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A general equilibrium analysis of climate change impacts on tourism

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Abstract

This paper studies the economic implications of climate-change-induced variations in tourism demand, using a world CGE model. The model is first re-calibrated at some future years, obtaining hypothetical benchmark equilibria, which are subsequently perturbed by shocks, simulating the effects of climate change. We portray the impact of climate change on tourism by means of two sets of shocks, occurring simultaneously. The first set of shocks translate predicted variations in tourist flows into changes of consumption preferences for domestically produced goods. The second set reallocate income across world regions, simulating the effect of higher or lower tourists' expenditure. Our analysis highlights that variations in tourist flows will affect regional economies in a way that is directly related to the sign and magnitude of flow variations. At a global scale, climate change will ultimately lead to a welfare loss, unevenly spread across regions.

Keywords: Climate change; Computable general equilibrium models; Tourism

1. Introduction

Climate plays an obvious role in tourist destination choice. The majority of tourists spend their holidays lazing in the sun, a sun that should be pleasant but not too hot. The Mediterranean particularly profits from this, being close to the main holiday-makers of Europe's wealthy, but cool and rainy Northwest. Climate change would alter that, as tourists are particularly footloose. The currently popular holiday destinations may become too hot, and destinations that are currently too cool would see a surge in their popularity. This could have a major impact on some economies. About 10% of world GDP is now spent on recreation and tourism. Climate change will probably not affect the *amount* of money spent but rather *where* it is spent. Revenues from tourism are a major factor in some economies, however, and seeing only part of that money move elsewhere may be problematic. This paper studies the economic implications of climate-change-induced changes in tourism demand.

The literature on tourist destination choice used to be largely silent on climate (Crouch, 1995; Witt and Witt, 1995), perhaps because climate was deemed to be obvious or beyond control of managers and perhaps because climate was seen to be constant. Recently, however, an increasing number of studies have looked at

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the effects of climate change on the behaviour of tourists from a particular origin or on the attractiveness of a particular holiday destination. Few of these studies look at the simultaneous changes of supply and demand at many locations. In fact, few of these studies look at all at economic aspects, the main exception being Maddison (2001), Lise and Tol (2002) and Hamilton (2003) who estimate the changes in demand of British, Dutch and German tourists, respectively. Hamilton et al. (2004) do look at the supply and demand for all countries, but their model is restricted to tourist numbers.

This paper tries to fill this gap in the literature. We study climate-change-induced variations in the demand for and the supply of tourism services. We go beyond a partial equilibrium analysis of the tourism market, however, and also add the general equilibrium effects. In this manner, we get a comprehensive estimate of the redistribution of income as a result of the expected redistribution of tourists due to climate change.

The paper is structured as follows. Section 2 presents our estimates of changes in international tourist flows. Section 3 outlines the general equilibrium model used in this analysis. Section 4 illustrates how tourism is included in this model. Section 5 discusses the basic tourism data. Section 6 shows the results of our climate change supposition and Section 7 offers a conclusion. An Appendix A describes the general equilibrium model structure and its main assumptions.

2. Estimates of changes in international tourist flows

We take our estimates of changes in international tourist flows from Hamilton et al. (2004). Theirs is an econometrically estimated simulation model of bilateral flows of tourists between 207 countries; the econometrics is reported in Maddison (2001), Lise and Tol (2002) and Hamilton (2003). The model yields the number of international tourists generated by each country. This depends on population, income per capita and climate. Other factors may be important too, of course, but are supposed to be captured in a country-specific constant. The tourists from each country are then distributed over the remaining 206 destination countries. The attractiveness of a destination country depends on its per capita income, climate, a country-specific constant, and the distance from the origin country.

Although simple in its equations, the model results are not. This is because climate change has two effects. On the one hand, climate change makes destination countries more or less attractive. On the other hand, climate change also affects the number of people who prefer to take their holiday in their home country rather than travelling abroad. This in itself leads to surprising results. The UK, for instance, would see its tourist arrivals fall because, even though its climate improves, its would-be tourists rather stay in their home country where the climate also gets better. As another example, Zimbabwe would see its tourism industry grow because, even though its climate deteriorates, it is still the coolest country in a region where temperatures are rising.

Table 1
Changes in international and interregional departures, and international arrivals, in 2050 (number of tourists)

Region	International		Interregional	
	Arrivals	Departures	Arrivals	Departures
USA	−7537352	−21688924	0	0
EU	−43222063	−37619622	−48324941	−48324941
EEFSU	3116282	−43201505	−6079379	−6079379
JPN	−417310	−4293235	0	0
RoA1	16063980	−27747421	−68948	−68948
EEx	−31822804	11251183	−2553533	−2553533
CHIND	−484779	−2117862	97167	97167
RoW	−50746662	10366678	−5547398	−5547398

Table 1[1] shows the changes in international and interregional departures and international arrivals for 2050 for the eight regions used in this study, based the SRES A1 scenario for climate change, economic growth, and population growth.[2] The assumed global mean warming is 1.03 °C in 2050 (relative to 1997); in 2010, it is 0.09 °C and in 2030, 0.46 °C. Obviously, the regional aggregation hides many effects, such as the redistribution of the tourists from southern to middle Europe. Fig. 1 shows total international flows for all countries for the same year and scenario.

3. Assessing the general equilibrium effects: model structure and simulation strategy

To assess the systemic, general equilibrium effects of tourism impacts, induced by global warming, we made an unconventional use of a multi-country world computable general equilibrium (CGE) model: the GTAP model (Hertel, 1996), in the version modified by Burniaux and Truong (2002), and subsequently extended by ourselves.

[1]Here is the meaning of acronyms: USA [USA], European Union [EU], Eastern Europe and Former Soviet Union [EEFSU], Japan [JPN], Rest of Annex 1 (developed) countries [RoA1], Energy Exporters [EEx], China and India [CHIND], Rest of the World [RoW]. Annex 1 (part of the Kyoto protocol, on the reduction of greenhouse gases emissions) lists the signing nations—broadly coincident with OECD countries.

[2]The SRES scenarios (Nakicenovic and Swart, 2000) are standard scenarios in climate change (impacts) analysis. The A1 scenario assumes moderate population and emissions growth and fast economic growth.

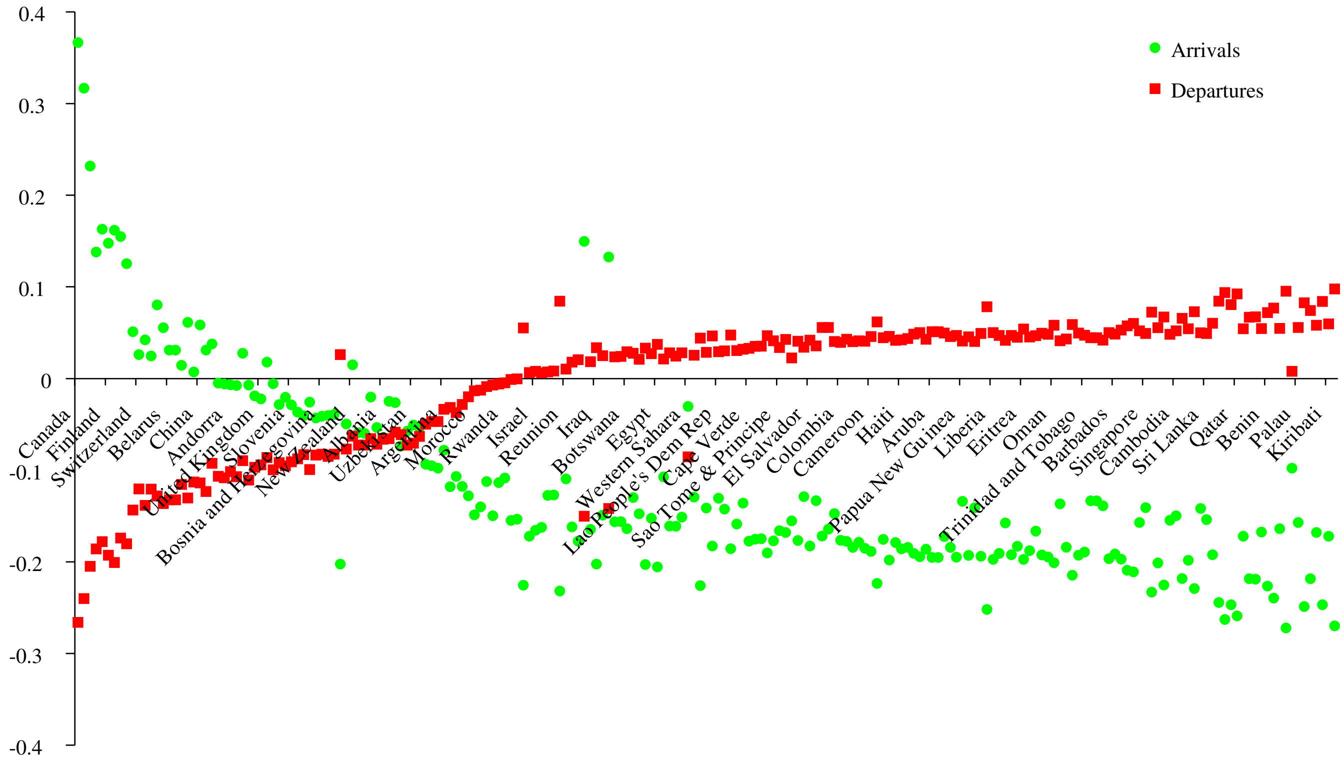

Fig. 1. The change in arrivals and departures due to climate change, as a percentage of arrivals and departures without climate change; countries are ranked according to their average annual temperature in 1961–1990.

A CGE model provides an internally consistent and detailed description of an economic system, highlighting trade linkages between industries, regions and markets. CGE models are primarily used to simulate and assess the structural adjustments, undertaken by economic systems as a consequence of shocks, like changes in technology, preferences or economic policy. We use a CGE model here to simulate the impact of exogenous changes in demand patterns and available income in different countries, induced by variations in tourism flows.

The mathematical structure of a CGE model can be very complex. The GTAP model is composed of hundreds of equations, defining market-clearing conditions, accounting identities, zero-profit conditions or behavioural relationships, in more than 5000 lines of computer code. The reader interested about the details of the GTAP model should refer to Hertel (1996), and to the technical material available on the GTAP site (www.gtap.org). A very concise description of the model, however, is provided in Appendix A of this paper.

Typically, parameters in a CGE model are selected such that the model replicates the observed structure of the economy, as described in a calibration data set for a recent, reference year. One problem of our application is given by the fact that we are interested in simulating changes occurring at some future dates, rather than at present time. Therefore, instead of relying on current calibration data, we base our exercise on a benchmark forecast of the world economic structure.

To this end, we derived hypothetical data-sets for selected future years (2010, 2030, 2050), using the methodology described in Dixon and Rimmer (2002). This entails inserting, in the model calibration data, forecasted values for some key economic variables, to identify a hypothetical general equilibrium state in the future.

Since we are working on the medium to long term, we focused primarily on the supply side: forecasted changes in the national endowments of labour, capital, land, natural resources, as well as variations in factor-specific and multi-factor productivity.

Most of these variables are ‘‘naturally exogenous’’ in CGE models. For example, the national labour force is usually taken as a given. In this case, we simply ‘shocked’ the exogenous variable ‘‘labour stock’’, changing its level from that of the initial calibration year (1997) to some future forecast year (e.g., 2030). In some other cases, we considered variables, which are normally endogenous in the model, by modifying the partition between exogenous and endogenous variables. In the model, simulated changes in primary resources and productivity induce variations in relative prices, and a structural adjustment for the entire world economic system. The model output describes the hypothetical structure of the world economy, which is implied by the selected assumptions of growth in primary factors.

We obtained estimates of the regional labour and capital stocks by running the G-Cubed model (McKibbin and Wilcoxen, 1998). This is a rather sophisticated dynamic CGE model of the world economy, which could have been used—in principle—to directly conduct our simulation experiments. We preferred to use this model as a data generator for GTAP, however, because the latter turned out to be much easier to adapt for our purposes, in terms of disaggregation scale and changes in the model equations.

We got estimates of land endowments and agricultural land productivity from the IMAGE model version 2.2 (IMAGE, 2001). IMAGE is an integrated assessment model (based on simultaneous modelling of natural and human, socio-economic systems), with a particular focus on the land use, reporting information about seven crop yields in 13 world regions, from 1970 to 2100. We ran this model by adopting the most conservative scenario about climate change (IPCC B1), implying minimal temperature variations.

A rather specific methodology was adopted to get estimates for the natural resources stock variables. As explained in Hertel and Tsigas (2002), values for these variables in the original GTAP data set were not obtained from official statistics, but were indirectly estimated, to make the model consistent with some industry supply elasticity values, taken from the literature. For this reason, we preferred to fix exogenously the price of the natural resources, making it variable over time in line with the GDP deflator, while allowing the model to endogenously compute the stock levels.

4. Impact modelling in the CGE framework

To model the tourism-related impact of climate change, we ran a set of simulation scenarios, by shocking specific variables in the model. More precisely, we portray the impact of climate change on tourism by means of changes in the structure of final consumption (the affected variable is the value of private domestic purchases, *VDP*) coupled with changes in international income transfers. The procedure we follow is conditioned by the fact that the GTAP database is centred on the concept of Gross Domestic Product. In other words, national income is defined as revenue produced within the borders of the national territory, independently of the citizenship of the persons involved. This should be kept in mind when considering the influence on the national income of an extra foreign tourist. Because of the GDP definition, the additional expenditure generated by tourism activities is not accounted for as exports, but as additional domestic consumption. Furthermore, foreign income spent inside the national territory amounts to a sort of income transfer.

Structural variations in domestic consumption are simulated on the basis of two hypotheses. First, it is assumed that aggregate tourism expenditure is proportional to the number of tourists, both domestic and foreign, visiting a country in a given year. This change is due to the variation in the arrivals of foreign tourists, and to the variation in the presence of domestic tourists. This second effect can be decomposed in two components: the variation in the "basis" of domestic tourists, and the variation in the departures of domestic tourists towards foreign destinations. Consequently, the structure of tourism expenditure is supposed not to differ, significantly, between an average foreign tourist and an average domestic tourist. Second, tourism expenditure is restricted to expenditure on hotels, restaurants, and recreational activities. Other consumption items, like transportation,[3] have not been taken into account, because of data limitations.

We consider estimated changes in arrivals, departures and domestic tourists, with and without climate change. In each year,[4] percentage variations in the total number of tourists, in country r, are computed as

$$\mu_r = \frac{\Delta A_r + \Delta RT_r - \Delta D_r}{|A_r^0 + RT_r^0|}, \tag{1}$$

where A_r are interregional[5] arrivals ($A_r{}^0$ in the baseline, i.e. without climate change), D_r are interregional departures ($D_r{}^0$ in the baseline), RT_r is the number of regional domestic tourists. We define $RT_r{}^0$, in the baseline, as $RT_r{}^0 = RA_r{}^0 + NT_r{}^0$, where $RA_r{}^0$ are intraregional arrivals and $NT_r{}^0$ is the basis of domestic tourists in the baseline. Also, we make the assumption that the basis of domestic tourists in each country, NT_r, is unaffected by climate change. This assumption is reasonable, at least for limited climate impacts, and it is unavoidable for our study because of the lack of estimates on the effect of climate change on domestic tourism.

Note that, in order to compute changes in tourist flows, we consider only interregional arrivals and

[3]Transportation is a special industry in most CGE models, including GTAP. International transport is treated in a way that makes impossible to trace the geographical origin of firms selling transport services. Domestic transport is a cost margin, working like indirect taxation. Most transport activities, involving some amount of self-production, are hidden under consumption of energy, reparation services, vehicles, etc. Transportation industries only account for services sold under formal market transactions.

[4]In Eq. (1), the time index is omitted. Note however that three such expressions are computed, one for each simulation year.

[5]These are international tourists. However, since a region typically comprises more than one nation, tourists moving from one country to another within the same region are accounted for as domestic tourists.

departures, disregarding arrivals and departures from and to countries within the same macro-region. This avoids an overestimation of regional income transfers, but results in an underestimation of climate impacts on tourism demand, since intra-regional impacts cannot show up in our results[6] (by construction, intra-regional arrivals must equal intra-regional departures). Combined with our assumption of no climate effects on the basis of domestic tourists in each country, this implies that $\Delta RT = 0$.

In our model, both recreational services and hotels-restaurants are sub-industries of the macro industry "Market Services". To derive the share of the sub-industry "recreational industry" in the aggregate, we computed

$$\lambda_{Rcr,r} = \frac{VDP_{Rcr,r}}{VDP_{MS,r}}, \tag{2}$$

where VDP stands for "value of domestic purchases" for recreational services (Rcr) and total Market Services (MS) in the base year. The term on the denominator was obtained from the GTAP 5 database at its maximum level of disaggregation.

Analogously, for hotels and restaurants (HT), we computed:

$$\lambda_{HT,r} = \frac{VDP_{HT,r}}{VDP_{MS,r}}. \tag{3}$$

However, because hotels and restaurants are merged with "Trade" in the GTAP 5 database, we reverted to an alternative information source for expenditure on hotels and restaurants in the base year (Euromonitor, 2002). Both Euromonitor and GTAP data on expenditures are based on official statistics whose accounting principles are homogeneous. In particular, the definition of private domestic expenditures and the criteria followed in order to aggregate sub-industries into macro industries are the same for the two sources. Only the *level of disaggregation* is different. Therefore, the two sources are compatible.

The exogenous change in the demand for Market Services, induced by the variation (positive or negative) in tourist flows, has therefore been computed in terms of shares of the base year expenditure:

$$\alpha_{MS,r} = \mu_r(\lambda_{Rcr,r} + \lambda_{HT,r}). \tag{4}$$

Yet, consumption levels, including those of Market Services, are endogenous variables in the model. Consequently, we can interpret our input data, expressing the additional tourism expenditure, as coming from a partial equilibrium analysis. In a partial equilibrium perspective, all the economic variables external to the sector under scrutiny are taken as given. In particular, one such analysis would disregard the simultaneous price changes occurring in all other markets. In practice, we impose a shift in some parameter values, which could produce the required variation in expenditure *if all prices and income levels would stay constant*.[7] In this case, the partial equilibrium flavour of this procedure comes from the assumption that the variation in tourists' flows due to climate change translates into a variation in the expenditure for the output of a *specific* sector (namely, Market Services).

However, when these partial equilibrium shocks are fed into a general equilibrium framework such as GTAP, the model allows the world economy to adapt to the shocks. Ex post, because of general equilibrium effects, the expenditure variation observed in the model output turns out to be slightly different from the initial variation. In other words, the world economy reacts to these shifts in Market Services demand by means of adjustments in price and income levels, which allow the system to attain a new general equilibrium.

In order to compute the extra income needed to finance the expenditure of foreign tourists, we consider the variation, with and without climate change, of the net tourism inflow (arrivals–departures) in each country. To be consistent with general equilibrium conditions, the algebraic sum of all income transfers introduced in the model equations must be zero. However, the sum over countries of all net tourism inflows is not, in general, zero, because our data on tourist flows allow for a tourist to travel to more than one destination per year. Some re-scaling is therefore necessary. The net additional expenditure generated by foreign tourists is estimated as

$$\Delta\tilde{E}_r = \Delta E_r - \sum_r \Delta E_r \frac{|\Delta E_r|}{\sum_r |\Delta E_r|}, \tag{5}$$

where $\Delta E_r = VDP_{MS,r}\alpha_{MS,r}$.

In the simulations, this element is inserted into the equation computing the national income as the total value of all domestic primary resources. This ensures that the redistribution of income is globally neutral and that income shocks have the same sign as demand shocks.

[6]We would expect intra-regional impacts to be particularly strong in Europe, given the tourist flows projections in Hamilton et al. (2004). Given the potential importance of intra-regional tourism we prefer to include ΔRT_r in (1), although in the present formulation we assume it to be zero. Finer disaggregations, which would solve this problem, are left for future research.

[7]To be more specific, in order to apply a given demand shock, baseline private aggregate expenditures in Market Services are modified using $\alpha_{MS,r}$ in Eq. (4). In order to comply with budget constraints and the Walras' law, expenditure shares in other sectors are rebalanced, by means of counteracting reductions for consumption items not related to tourism. This does not affect the partial equilibrium interpretation of the shocks on expenditures for Market Services.

5. Baseline estimates for domestic tourism volumes

In order to compute the estimated variation in the total number of tourists, some data on the number of domestic tourists in the baseline (NT_r^0) is necessary. This parameter is included in RT_r^0, in the denominator of Eq. (1).

For most countries, the volume of domestic tourist flows is derived using 1997 data of the Euromonitor (2002) database. For some other countries, we rely upon alternative sources, such as national statistical offices, other governmental institutions or trade associations. For very small states, we assume that the number of domestic tourists is zero. This holds for Andorra, Malta, Monaco and San Marino, while data were available for Hong Kong, Macau, Singapore and Liechtenstein. For those countries in which data on domestic tourism is not available, we use a weighted mean of figures for other countries in the same region.

We update these values to 2010, 2030 and 2050, relying on Eq. (2) in Hamilton et al. (2004), reproduced here:

$$\ln \frac{D_i}{pop_i} = 1.51 - 0.18T_i + 4.83 \times 10^{-3}T_i^2 - 5.56 \times 10^{-2}Border + 0.86 \ln Y_i - 0.23 \ln Area_i, \quad (6)$$

where D_i, pop_i, Y_i and T_i denote, respectively, tourists' departures, population, per capita income and temperature in country *i*. *Border* and *Area* express, respectively, the number of land borders and the land area (in square kilometres) of the destination. In order to apply this framework to domestic tourism, we assume, in particular, that income influences the decision of being a tourist at home exactly in the same way as the decision of being a tourist abroad. Moreover, we assume that the rest of the explanatory variables in Eq. (6) do not change with time or are not relevant for the basis of domestic tourists. Also, we do not impose any upper limit to the number of holidays taken per year.[8] Then, Eq. (6) boils down to

$$\ln \frac{Dt_i}{pop_i} = 1.51 + 0.86 \ln Y_i, \quad (7)$$

where Dt_i are domestic tourists in country *i*. The updated values of domestic tourists in country *i* in year *t* can be estimated from baseline data through

$$Dt_i^t = \left[1 + 0.86\,\frac{Y_i^t - Y_i^0}{Y_i^0}\right] \frac{pop_i^t}{pop_i^0}\, Dt_i^0. \quad (8)$$

Table 2 collect the main model assumptions.

[8]The latter assumption is necessary because income growth in the long run can translate into a very high tourist activity. Imposing restrictions would be fairly arbitrary, however, and fortunately our combination of income projections and income elasticity does not lead to unrealistic results for 2050.

Aggregated regional values for 2010, 2030 and 2050, are shown in Table 3 below. To these values one must then add intra-regional tourist arrivals in the baseline simulations for each year (RA_r^0) (derived from the tourist arrivals Eq. (1) in Hamilton et al. (2004)) to get the total number of people performing their tourist activities within their macro-region of origin in the baselines, RT_r^0.

In 1997, domestic tourists were lower than regional population, with the exception of the USA, "Rest of Annex 1" (other developed, RoA1) countries and the EU. Updating the 1997 data with Eq. (8), the relative ranking of domestic tourism activity remains unchanged. However, in 2050, there is enough income to allow for at least 1.26 domestic tourist experiences for everybody in the world. In some regions, due to the assumed lack of an upper limit to tourism expenditure, domestic tourist activity becomes very intensive (up to 8.41 experiences per year, for US residents).

6. Simulation results

In our simulations, economic impacts get more substantial with time, because of rising temperature levels. Time also plays a role in the distribution of costs and benefits, bringing about a few important qualitative changes. For economy of space, we shall focus our discussion on results for the year 2050. Results for 2010 and 2030 are reported only when qualitatively different from those of 2050.

6.1. Shocked variables

Table 4 shows the climate change impacts on private domestic demand and household income, in terms of variation from the baseline. Notice that, for the European Union, shocks are positive in 2010 and 2030, but they become negative in 2050.

At the global (world) level, these shocks are neither positive nor negative, as they entail a redistribution of income both within a region (changes in consumption patterns) and across regions (income transfers). Therefore, aggregate results are solely due to structural composition effects.

Shifts in demand and income are different before and after the simulation, because the imposed swing is based on the partial equilibrium assumption of unchanged prices and income.[9] The difference between shocks and equilibrium level is larger in relative terms for demand shocks than for income shocks.

[9]See the discussion of Eq. (4) in Section 4.

Table 2
Main assumptions applied in modelling the impacts of climate change on the tourism industry

Variable/parameter	Description	Assumption
μ_r	Impact of climate change on aggregate tourism expenditure	Proportional to the climate-change-induced variation in the number of tourists visiting a country in a given year
μ_r		The structure of tourism expenditure is the same for an average foreign tourist and an average domestic tourist
μ_r		Tourism expenditure is restricted to expenditure for market services and in particular, for hotels, restaurants, and recreational activities
$\alpha_{MS,r}$	Exogenous change in the demand for market services (due to the variation in tourist flows)	Proportional to the shares of recreation and hotels & restaurants in the base year expenditure for market services: $\alpha_{MS,r} = \mu_r(\lambda_{Rcr,r} + \lambda_{HT,r})$
ΔA_r	Change in arrivals	Only interregional
ΔD_r	Change in departures	Only interregional
NT_r	Basis of domestic tourists	Unaffected by climate change. Coupled of the assumption of no intra-regional flows, it implies $\Delta NT_r = 0$
ΔE_r	Income transfers	Computed as the change in base year expenditure for market services due to the change in the net tourism inflow) in each country: $\Delta E_r = VDP_{MS,r}\alpha_{MS,r}$
$\Delta \tilde{E}_r$	Income transfers	Income transfers are rescaled in order to have zero sum at world level
Dt_i	Domestic tourists	Future values updated using Eq. (6) (Hamilton, Maddison, & Tol, 2004) assuming that income is the only relevant explanatory variable
Dt_i		0 for Andorra, Malta, Monaco and San Marino

Table 3
Domestic tourism in the base year and projections for simulation years, in terms of ratio of tourists to population (left) and total number of tourists (thousands, right)

Region	Tourist activity				Final tourist volumes (thousands)		
	1997	2010	2030	2050	2010	2030	2050
USA	3.68	4.42	6.14	8.41	1335882	2057638	2981454
EU	1.41	1.87	2.90	4.22	706615	1076790	1521253
EEFSU	0.64	0.97	1.65	2.54	393339	661034	1018919
JPN	0.62	0.75	1.23	2.02	94211	146391	224582
RoA1	2.71	3.32	4.79	6.93	235569	358444	522031
EEx	0.74	0.94	1.19	1.56	834140	1338591	2044761
CHIND	0.44	0.56	0.84	1.26	1405922	2378905	3769251
RoW	0.85	1.08	1.43	1.92	2259955	3765227	5793315

Table 4
Initial shocks on private domestic demand and private household income

Region	Private domestic demand for Market Services (% change)			Private households' real income (1997 Millions US$)		
	2010	2030	2050	2010	2030	2050
USA	0.0004	0.047	0.110	10.833	2373.6	9279.3
EU	0.0005	0.008	−0.080	13.050	373.26	−9424.3
EEFSU	0.0027	0.310	0.712	7.652	1803.9	7419.0
JPN	0.0014	0.162	0.361	18.759	4013.0	15987.2
RoA1	0.0051	0.631	1.517	24.342	5312.9	21516.3
Eex	−0.0022	−0.243	−0.530	−34.377	−6348.9	−20576.5
CHIND	0.00002	0.003	0.008	0.033	9.221	39.660
RoW	−0.0025	−0.265	−0.568	−40.292	−7536.9	−24240.7

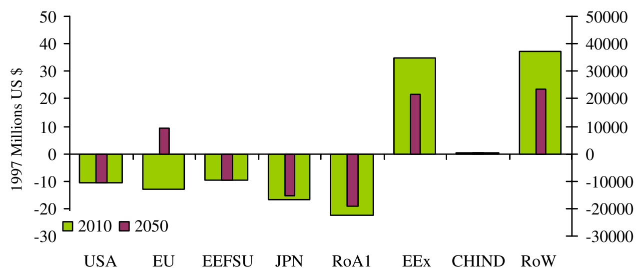

Fig. 2. Net exports in 2010 (wide, light bars; left axis) and in 2050 (narrow, dark bars; right axis).

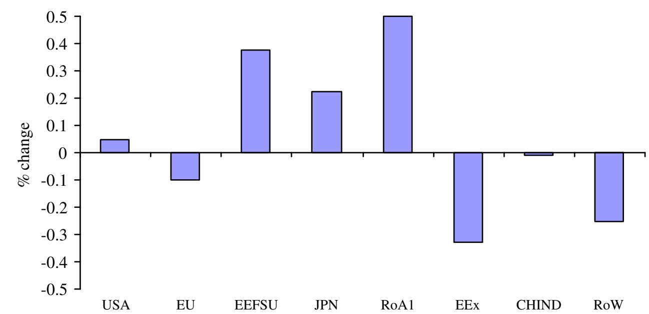

Fig. 3. GDP percentage changes with respect to the baseline in 2050.

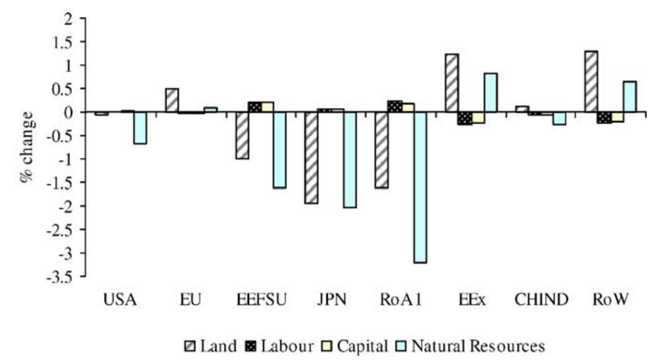

Fig. 4. Real primary factors' prices. Change with respect to the baseline, 2050.

6.2. Trade

Fig. 2 shows the effects in terms of regional trade balances. Any increase (decrease) in tourism expenditure is generally associated with increased (decreased) net imports.

This is due to a series of overlapping effects. First, higher income levels induce higher imports. In the model, general equilibrium conditions require the equality of the balance of payments, but the trade balance may be in deficit, if this is compensated by capital inflows. International investment is driven by expectations on future returns, which are linked to current returns (see Appendix A). Higher domestic demand creates an upward pressure on the price of primary resources, and higher returns on capital attract foreign investment. Because of accounting identities, financial imbalances mirror trade balance surpluses or deficits.

On the other hand, if the share of expenditure on services rises within the demand structure, the aggregate propensity to import decreases, because the share of imports in the services is generally lower than in the rest of the economy. This effect is, however, dominated by the first one. There is only one exception: China and India [CHIND] in the year 2010.

6.3. Gross domestic product

In general variations in the GDP (Fig. 3) follow the shocks' pattern. However, in terms of magnitude, the relative ranking of our initial shocks does not always coincide with the relative ranking of GDP changes. This is a consequence of setting our analysis in a general equilibrium framework, where trade and substitution effects can dampen or amplify the impact of initial shocks.

6.4. Primary factors and industrial output

Demand for primary factors is linked to final demand. As services use neither land nor natural resources, but rely on capital and labour in very similar shares, relative demand for these factors grows in those regions experiencing positive shocks, and vice versa.

Supply of primary factors is fixed in the short run. When demand for services increases, prices of labour and capital also increase (Fig. 4).[10] On the other hand, the price of other primary resources falls, despite the fact that positive shocks are associated with more expenditure generated by foreign tourists. As it has already been pointed out, the increased return on capital also triggers the multiplicative effect on foreign investment.

Table 5 shows variations in industrial production levels for 2050. Comparing it with Fig. 4, it can be noticed that decreases (increases) in land prices are generally associated with decreases (increases) in production levels for some agricultural industries. Also, decreases (increases) in prices of natural resources are associated with decreases (increases) in the output of energy production industries, such as coal and oil.

6.5. CO_2 emissions

Fig. 5 displays the impact on the yearly amount of CO_2 emissions. In our simulations, variations in CO_2 emissions are quite small. However, recall that we

[10]Again, factor price changes are analogous but smaller in most regions in 2010 and 2030. The main exception is the EU in 2010 and in 2030, where changes have signs opposite to those observed and 2050 (as a direct consequence of the change of shocks' signs).

Table 5
Percentage changes in industrial output with respect to the baseline in 2050

Sector	USA	EU	EEFSU	JPN	RoA1	EEx	CHIND	RoW
Rice	−0.007	0.102	−0.487	−0.439	−0.759	0.355	0.014	0.299
Wheat	−0.078	−0.021	−0.149	0.298	0.300	0.146	−0.021	0.122
Cereals	0.035	0.074	0.031	0.168	0.149	−0.011	0.042	−0.080
Vegetables & fruits	0.065	0.088	0.027	−0.045	0.057	0.100	0.016	0.100
Animals	−0.090	0.040	−0.165	−0.287	−0.460	0.139	−0.013	0.151
Forestry	−0.211	0.024	−0.396	−0.375	−0.751	0.217	−0.020	0.169
Fishing	−0.177	0.049	−0.490	−0.396	−0.721	0.312	−0.040	0.325
Coal	−0.084	0.061	−0.333	−0.443	−0.868	0.280	−0.004	0.202
Oil	−0.096	−0.040	−0.406	−0.488	−0.501	0.148	−0.041	0.089
Gas	−0.095	0.168	−0.604	−1.034	−0.951	0.480	−0.125	0.341
Oil products	0.042	0.120	−0.268	−0.314	−0.808	0.098	0.018	0.113
Electricity	−0.099	0.125	−0.465	−0.498	−1.940	0.208	−0.025	0.314
Water	−0.058	0.074	−0.217	−0.399	−0.372	0.178	0.010	0.194
Energy intensive industries	−0.143	0.154	−0.720	−0.470	−1.610	0.423	−0.017	0.406
Other industries	−0.089	0.099	−0.535	−0.476	−1.445	0.407	0.012	0.324
Market services	0.062	−0.038	0.376	0.204	0.764	−0.288	−0.013	−0.223
Non-market services	−0.081	−0.011	−0.091	−0.180	−0.619	−0.015	0.028	−0.034

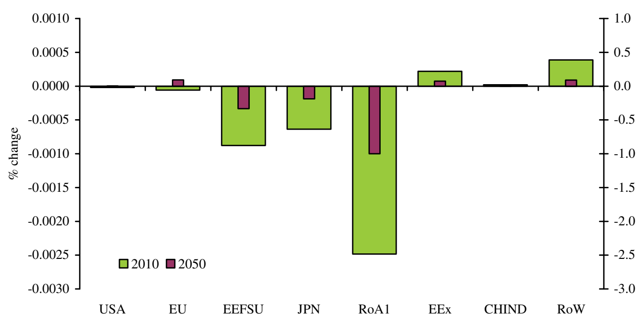

Fig. 5. CO_2 emissions. Changes with respect to the baselines in 2010 (wide, light bars; left axis) and in 2050 (narrow, dark bars; right axis).

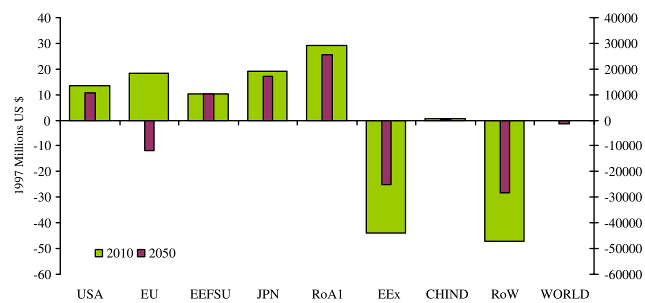

Fig. 6. Equivalent variation in 2010 (wide, light bars; left axis) and in 2050 (narrow, dark bars; right axis). Equivalent variation measures the amount of income variation, at constant prices (1997 US$), which would have been equivalent to the simulation outcome, in terms of utility of the representative consumer.

excluded transportation industries from the set of tourism activities.

Interestingly, emissions generally move in the opposite direction of GDP and demand shocks. This means that the industry mix drives the effect: when more tourists arrive, consumption patterns change towards relatively cleaner industries.

6.6. Welfare

Fig. 6 illustrates the effects on income equivalent variations (a welfare index). Total (world) welfare constantly decreases during the three periods.[11] At the regional level, welfare impacts have the same sign as income and demand shocks.

The main winners are the countries whose climate is currently too cold to attract many tourists, such as the former Soviet Union's countries and Canada (which is inside the Rest of Annex 1 group). Also, USA and Japan gain substantially. The EU enjoys a tiny welfare gain in 2010 and 2030, but suffers substantial losses in 2050. Welfare losses are mainly borne by the Rest of the World macro-region, which gathers the poorest countries and, incidentally, those that are also more exposed to other negative climate change effects (relevant for the tourism industry), such as sea-level rise (Bosello, Lazzarin, Roson, & Tol, 2004).

Following Hanslow (2000), and Huff and Hertel (2000), we decompose the welfare changes in a series of components. As Fig. 7 shows, most of the change in welfare is due to income variations, with the exception of China and India [CHIND], where allocative and trade effects prevail. This suggests that, for most regions, the main structural effect is due to the additional spending generated by foreign tourists.

[11] In this setting, climate conditions do not have any direct impact on utility. As stated previously, the shocks are neutral in the aggregate, as they only imply a redistribution of resources. Yet, Fig. 6 highlights that this redistribution generates small welfare losses.

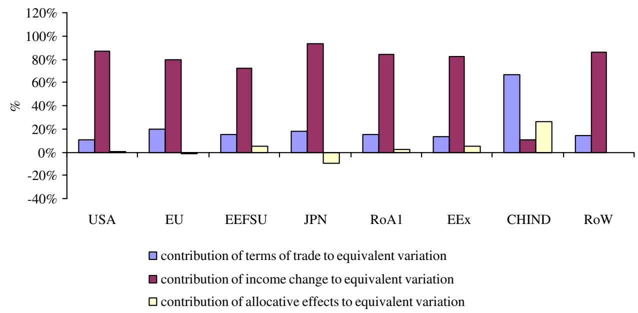

Fig. 7. Welfare decomposition of equivalent variation (2050).

7. Conclusion

Climate change will affect many aspects of our lives, and holiday habits are among the ones most sensitive to variations in climate. This implies that a very important service sector, the tourism industry, will be directly affected, and this may have important economic consequences.

This paper is a first attempt at evaluating these impacts within a general equilibrium framework, and establishes two things. Firstly, we show that tourism has impacts throughout the economy. This implies that economic studies, focusing on the tourism industry only, miss important effects. Secondly, we estimate the economy-wide impacts of changes in international tourism induced by climate change. Impacts on domestic demand and household income spread to the rest of the economy through substitution with other goods and services, and through induced effects on primary factors demand and prices. Also, changes in the rate of return of capital influence investment flows, which affects income and welfare.

Despite the crude resolution of our analysis, which hides many climate-change-induced shifts in tourist destination choices, we find that climate change may affect GDP by −0.3% to +0.5% in 2050. Economic impact estimates of climate change are generally in the order of −1% to +2% of GDP for a warming associated with a doubling of the atmospheric concentration of carbon dioxide (Tol, 2002), which is typically put at a later date than 2050. As these studies exclude tourism, this implies that regional economic impacts may have been underestimated by more than 20%. The global economic impact of a climate-change-induced change in tourism is quite small, and approximately zero in 2010. In 2050, climate change will ultimately lead to a non-negligible global loss.

Net losers are Western Europe, energy exporting countries, and the rest of the world. The Mediterranean, currently the world's prime tourism destination, would become substantially less attractive to tourists. The "Rest of the World" region contains the Caribbean, the second most popular destination, which would also become too hot to be pleasant. The "Rest of the World" also comprises tropical countries, which are not so popular today and would become even less popular under global warming. Energy exporting countries lose out because energy demand falls. China and India are hardly affected. North America, Australasia, Japan, Eastern Europe and the former Soviet Union are positively affected by climate change.

This study has a number of limitations, each of which implies substantial research beyond the current paper. We already mentioned the coarse spatial disaggregation of the CGE model. In particular, finer disaggregation could highlight that climate impacts in Europe will be very different between northern countries and southern countries.

We only consider the direct effects of climate change on tourism. We ignore the effects of sea level rise, which may erode beaches or at least require substantial beach nourishment, and which may submerge entire islands, particularly popular atolls (Bosello et al., 2004). In the aggregate, we likely underestimated the costs of climate change on tourism. Disaggregate effects may be more subtle. Remaining atolls may be able to extract a scarcity rent, perhaps even witness a temporary surge in popularity under the cynical slogan "come visit before it is too late". We also overlooked other indirect effects of climate change, such as those on the water cycle, perhaps misrepresenting ski-tourism, and those on the spread of diseases (Bosello, Lazzarin, Roson, & Tol, 2005), perhaps further deterring tourists. On the economic side, the structure of the CGE does not allow us to estimate the effects of tourism travel, but only the effects of tourism expenditure in the destination country. Finally, our exercise is based on a rather ad hoc scenario, in which all climate change effects occur suddenly and unexpectedly in a given reference year. In reality, climate change and its impacts are phenomena, which evolve over time, and so do the expectations and the adaptive behaviour of economic agents. All these issues are deferred to future research.

Such research is worthwhile. We show that there is a substantial bias in previous studies of the economic impacts of climate change, and therewith a bias in the recommendations of cost–benefit analyses on greenhouse gas emission reduction. We also show that the economic ramifications of climate-change-induced tourism shifts are substantial.

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Appendix A. A concise description of GTAP-EF model structure

The GTAP model is a standard CGE static model, distributed with the GTAP database of the world economy (www.gtap.org).

The model structure is fully described in Hertel (1996), where the interested reader can also find several simulation examples. Over the years, the model structure has slightly changed, often because of finer industrial disaggregation levels achieved in subsequent versions of the database.

Burniaux and Truong (2002) developed a special variant of the model, called GTAP-E, best suited for the analysis of energy markets and environmental policies. Basically, the main changes in the basic structure are:

- energy factors are taken out from the set of intermediate inputs, allowing for more substitution possibilities, and are inserted in a nested level of substitution with capital;
- database and model are extended to account for CO_2 emissions, related to energy consumption.

The model described in this paper (GTAP-EF) is a further refinement of GTAP-E, in which more industries are considered. In addition, some model equations have been changed in specific simulation experiments. This appendix provides a concise description of the model structure.

As in all CGE models, GTAP-EF makes use of the Walrasian perfect competition paradigm to simulate adjustment processes, although the inclusion of some elements of imperfect competition is also possible.

Industries are modelled through a representative firm, minimizing costs while taking prices are given. In turn, output prices are given by average production costs. The production functions are specified via a series of nested CES functions, with nesting as displayed in the tree diagram of Figure A1.

Notice that domestic and foreign inputs are not perfect substitutes, according to the so-called ''Armington assumption'', which accounts for product heterogeneity.

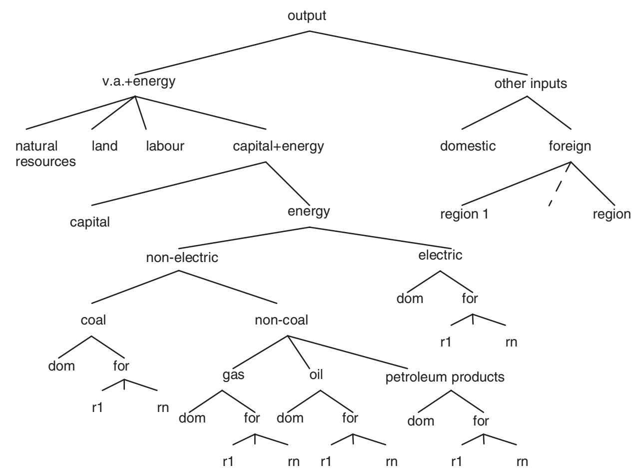

Fig. A1. Nested tree structure for industrial production processes.

In general, inputs grouped together are more easily substitutable among themselves than with other elements outside the nest. For example, imports can more easily be substituted in terms of foreign production source, rather than between domestic production and one specific foreign country of origin. Analogously, composite energy inputs are more substitutable with capital than with other factors.

A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, land, labour, capital). Capital and labour are perfectly mobile domestically but immobile internationally. Land and natural resources, on the other hand, are industry-specific.

This income is used to finance the expenditure of three classes of expenditure: aggregate household consumption, public consumption and savings (Fig. A2). The expenditure shares are generally fixed, which amounts to say that the top-level utility function has a Cobb–Douglas specification. Also notice that savings generate utility, and this can be interpreted as a reduced form of intertemporal utility.

Public consumption is split in a series of alternative consumption items, again according to a Cobb–Douglas specification. However, almost all expenditure is actually concentrated in one specific industry: Non-market Services.

Private consumption is analogously split in a series of alternative composite Armington aggregates. However, the functional specification used at this level is the Constant Difference in Elasticities form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods.

In the GTAP model and its variants, two industries are treated in a special way and are not related to any country.

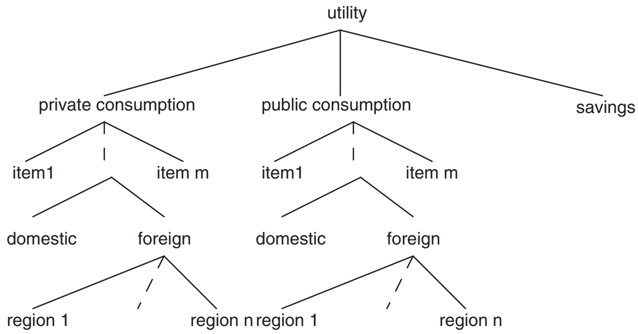

Fig. A2. Nested tree structure for final demand.

International transport is a world industry, which produces the transportation services associated with the movement of goods between origin and destination regions, thereby determining the cost margin between f.o.b. and c.i.f. prices. Transport services are produced by means of factors submitted by all countries, in variable proportions.

In a similar way, a hypothetical world bank collects savings from all regions and allocates investments so as to achieve equality of expected future rates of return. Expected returns are linked to current returns and are defined through the following equation:

$$r_s^e = r_s^c \left(\frac{ke_s}{kb_s} \right)^{-\rho},$$

where r is the rate of return in region s (superscript e stands for expected, c for current), kb is the capital stock level at the beginning of the year, ke is the capital stock at the end of the year, after depreciation and new investment have taken place. ρ is an elasticity parameter, possibly varying by region.

Future returns are determined, through a kind of adaptive expectations, from current returns, where it is also recognized that higher future stocks will lower future returns. The value assigned to the parameter ρ determines the actual degree of capital mobility in international markets.

Since the world bank sets investments so as to equalize expected returns, an international investment portfolio is created, where regional shares are sensitive to relative current returns on capital.

In this way, savings and investments are equalized at the international but not at the regional level. Because of accounting identities, any financial imbalance mirrors a trade deficit or surplus in each region.

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