A GENERAL EQUILIBRIUM ANALYSIS OF CLIMATE CHANGE IMPACTS: METHODOLOGY AND EARLY RESULTS

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Abstract

A world CGE model is used to assess the economic implications of a number of phenomena associated with the climate change. The model is first re-calibrated at some future years, obtaining hypothetical benchmark equilibria, under specific assumptions of growth of primary factors and productivity in different regions of the world. The benchmark equilibria are subsequently perturbed by shocks, simulating the effects of climate change phenomena. The shocks are interpreted as exogenous shifts in productivity, changes in endowments, international income transfers or variations in demand structure, technology and preferences. Three applications are presented, with the aim of illustrating the overall methodology of the model and some early results. Effects due to sea-level rise are simulated through losses in the endowments of land or, in an alternative scenario, through additional expenditure in coastal protection. Effects of climate change on human health are simulated by means of variation in labour productivity, and expenditure on health services. Effects on tourism are modelled as income transfers and changes in consumption patterns.

Keywords: *Impacts of climate change, computable general equilibrium, climate change.*

JEL Classification: C68, D58, Q25

1. Introduction

Climate change is a complex phenomenon, which is affecting and will affect the humankind in so many different ways.

So far, most scientific analyses of the climate change have focused on the implications of given scenarios of economic growth on the evolution of climate and weather. Much less attention has been paid to the implications of climate change on the economy.

When these feedback effects have been taken into account, like in the class of Integrated Assessment Models, this has been done in a crude and unrealistic way. For example, most models consider a limited number of industries (sometimes only one good, available for both consumption and investment), and have a poor or absent description of international trade and capital flows (Manne et al. (1995), Nordhaus and Yang (1996)). Furthermore, the multi-dimensional nature of the impacts on the economic systems is disregarded: this is usually accommodated by specific ad-hoc relationships, making a certain fraction of potential income "melting away" as temperature increases.

On the other hand, CGE models have been extensively used for the assessment of environmental economic policies. Whereas CGE models provide a more accurate, realistic and consistent picture of the economic systems, their range of applicability is limited by two elements. First, most CGE analyses are conducted within a short-medium term horizon, whereas the climate change is a long-term phenomenon. Second, the environmental dimension is not really present in the models, as it is often a matter of interpretation. For example, if carbon emissions are associated with energy consumption, carbon taxes are equivalent to some type of energy consumption taxes.

Very few attempts have been made at using CGE models on a longer time horizon, to evaluate the various economic shocks induced by the climate change[1]. This paper describes the methodology and some early results obtained by the modelling team of the EEE Programme at the Abdus Salam ICTP in Trieste, working in collaboration with the Fondazione Eni Enrico Mattei and the University of Hamburg.

Our approach is based on a two-stage procedure. Hypothetical future equilibria of the world economy are generated first, by means of a method that we name "pseudo-

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[1] A few studies considered a limited number of impacts: e.g., Darwin and Tol (2001), Deke et al. (2001).

calibration". Subsequently, conventional comparative-static analysis is conducted, by simulating specific shocks related to the climate change.

This paper illustrates the overall methodology of the project and some early simulation results. The next section describes the pseudo-calibration method. The following sections present simulation strategies and results for the analysis of three kinds of impacts: sea-level rise, human health and tourism. A final section describes some further simulation experiments, currently under development, and discusses open issues and prospects for future research.

2. The Pseudo-Calibrations

In the CGE jargon, "calibration" refers to a standard procedure for the estimation of structural parameters of the model, based on available information on prices and quantities, normally obtained from a Social Accounting Matrix (SAM).

Dixon and Rimmer (2002) suggest that, after a standard SAM-based calibration, a CGE model can be used to update the initial data set, by forcing it (trough an appropriate swapping between endogenous and exogenous variables) to reproduce observed values for variables like the main national accounting aggregates, international trade flows, or employment levels. Likewise, forecasted values for key economic variables can be "plugged in" to identify hypothetical general equilibrium states in the future.

We performed this kind of exercise using a variant of the GTAP model. GTAP (Global Trade Analysis Project) is an extensive database of the world economy, associated with a static CGE model (described in Hertel (1996)). GTAP-E is a variant of this model, developed by Burniaux and Truong (2002), which provides a different treatment of the energy sector[2] and includes carbon emissions in the data. We developed further the GTAP-E model version (GTAP-EF), by augmenting the industrial disaggregation, especially in the agricultural sector.

[2] To model energy substitution, energy factors are taken out of the set of intermediate inputs, and put in an aggregate composite which combines with capital, within the value added nest. Inside the energy aggregate, there is substitution between electric and non-electric factors. Inside the non-electric aggregate, there is substitution between coal and a composite of other inputs.

Since we are working on the medium-long term, to get a benchmark equilibrium 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 years (2010, 2030, 2050). In some other cases we considered variables, which are normally endogenous in the model, by modifying the partition between exogenous and endogenous variables.

We obtained estimates of the regional labour and capital stocks by running the G-Cubed model (McKibbin and Wilcoxen (1998)), which is a rather sophisticated dynamic CGE model of the world economy. We coupled this model with GTAP, rather than using it directly, primarily because the latter turned out to be much easier to adapt to 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, with a particular focus on the land use, reporting information on seven crop yields in 13 world regions, from 1970 to 2100. We ran this model by adopting the most conservative scenario about the climate (IPCC B1), implying minimal temperature changes.

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 compute endogenously the stock levels.

3. Sea Level Rise

Of the many impacts of climate change, sea level rise is often seen as one of the more threatening. The impacts of sea level rise are straightforward – more erosion, more floods, unless costly adaptation is undertaken – and unambiguously negative (unless one happens to be in the dike building sector). Sea level rise could have very substantial impacts in river deltas, and may wipe out entire islands and island nations.

Therefore, sea level rise figures prominently in assessments of the impacts of climate change, and the costs of sea level rise figures equally prominently in estimates of the costs of climate change. The majority of estimates of the economic damages of global warming rely on the methodology of direct costs, that is, damage equals price times quantity. The direct cost method ignores that the quantity change – say, the amount of land lost to sea level rise – may well affect the price – say, of coastal land. Furthermore, this method ignores that changes in one market – say, the market of land – has implications for all other markets.

We evaluate the impacts of sea level rise in the eight regions of GTAP-EF. For each region, we estimated the potential dryland loss without protection. Our main source of information is the GVA (Global Vulnerability Assessment; Hoozemans *et al.*, 1993), an update of work earlier done for the Intergovernmental Panel on Climate Change (IPCC CZMS, 1990, 1991). The GVA reports impacts of sea level rise for all countries in the world. Dryland losses are not reported in the GVA, but they are, for selected countries, by Bijlsma *et al.* (1996), Nicholls and Leatherman (1995), Nicholls *et al.* (1995) and Beniston *et al.* (1998).

The GVA reports the costs of fully protecting the coast, with protection standards varying in an ad hoc but sensible way with population density and per capita income. Protection costs are given for a 1 metre sea level rise between 2000 and 2100, which is not very likely. However, costs are assumed to be linear in dike height (and so in sea level rise), and therefore readily scaled. The GVA reports the average annual investment over the century, which we annuitised.

To model the effects of sea-level rise, we run a set of simulation experiments, by shocking some specific variables in the model, depending on the policy scenario considered.

In the "no-protection" scenario, we assume that no defensive expenditure takes place, so that some land is lost in terms of productive potential, because of erosion, flooding and salt water intrusion. This case can be easily accommodated in the model by exogenously reducing the endowment of the primary factor “land” in all countries, in variable proportions.

In the “full-protection” scenario, on the contrary, we assumed that no land is lost because of sea-level rise, but this outcome requires some specific infrastructure investment. In practice, these measures can take the form of dike building or elevation, beach nourishment, and protection of freshwater resources. In the model, this translates into an exogenous increase of regional investment expenditure.

To fully assess the results of this simulation exercise, it is important to understand how we modified the mechanism of investment allocation in the GTAP-EF model, as well as the difference between our approach and some alternative modelling strategies.

Regional investments are endogenous variables in the GTAP framework. Furthermore, savings and investments are not equalized domestically, but only at the global scale.[3] Savings are generated because of the presence of a composite good “saving” in the utility function of each regional representative consumer. A hypothetical “world bank” then collects savings and allocates investments, realizing the equalization of regional *expected* returns.[4]

We modified this procedure in the following way. We made the regional investment variables exogenous, and we fixed their level, augmenting their calibration values by some given percentages, accounting for region-specific additional investment expenditure for coastal protection. To ensure the equalization of global saving and investment, we then allowed for an endogenous adjustment of regional savings. Assuming that all regional investments increase by the same percentage (reflecting the GTAP assumption of perfect international mobility of capital), we asked the model to calculate the implied changes in the shares of national income devoted to savings.

Clearly, since global investment increases, so do global and hence domestic savings. To save more, each representative consumer has to consume less, thereby reducing her immediate utility. However, there is no direct link between consumption levels and

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[3] The condition equalizing global saving and investment is the redundant equation in the Walras general equilibrium system.

[4] The interested reader may find a complete description of the investments allocation mechanism in Hertel (1996). Here, it is sufficient to say that this mechanism attains a compromise between a neo-classical arbitrage and a home-biased asset allocation.

additional investment expenditure. This is because domestic saving and investment are not equalized, meaning that each economy can run a foreign debt. If a region would be especially vulnerable to the sea-level rise, it would require relatively more defensive expenditure. Part of this spending would then be financed through foreign capital inflows. Our methodology significantly differs from the one adopted by Darwin and Tol (2001) and Deke *et al.* (2002) who also perform a simulation experiment on capital investment for coastal protection. Darwin and Tol model defensive expenditure simply by assuming that some fraction of the capital, used in the production of goods and services, is converted to unproductive defensive infrastructure. The hypothesis of capital conversion is clearly unrealistic in the short run, but could be justified as an approximation of a long-run equilibrium in which defensive investment completely offsets productive investment, although there is no specific reason to believe that this offset would be one-for-one. Deke *et al.* (2002) subtracts investments in coastal protection from overall investment, without building up a "coastal protection capital" or even creating a demand for dike building. Our approach is different, and provides the advantage of accounting for the multiplicative effects of changes in the demand structure. For example, our model generates higher growth rates for the construction industry wherever new infrastructure is built.

Table I shows the effects of sea level rise for the no-protection scenario in the year 2050, based on a uniform increase of 25 cm.

Tab. I: No protection scenario: main economic indicators (2050)

	Land lost (% change w.r.t. baseline)	Land lost in km^2	Value of land lost		GDP (% change w.r.t. baseline)	Household utility index (% change w.r.t. baseline)	CO_2 Emissions (% change w.r.t. baseline)
			1997 million US$	% of GDP			
USA	-0.055	5000	102	0.0002	-0.002	-0.005	0.010
EU	-0.032	1015	187	0.0010	-0.001	-0.005	0.012
EEFSU	-0.018	4257	611	0.0100	-0.002	-0.006	0.005
JPN	-0.153	575	20	0.0001	-0.001	0.003	0.035
RoA1	-0.006	1065	221	0.0030	0.000	0.008	0.015
EEx	-0.184	31847	15556	0.1010	-0.021	-0.015	-0.008
CHIND	-0.083	10200	324	0.0030	-0.030	-0.062	-0.024
RoW	-0.151	71314	13897	0.0600	-0.017	-0.014	-0.012

The fraction of land lost is quite small in all regions. The highest losses affect Oil Exporter Countries (EEx), loosing 0.18% of their dry land, followed by Japan (JPN) and the Rest of the World (RoW), both with a 0.15% loss. The value of the land lost is large in absolute terms, but quite small if compared to GDP (EEx has the biggest value: 0.1% of GDP). Generally, developing regions – CHIND and RoW – experience direct losses higher than those of developed countries, because their economies are more agricultural. The high loss in EEx is partly due to their losses of energy exports (see below).

GDP falls in all regions, especially in CHIND (-0.030%), EEx (-0.021%) and RoW (-0.017%).[5] Two aspects are worth noticing: first, general equilibrium effects influence the cost distribution. GDP losses for the Former Soviet Union (EEFSU), the Rest of Annex 1 (RoA1), EEx and RoW are lower than the direct cost of the lost land, whereas the opposite occurs to USA, EU, JPN and CHIND; in the case JPN, the GDP losses are even 10 times as large as the direct costs. Second, there is no direct relationship between the environmental impact and the economic impact. For instance, JPN exhibits the second highest amount of land lost, but the second smallest loss of GDP. CHIND, on the contrary, has the third smallest relative amount of land lost, but the highest cost in terms of GDP. This highlights the importance of conducting a general equilibrium analysis in this context, as substitution effects and international trade work as impact buffers or multipliers.

In the protection scenario, there is no negative economic shock, since –by assumption– the stock of land resources is fully preserved. However, the structure of final demand changes, because investment increases and household consumption decreases.

[5] Note that the change in the *net* domestic product is the sum of the change the *gross* domestic product and the direct costs of land loss. This implies that, overall, the direct cost method underestimates the true costs of land loss, a point also noted by Darwin and Tol (2001).

Tab. II: Total protection scenario: main economic indicators (2050)

Region	Coastal protection expenditure		Investment induced by coastal protection (% change w.r.t. baseline)	GDP (% change w.r.t. baseline)	Household utility index (% change w.r.t. baseline)	CO_2 Emissions (% change w.r.t. baseline)
	1997 million US$	% of GDP				
USA	5153	0.010	0.151	0.001	-0.206	-0.069
EU	11213	0.025	0.302	-0.022	-0.296	-0.160
EEFSU	23076	0.332	3.179	0.049	0.033	-0.133
JPN	7595	0.032	0.242	-0.009	-0.605	-0.344
RoA1	71496	0.799	9.422	0.103	-0.009	-0.130
EEx	363856	0.185	2.235	0.015	-0.223	-0.069
CHIND	11747	0.106	1.254	0.003	-0.889	-0.116
RoW	38808	0.148	1.817	0.009	-0.310	-0.115

Table II shows the additional expenditure for the various regions. Figures are relatively small in terms of GDP, but substantially higher than the value of land lost: the highest values are for RoA1 (0.80% of GDP) and EEFSU (0.33% of GDP), the lowest for USA (0.01% of GDP).[6] The high value for RoA1 results from a combination of length of coast exposed and high protection cost, particularly in Canada, Australia and New Zealand. To meet this extra demand for investment, all regions increase uniformly (+ 1.9%) their savings, reducing at the same time private consumption, especially in CHIND (- 0.96%), JPN (- 0.56%) and RoW (- 0.35%). The impact on regional GDP is mixed: EU and JPN experience small losses (- 0.02% and - 0.01%, respectively), while all other regions gain slightly. EU and JPN attract little additional investment and are hit hard by the price increase of fossil fuels; USA also attracts little investment, but suffers less from the energy price increase.

Regional impacts are determined by the interplay of demand effects and changes in the terms of trade. Because of the need to finance defensive infrastructure, the most vulnerable regions (RoA1, EEFSU) experience net investment inflows, stimulating a regional GDP growth. Note that this additional GDP does not offset the costs of dike building; GDP net of coastal protection is lower for all regions compared to the case without climate change.

[6] Indeed, using cost-benefit analysis, Fankhauser (1994) and Yohe *et al.* (1994) find that it is optimal to protect some but not all coasts.

At an aggregate level, effects are stronger, and globally an order of magnitude more negative, in the total protection scenario than in the no protection case. This seems to suggest that it would be better, economically speaking, to avoid a full protection policy. This would not be entirely correct, however, since results shown here only hold for the short run.

There are also quite substantial distributional effects in the total protection scenario. Asian regions – JPN and CHIND – are especially worse off in these circumstances. EEFSU is the only region getting short term utility gains, because it receives the second highest influx of investments in coastal protection, stimulating regional GDP and income, and because it benefits from the increased value of energy exports. The utility loss of RoAx1 is relatively small, because it receives so much investment for coastal protection.

4. Human Health

Of the many impacts of climate change, those on human health are often placed amongst the most worrying. The impacts of climate change on human health are many and complex. Global warming would increase heat-related health problems, which mostly affect people with pre-established cardiovascular and respiratory disorders. On the other hand, global warming would reduce cold-related health problems, again most prevalent in people with cardiovascular disorders. Climate change would affect the range and abundance of species carrying diseases, and would affect the virulence of those diseases as well. Malaria, in particular, is generally thought to increase because of climate change. Other vector-borne diseases may increase or decrease, but make much less victims than does malaria. Climate change will allow diseases to invade immunologically naïve populations with unprepared medical systems.

Tol (2002a) presents estimates of the change in mortality due to vector-borne diseases (viz., malaria, schistosomiasis, dengue fever) as the result of a one degree increase in the global mean temperature. The estimates result from overlaying the model-studies of Martens *et al.* (1995, 1997), Martin and Lefebvre (1995), and Morita *et al.* (1994) with mortality figures of the WHO (Murray and Lopez, 1996). Martens *et al.* (1995, 1997) standardize their results to an increase in the global mean temperature of 1.16°C. We use the relationship between per capita income and disease incidence developed by Tol and

Dowlatabadi (2001),[7] using the projected per capita income growth of the 8 GTAP-EF regions for the countries within those regions. The resulting changes in national mortality and morbidity are then aggregated to the GTAP-EF regions. The annual loss of labour productivity is assumed to be equal to the number of additional malaria deaths plus the additional years of life diseased by malaria, divided by the total population.

Martens (1998) reports the results of a meta-analysis of the change in cardiovascular and respiratory mortality for 17 countries. Tol (2002) extrapolates these findings to all other countries, using the current climate as the main predictor. The result is a model that is quadratic in the temperature change. Cold-related cardiovascular, heat-related cardiovascular, and (heat-related) respiratory mortality are specified separately, as are the cardiovascular impacts on the population below 65 and above. Heat-related mortality is assumed to only affect the urban population. Scenarios for urbanization and aging are based on Tol (1996, 1997).[8] We use this model directly on a country basis, before aggregating to the regions of GTAP-EF.

The literature on the costs of diseases is thin. Substantial information appears to be in the grey literature on public health advice, specific for each country. There a few papers in the open literature, however. Kiiskinen *et al.* (1997) report the average costs of cardiovascular diseases, \$21,000 per case, for Finland. Blomqvist and Carter (1997), Gbesemete and Gerdtham (1992), Gerdtham and Jönnson (1991), Getzen (2000), Govindaraj *et al.* (1997), Hitires and Posnett (1992), and di Matteo and di Matteo (1998) estimate the income elasticity of health expenditures for countries in the OECD, Latin America and Africa for the period 1960-1991. The average is 1.3. We use this to extrapolate the Finnish costs of cardiovascular diseases. Weiss *et al.* (2000) report the

[7] Vulnerability to vector-borne diseases strongly depends on basic health care and the ability to purchase medicine. These factors are assumed to be linearly related to per capita income. The data of the WHO (Murray and Lopez, 1996)) suggest a linear relationship between per capita income and mortality due to malaria, schistosomiasis, and dengue fever for the Middle East, Latin America, and South and Southeast Asia. Centrally Planned Asia (too low mortality) and Africa (too high) mortality are outliers. A regression of vector-borne mortality and per capita income suggests that populations with an income above \$3100 per head.

[8] The income elasticity of the share of the population over 65 is 0.25.

costs of asthma for the USA. The direct costs[9] amount to \$430 per case, or \$40,000 per year diseased.[10] We assume that asthma is representative for all respiratory disease, and again extrapolate to other countries using an income elasticity of 1.3.

In the CGE model, health impacts produce economic effects through two main channels: first, there is a variation of working hours, which is equivalent to a change in the regional stock of labour force; second, there is a variation in the expenditure for health services. Both these effects could, in principle, be positive or negative in each region. This is because the incidence of some illnesses may be higher or lower when temperature increases. The "composition" also matters: some diseases are more costly to treat than are others.

Variations in the number of disease cases are estimated on the basis of specific relationships based on temperature changes and income levels described above. The number of additional cases has then been translated into changes of working hours, and the exogenous variable "regional labour stock" has been shocked in the model, in a way similar to the one followed to get future equilibrium benchmarks.

Changes in the consumption of health services are more difficult to model, however, as these refer to variables which are normally endogenous in the model. Here, we interpreted our input data, expressing additional health expenditure in terms of GDP, as coming from a partial equilibrium analysis, which disregards the simultaneous price changes occurring in all other markets. In practice, we imposed a shift in parameter values, which could produce the required variation in expenditure *if all prices and income levels would stay constant*.

It turns out that this is equivalent to a shift in factor-specific productivity, with opposite sign. A doubled factor productivity, for example, means that the same services can be obtained with half the original input. Consequently, we adopted the following procedure. We computed the magnitude of the absolute variation of expenditure, and we derived the percentage variation in the demand for health services. This extra demand is split between the public and the private sector, and the productivity of health services is then

[9] Weiss *et al.* (2000) also estimate the indirect costs to the economy.
[10] The average treatment for asthma lasts 4 days.

varied for the final demand (public and private), within the broader class of non-market services.

The simulation experiment is then obtained through the two simultaneous shocks on labour endowments and on the structure of final demand.

Tab. III. Impacts on human health: main economic indicators
(% variation from baseline 2050)

	Labour Productivity	Public Sector Demand for Health Care (NMserv)	Private Demand for Health Care (NMServ)	GDP	Household Utility Index	CO^2 Emissions
USA	-0.132	7.359	4.993	-0.087	-1.735	-0.744
EU	0.166	-1.843	-1.908	0.200	0.847	0.569
EEFSU	0.702	-6.394	-5.474	0.499	2.278	0.773
JPN	-0.084	7.692	3.698	-0.138	-1.432	-0.116
RoA1	0.394	-6.099	-5.307	0.395	2.305	1.168
Eex	-0.837	10.741	14.398	-0.472	-2.761	-0.973
CHIND	0.189	-0.662	-2.792	0.104	0.272	0.229
RoW	-0.675	10.483	38.307	-0.634	-3.225	-1.454

Two mechanisms drive the results, summarized in table III for the year 2050. Changes in labour productivity (positive and negative) directly affect the economy resources, so they have the nature of a typical macroeconomic shock. Changes in health expenditure, on the other hand, only influence the composition of demand, not its aggregate level (directly), nor the aggregate income level.

Labour productivity declines in USA , JPN, Eex, and RoW. In the first three cases the effect is driven by the higher incidence of cardiovascular and respiratory diseases, in the latter case by the incidence of vector borne diseases. In the regions experiencing labour productivity gains (EU, EEFSU, RoA1, CHIND) vector borne diseases are practically absent, while the decrease in mortality/morbidity associated to cold stress more than compensates the increase in heat stress related diseases. In general, a higher incidence of illnesses is associated with more demand for health and vice versa

The direct effect of a lower (higher) labour productivity is to lower (raise) labour demand and thus wages. This on its turn reduces (increases) households' income and consumption demand. There is also a negative (positive) effect on the supply side, as the decreased (increased) productivity of labour reduces (raises) industrial production. This is particularly evident in labour intensive industries like market and non market services.

Changes in wages have spill-over effects on the price of other primary resources (land, capital, natural resources). For example, if wages decline, there is a tendency to substitute relatively more expensive resources with labour. However, all primary resources are in fixed supply, in the short run. Lower demand for any stock is directly translated into lower prices, and vice versa. Therefore, prices of all primary resources typically move in the same direction.

Since a fall in labour productivity drives down the price of capital in a region, investment demand (a component of GDP) also decline locally, and the opposite occurs when labour productivity increases. Therefore, this mechanism amplifies the macroeconomic impact of variations in labour productivity (or, equivalently, in the labour force).

On the other hand, changes in the terms of trade work in the opposite direction, by smoothing the macroeconomic shocks. For example, lower labour productivity creates relative scarcity of (differentiated) domestic goods, thereby increasing the price of exports and decreasing the price of imports.

5. Tourism

Climate plays an obvious role in tourist destination choice. The majority of tourists spends 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, however, 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 has looked at 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) who estimates the changes in demand of British tourists. Hamilton *et al.* (2003a,b) do look at supply and demand for all countries, but their model is restricted to tourist numbers.

We take our estimates of changes in international tourist flows from Hamilton *et al.* (2003). Theirs is an econometrically estimated simulation model of bilateral flows of tourists between 207 countries; the econometrics are reported in Maddison (2001), Lise and Tol (2002) and Hamilton (2003). The model generates 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.

The procedure we followed to simulate the tourism impacts in the CGE model was conditioned by the GTAP concept of Gross Domestic Product. In GTAP, 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. Accordingly, in the model we simulated the effects of a tourists' flows variation by altering two sets of variables, considering changes in the structure of final consumption and changes in international income transfers.

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[11], have not been taken into account, because of data limitations.

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 share of the base year expenditure. Because consumption levels, including those of market services, are endogenous variables in the model, we adopted a procedure similar to the one already described for the increases in health expenditure. To achieve, say, an increase of tourism expenditure at constant prices and income, we then lowered the tourism services productivity, for instance in terms of utility.

To compute the extra income needed to finance the expenditure of foreign tourists, we considered the net additional expenditure generated by foreigners. During the simulations, this element has been inserted into the equation computing the national income.

[11] 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.

Tab. IV: Impacts on tourism: main economic indicators
(% variation from baseline 2050)

Region	Shift in household demand for market services		ΔIncome Flows (1997 $)	GDP	House-hold utility index	CO_2 Emissions
	Ex-ante exo-genous	Ex-post endo-genous				
USA	0.110	0.151	9277	0.000	0.044	0.001
EU	-0.080	-0.123	-9430	0.001	-0.048	0.092
EEFSU	0.712	1.006	7404	0.015	0.296	-0.334
JPN	0.361	0.481	15964	-0.013	0.137	-0.188
RoA1	1.517	2.020	21455	0.011	0.547	-1.000
EEx	-0.530	-0.773	-20618	-0.013	-0.254	0.075
CHIND	0.008	0.012	40	0.002	0.001	0.003
RoW	-0.568	-0.791	-24280	0.001	-0.242	0.088

Table IV presents some simulation variables and macroeconomic aggregates for the year 2050. Climate change induces negative shocks for the tourism industries of Europe (EU), Energy Exporting Countries (EEx), and the Rest of the World (RoW). Clearly, this is an averaged outcome: for example, in Europe it combines gains from Northern regions with losses from Mediterranean countries[12].

Shifts in demand are different before and after the simulation, because the imposed swing is based on the partial equilibrium assumption of unchanged prices and income. However, GDP does vary because of the income inflow, or outflow, due to the variation in the number of foreign tourists. This effect amplifies the shock.

Because market services are almost completely produced domestically, a change in the structure of demand, e.g., with a higher share for services, implies a lower aggregate propensity to import. The higher open-economy Keynesian multiplier also strengthens the shock, as well as the investment inflow associated with higher returns for capital.

[12]Actually, in earlier years (e.g., 2010), the model is based on estimated slight positive gains for Europe.

6. Open Issues and Future Research

The simulation exercises which have been realized with the GTAP-EF model entails collecting and processing heterogeneous information coming from specific sectoral studies. To carry out simulations in the CGE model, this information has been translated in terms of: (a) changes in stocks of primary resources, (b) changes in aggregate or factor productivity, (c) exogenous variations in the structure of intermediate and final demand, and (d) changes in income transfers.

Other analyses, currently under development, include impacts on: energy demand, extreme events, water availability, land use and agricultural productivity.

We shall consider changes in energy demand due to heating and cooling, using exogenous shifting factors in the demand equations (so that energy demand will continue to be an endogenous variable in the model).

Extreme events will be considered in two different aspects. The changed likelihood of extreme events will directly affect the demand for insurance services, whereas the impact of specific events occurring in specific regions will be modelled in terms of loss of resources.

As water is, in most cases, a non-marketed, "hidden" factor, water availability will be modelled through changes in multifactor industrial productivity. In addition, the production of "effective water" by an additional industry (water treatment) will be inserted into the base model.

Variations in the concentrations of carbon dioxide have a direct impact on crop yields, and the model will embody information on this phenomenon coming from existing studies, together with variations in the land patterns (determining the stock of land resources at the industry level).

All these exercises will shed light on the structural changes triggered by the climate change on the world economy. However, it is clear that they are based on a rather ad-hoc scenario, in which all the effects of the climate change occurs suddenly and unexpectedly in a certain reference year.

In reality, climate change is a phenomenon smoothly evolving over time. Impacts and adaptation will also unfold over time, influencing, in turn, the climate change itself.

To capture the dynamic interactions of human and natural systems, a dynamic general equilibrium model is being developed, in parallel with the more conventional static one.
As most dynamic CGE model, this model will depict the economic evolution path as a series of equilibria, linked by capital and foreign debt accumulation. The evolution will be driven by static recursive and/or quasi-rational expectations, exogenous growth in labour supply and productivity. The model will eventually interact with a climatic model, thereby creating a fully-fledged Integrated Assessment Model.

Acknowledgements

This paper summarizes and merges preliminary notes and draft papers, to which several people have contributed to. In particular, Richard Tol has contributed to simulation inputs and in writing the introductory text of most experiment descriptions. Francesco Bosello and Marco Lazzarin performed the computer simulations for sea level and health impacts. Maria Berrittella and Andrea Bigano performed the computer simulations for tourism. More generally, the whole project is a team work.
We had useful discussions about the topics of this paper with Carlo Carraro, Sam Fankhauser, Marzio Galeotti, Andrea Galvan, Claudia Kemfert, Hans Kremers, Hom Pant, Katrin Rehdanz, Kerstin Ronneberger and Guy Wyseman. The Volkswagen Foundation through the ECOBICE project, the EU DG Research Environment and Climate Programme through the DINAS-Coast project (EVK2-2000-22024), the US National Science Foundation through the Center for Integrated Study of the Human Dimensions of Global Change (SBR-9521914), the Michael Otto Foundation for Environmental Protection, and the Ecological and Environmental Economics programme at ICTP-Trieste provided welcome financial support.

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Appendix

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 various 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.
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.

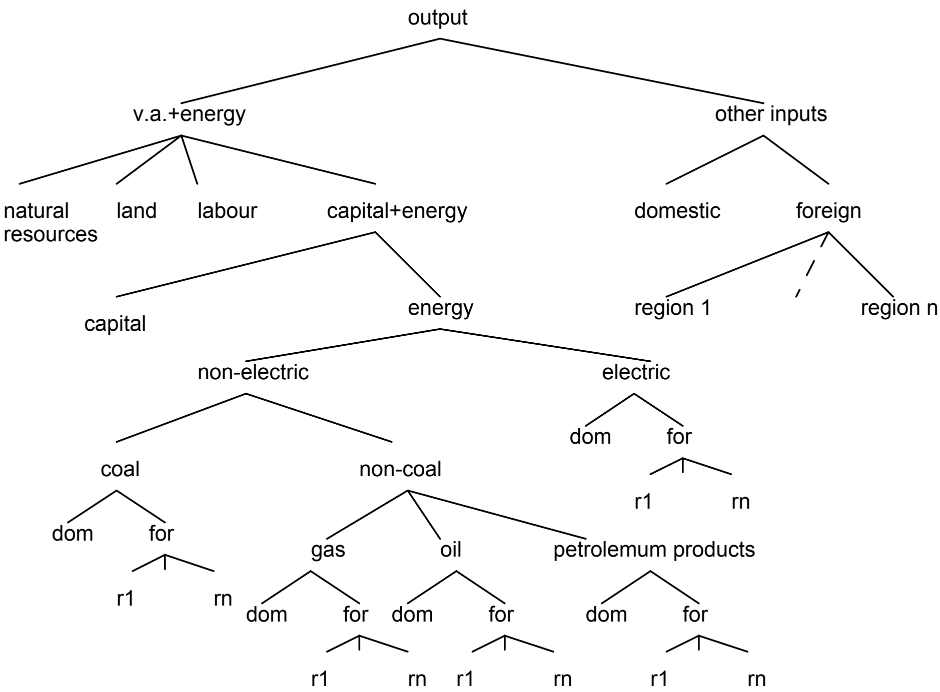

Figure A1 – Nested tree structure for industrial production processes

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 (figure 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 Elasticies 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.

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.

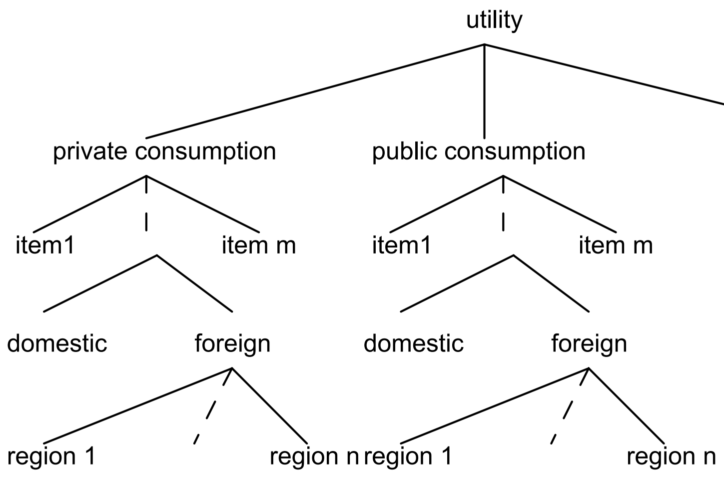

Figure A2 – Nested tree structure for final demand

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.