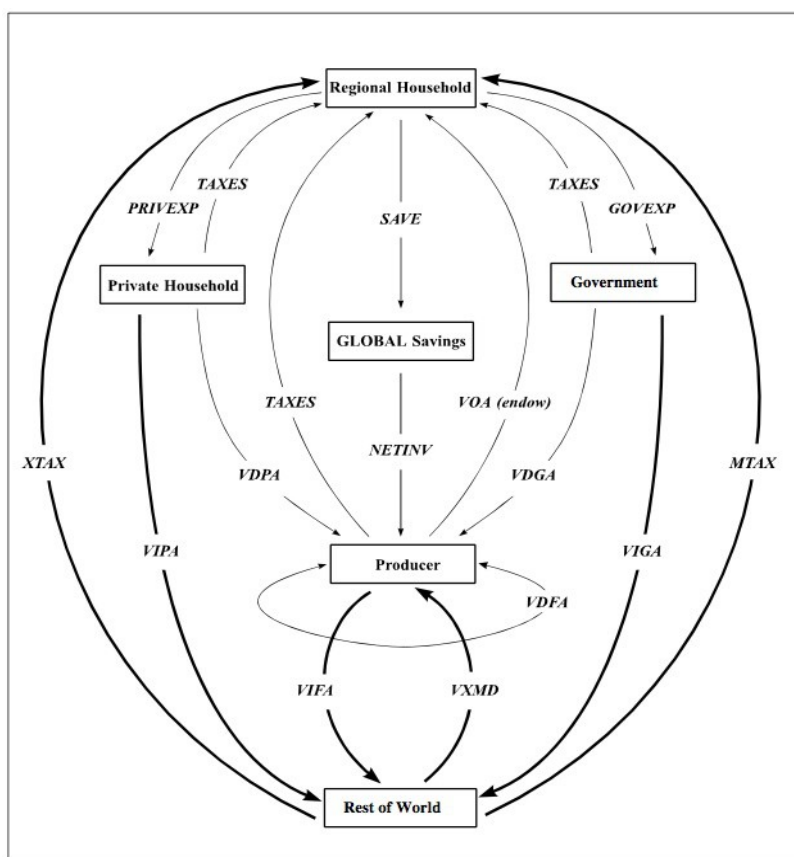


Figure A1 – Income flows in the GTAP Model

Equation and identities in the model include the following conditions:

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

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

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

Simulations entail changing some exogenous variables or parameters, bringing about the determination of a counterfactual equilibrium. The partition between endogenous and exogenous variables, as well as the regional and industrial disaggregation level, is not fixed but depends on the scope of the simulation exercise.