Bosello, Francesco; Bigano, Andrea; Roson, Roberto; Tol, Richard S.J.

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Andrea Bigano, Francesco Bosello,
Roberto Roson and Richard S.J. Tol

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Andrea Bigano, *Fondazione Eni Enrico Mattei and REF, Ricerche per l'Economia e la Finanza*
Francesco Bosello and Roberto Roson, *Fondazione Eni Enrico Mattei and Ca'Foscari University of Venice*
Richard S.J. Tol, *Research unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Institute for Environmental Studies, Vrije Universiteit and Engineering and Public Policy, Carnegie Mellon University*

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Summary

Climate change impacts on human life have well defined and different origins, nevertheless in the determination of their final effects, especially those involving social-economic responses, interactions among impacts are likely to play an important role. This paper is one of the first attempts to disentangle and highlight the role of these interactions. It focuses on the economic assessment of two specific climate change impacts: sea-level rise and changes in tourism flows. By using a CGE model the two impacts categories are first analyzed separately and then jointly. Comparing the results it is shown that, even though qualitatively joint effects follow the outcomes of the disjoint exercises, quantitatively impact interaction do play a significant role. Moreover it has been also possible to disentangle the relative contribution of each single impact category to the final result. In the case under scrutiny demand shocks induced by changes in tourism flows outweigh the supply side shock induced by the loss of coastal land.

Keywords: Climate Change, Sea Level Rise, Tourism, Computable General Equilibrium Models

JEL Classification: C68, D58, Q25

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Address for correspondence:

Francesco Bosello
Fondazione Eni Enrico Mattei
c/o Palazzo Querini Stampalia
Castello 5252
30122 Venezia
Italy
E-mail: Francesco.bosello@feem.it

1. Introduction

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 coastal erosion and sea floods, unless costly adaptation is undertaken – and unambiguously negative. Sea level rise could have very substantial impacts in river deltas, on coastal zones which are often more densely populated and richer of infrastructures 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.

Climate change plays an obvious role in tourist destination choice as well. Indeed the "amenity of climate" is recognised as one of the major determinants of tourism flows. The Mediterranean particularly profits from this, being close to the main holidaymakers of Europe's wealthy, but cool and rainy Northwest. Tropical islands are another example, where in the recipe of a dream holiday their "perfect" climate is a fundamental ingredient.

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. Just consider that about 10% of world GDP is now spent on recreation and tourism.

In two previous papers: Bosello et al. (2004) and Berrittella et al. (forthcoming), we analyzed the impact on the world economic system of, respectively, climate-change induced increase in sea level and change in tourism flows. Both studies are characterised by the use of CGE models, which allow assessing the "systemic" effects induced by changes in resources, technologies and consumption patters[1]. There are no other papers that look at the general equilibrium effects of climate-change-induced changes in tourism. Darwin and Tol (2001) and Deke et al. (2001) study the general equilibrium effects of sea level rise, but not as comprehensively as do Bosello et al. (2004).

In this paper, we follow the same approach, for a joint analysis of climate change impacts on tourism and seal level. Combining the two impact studies into a single, integrated analysis

[1]Note that we restrict our attention to the static economic effects of climate change impacts. See Fankhauser and Tol (2005) for a discussion of the impact of climate change on economic growth.

provides two main advantages: (1) the possibility of highlighting the complex interactions between the two adjustment processes; and (2) the potential for considering a direct effect of sea level rise on tourism destination choices. Jorgenson et al. (2004) and Kemfert (2002) study the combined impacts of climate change using a computable general equilibrium model, but they do not look at the impacts separately – and therefore do not estimate the interaction. Besides, Jorgenson et al. (2004) is limited to the USA, while neither Jorgenson et al. (2004) nor Kemfert (2002) includes tourism. Fankhauser and Tol (1996) first lamented the lack of integration between the different impacts of climate change, a point repeated by Tol *et al.* (2000) and Tol (2005); this is the first study of the economic interactions between the impacts of climate change.

In addition, this paper improves upon the two previous studies, in terms of methodology: an updated data base is used, to compute land losses; a more detailed geographical disaggregation is adopted (16 regions instead of 8) and a new procedure to model demand shifts in tourism destination choices is introduced.

In what follows section 2 describes the setting up of the benchmark for our CGE model, section 3 briefly introduces the sources for climate change impacts, section 4 describes the simulation exercises, section 5 presents results, finally section 6 concludes.

2. Economic model and benchmark

This study has been conducted through an unconventional use of a multi-country world CGE model: the GTAP model (Hertel, 1996), in the version modified by Burniaux and Truong (2002), and subsequently extended by ourselves.[2]

First, benchmark data-sets for the world economy at some selected future years (2010, 2030, 2050) have been derived, using the methodology described in Dixon and Rimmer (2002). This entails inserting, in the model calibration data, forecast 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: projected 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

[2] A more complete description of the modelling approach can be found in Roson (2003).

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.

We obtained estimates of the regional labour and capital stocks by running the G-Cubed model (McKibbin and Wilcoxen, 1998), whereas estimates of land endowments and agricultural land productivity have been obtained from the IMAGE model version 2.2 (IMAGE, 2001). IA rather specific methodology was adopted to get estimates for the natural resources stock variables.[3]

By changing the calibration values for these variables, the CGE model has been used to simulate a general equilibrium state for the future world economy. This is the benchmark for all subsequent exercises. Therefore, this benchmark corresponds to the case in which no economic impacts of climate change have taken place, whereas the counterfactual scenarios consider the effects generated by one or more impacts.[4]

3. Input data and models

3.1. Sea level rise

We evaluate the impacts of sea level rise in the 16 regions of GTAP-EF. For each region, Table 2 (second column) presents estimates of the potential dryland loss, in the absence of any protection intervention. Our main source of information is the Global Vulnerability Analysis (Hoozemans et al., 1993), complemented with the estimates of Bijlsma *et al.* (1996), and the model of coastal protection of Fankhauser (1994). Combined as described in Tol (2002), these data specify, per country, the amount of land lost due to a sea level rise of one metre. Land loss is assumed to be linear in sea level rise.

3.2. Tourism

The impacts of climate change on tourism are based on the Hamburg Tourism Model (HTM),

[3]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.

[4]There is no explicit dynamics in the model. The simulation exercises are comparative static.

version 1.2 (Bigano et al., 2005).[5] HTM is an econometric simulation model, estimating the number of tourists by country, the share of international tourists in total tourists, and tourism flows between countries. The model is calibrated for 1995. The number of tourists is determined by population and economic growth. The share of international tourists is larger in richer countries, as well as in those countries that are very hot or cold. Poorer countries and countries that are very hot or very cold are also less attractive to foreign tourists. The scenario for population growth, economic growth, and global warming is the IPCC SRES A1B (Nakicenovic and Swart, 2001). The regional warming pattern is the average of 14 GCMs from COSMIC (Schlesinger and Williams, 1998).

4. Including Impacts in the CGE Model

To model the specific effects of climate change, we run a set of simulation experiments, by shocking specific variables in the model, depending on the scenario considered. Four different simulation exercises are compared: sea level rise "alone", tourism "alone", sea level rise and tourism combined, and an additional simulation on tourism alone, in which the effects of sea level rise on tourism destination are disregarded.

4.1. Sea Level

This simulation considers a "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.

4.2. Tourism

This scenario considers the effects of climate change on tourism in isolation or, equivalently, the effects on tourism associated with full protection of coastal areas. The shocks are computed as variations in the domestic expenditure for Market Services, accounting for higher (lower) expenditure on recreational activities, hotels and restaurants, generated by more (less) tourists in a country. These shocks are imposed as *exogenous* shifting factors in demand patterns. In addition, national incomes are also modified in order to account for the

[5] Berrittella et al. (forthcoming) is based on results of HTM1.0 (Hamilton *et al.*, 2005). Compared to version 1.0, version 1.2 of HTM explicitly represents the trade-off between holidays abroad and in the home country. HTM1.2 of course also has a different parameterisation of international arrivals and departures.

extra revenue, available for consumption, brought about by tourists.

4.3. Sea Level and Tourism

In this simulation exercise the joint effects on tourism and sea level are considered. Consequently, a simultaneous change in land endowments, consumption patterns and available national income is imposed.

However, changes in tourism flows are not the same as those considered in the "tourism alone" case. This is because the direct impact of sea level on tourism destinations is taken into account.

Nonetheless, except for some noteworthy exceptions (CAN, WEU and FSU) changes in tourism flows are not very significant (the difference is lower than 4%, see Table 1).

4.4. The "diagnostic" simulation on tourism

This simulation amounts to imposing to the CGE model exactly, but only, the same shocks on market services demand of the disjoint sea level and tourism simulation. As these shocks are slightly different from those of the "tourism alone" simulation, this is necessary to isolate the role of interactions of effects in the joint shock exercise from that played by the difference in the starting points.

5. Results

In this section, simulation results for the year 2050 are reported and commented, in terms of variation from the no-climate-change baseline equilibrium. Results for other reference years are qualitatively similar.

5.1 Sea level rise

Table 2 shows the effects of sea level rise in the absence of protection intervention, based on a uniform increase of 25 cm.

The fraction of land lost is quite small in all regions. The highest losses affect those areas characterised by a higher proportion of coastal zones over their total land or by more vulnerable coastal zones: South East Asia (SEA), South Asia (SAS) and the Rest of the World (ROW), including also all small island states (losing, respectively, -0.839%, -0.396% and -0.167% of their dry land).

The value of the land lost is large in absolute terms, but quite small if compared to GDP. Generally, developing regions experience direct losses higher than those of developed

countries, because agriculture contributes with a higher share to the production of income in their economies and land is relatively more valuable.

In terms of general equilibrium effects, GDP falls in all regions. The decrease is relatively high in SEA and SAS.

The overall mechanism at play is clearly identifiable: land loss is a direct resource shortfall, that is, a negative economic shock, which reduces income and consumption levels. At the same time the value of primary resources tends to fall, with the exception of the resource "land", which is getting scarcer (Table 3).

Table 2 highlights two other interesting aspects. GDP losses in developing countries (Asian, African and Latin American countries, with the exception of China), are lower than the direct cost of land lost, whereas the opposite occurs in most developed countries (here the exception is Canada). In some cases (e.g. Japan and Korea (JPK) and USA) GDP losses are one order of magnitude larger than direct costs. Furthermore, there is no simple relationship between environmental impact and economic impact. For instance, Japan and Korea undergo a relatively high land loss, but their loss of GDP is the second smallest. China (CHI), on the contrary, has a small relative amount of land lost, but the third highest cost in terms of GDP.

Capital flows, international trade and substitution effects interact to determine the final result. The international allocation of investments is driven by the relative price of the capital in each country. The higher the capital return, the higher the share of international investments flowing into a country, with implications in terms of regional GDP variations, since investment is one component of GDP.

In turn, changes in the price of capital services are determined by two overlapping, and opposite, effects. On one hand, the negative shock lowers the value of national resources, including capital. On the other hand, economies try to substitute land with capital. Capital supply is fixed in the short run, though, and the higher demand for capital translates into higher capital returns.

The fall in the relative price of capital services is particularly strong in Small Island States (SIS), CHI, SEA and SAS (Table 3) with consequent investment outflow. This contributes to the fall in GDP.

International trade also matters, through its effects on the terms of trade. In particular, two main effects are at work here (see Table 4): higher world prices for agriculture benefit net-exporters of agricultural goods (roughly concentrated in the developed world with countries

like e.g. USA, Australia (in ANZ), Canada (CAN), some European countries (in WEU) and FSU), whereas lower prices for oil, gas, coal, oil products, electricity, energy intensive industries harm the net-exporters of raw materials and energy products (broadly speaking developing regions, but also the FSU).

Finally, primary factor substitution possibilities within economic systems are also important. Labour, capital and *energy* substitute for the land loss. At the same time, overall economic activity falls. Note that in some regions, mostly developed, the former effect dominates. This can be noticed by observing Table 2 where CO_2 emissions increase, despite the fall in GDP (e.g. in ANZ, JPK, CAN).

5.2 Tourism

The impacts described here are derived by looking at tourism alone, assuming away the effect of sea level rise on the relative attractiveness of tourist destinations.

Demand and Prices

The general equilibrium effects on endogenous demand have the same signs as the exogenous shocks. With no exception, the transmission of the shock trough the economy reinforces the original shock. In equilibrium, changes in demand are on average 50% larger than the original shocks. The largest relative change (204%) occurs in FSU where, however, the smallest absolute changes take place[6].

In terms of production, the shocks have, with no exceptions, a direct effect on the production of Market Services. Generally speaking, there are inverse effects on the production of all other goods and services which derive directly from the endogenous counterbalancing variation in the demand of all others goods and services introduced in order to keep the economy in equilibrium[7].

In terms of magnitude, effects are proportional to the size of the original shock: tiny in the case of the productive sectors in FSU, sizeable in the case of ROW and to a lesser extent, JPK, CAM and MDE. CHI on the other hand, which undergoes the second highest shift in

[6] This is counter-intuitive: in general, one expects general equilibrium mechanisms to absorb partially the initial impacts. However, in this scenario demand shocks are coupled with income transfers, which influence demand by changing the amount of money that can be spent on goods and services, including Market Services, in the receiving regions. Note that Market Services are a luxury good.

[7]However, due to the interplay of indirect general equilibrium effects this pattern is reversed in CAN, WEU and JPK (with positive effects on some of their agricultural products), ANZ, NAF and the FSU (with negative effects on most of their energy and energy intensive products).

demand of Market Services, (more consistent than MDE or CAM), experiences a very limited effect on output and GDP. WEU experiences important reductions in the production of energy and energy intensive goods, stronger than the direct positive effect on Market Services' output.

As to the prices of goods and services[8], the prices of Market Services follow the shocks in all countries but CAN. The patterns for the remaining sectors are not so clear cut. In general (with the exception of Canadian energy and energy intensive goods, bar gas), the effects on agricultural products' prices display signs opposite to those of the shocks, while the effects on all other goods and services' prices display the same as those of the shocks. The effect on fisheries is mixed. Prices absorb most of the shocks, as the magnitude of their changes is in general larger than the magnitude of production changes.

Primary factors

In terms of primary factor prices (see Table 6), in general there is a concordance of sign between price changes and the shocks for all factors but for land. Since Market Services is a labour- and (to a lesser extent) capital-intensive sector, one would expect that the price of these two factor would increase (decrease) in presence of a positive (negative) shock on tourism demand. This pattern clearly takes place in all regions but Canada, with the sole exception of land. Indeed Canada is the only region experiencing a (slight) decrease in GDP (in value term) even in the presence of an increase in tourism flows (see further). This negative aggregate effect is prevailing and hits negatively demand and thus price of capital and labour. In accordance with all the regions with a negative impact on GDP, Canadian land price increases. This is due to a demand re-composition favouring anyway agricultural products. In WEU the positive demand and subsequently GDP shock (in value and quantity) increases the price of all production factors including land.

Welfare effects, capital flows and terms of trade

In welfare terms, the effects on nominal GDP are one order of magnitude larger than the effects on real GDP and, in general, consistent with the shocks (see Table 5). The only exception is Canada, worse off after the shocks notwithstanding the increase in demand. In quantity terms, the discrepancy between shocks and GDP is slightly more pronounced: JPK actually experiences an overall decrease in production, hence its increase in value GDP

[8] For economy of space, price results are not presented here, but are available from the authors upon request .

derives from the facts that goods produced by this region become more expensive. In SAS and MDE the reverse happens: these regions increase their production, but their goods now command lower prices[9].

In order to understand these results, one must take into account at least three factors.

First, direct income transfers play an obvious direct role on welfare of the receiving countries: The fact that the income inflow does not result in an increase in GDP in the case of Canada can be due to the relatively small magnitude of the transfers accruing to this country, coupled with the adverse effect of other factors.

A second factor is the reaction of capital markets to the sum of these shocks. The price of capital, and hence, its return, is influenced in each region by the pressures exerted on factors' demand by the re-composition in the output mix following the change in the demand structure of the internal market. Capital, being the only internationally mobile production factor, moves from region to region in response the changes in its relative price. In the case under scrutiny, in general regions experiencing a negative shock also experience an outflow of foreign investments (the returns they offer decrease), while countries where the demand shock is positive face the opposite financial prospects (increased capital inflows, increased returns). USA, FSU and NAF, notwithstanding the absolute decrease in returns, experience an increase in capital inflows. This can happen if in relative terms they still offer higher returns than other regions. Note however that, in the case under scrutiny, the correspondence between capital flows and changes in GDP is not so clear-cut as in the case of sea level rise. In particular, GDP falls in some regions attracting capital flows (USA, FSU and NAF).

Third, an important role is played by the way the model conciliates the demand shocks with budget balance and Walras' law. Recall that the model generates endogenously variations in the demand of all other goods and services in order to shift the world economy to a true alternative general equilibrium. These compensating demand variations may lead to variations in aggregate indexes, such as GDP, well in excess of the original exogenous demand shocks.

A potentially important factor that may help explain the variations in GDP is the relative strength of a given region on the world market, as expressed by its terms of trade. However, everywhere but in SAS their role is overshadowed by the effect of income transfers. Changes in terms of trade mimic the changes in Market Services' demand[10].

[9] In the case of SAS, there is a price reduction on the domestic market only, because its terms of trade improve.

[10]SAS, although adversely affected in terms of direct demand for Markets Services, receives a partial indirect benefit from the new situation, by selling (expensive) inputs to regions where the tourism business improves. Although its terms of trade improve and its overall production expands, this does

In JPK, the joint effect of improved terms of trade, positive income transfers and large capital inflows results in an increase of GDP notwithstanding the decrease in overall production.

Carbon Emissions

Finally an overall, inverse correspondence between sign of the shocks and sign of the effects exists in the case of CO_2 emissions, with the exception of FSU and China (see last column of Table 5). The explanation is that the Market Services sector is not an energy intensive one, and hence there is an inverse correlation between its level of activity and CO_2 emissions. Since most shocks are negative, at first glance one would then conclude that climate change, at least in the case of its direct impacts on tourism, induces a perverse effect by shifting the economy to more energy intensive, and hence polluting sectors. This conclusion is however not granted because the results cannot provide a complete picture of the phenomenon: The shift towards cleaner industries in CAN, WEU and JPK can well counterbalance the effect just described. Moreover, for modelling reasons, the effect on transport emissions (in particular those due to air transport) is completely missing from the picture. One could in fact expect important countervailing effects on CO_2 emissions caused by the reshuffling of travel activities from and to world tourist destinations diversely affected by climate change.

5.3 Joint impacts on tourism and land

In this section we describe the results of introducing jointly shocks on tourist demand and land availability. This joint effect takes place trough two channels. First, tourist flows, which are a function of climate and land availability at each destination, are adjusted to take into account the loss of land. Second, both the resulting adjusted shocks on domestic demand for market services and the shocks on land availability are applied to the model. In practice a set of demand and supply-side shocks are imposed jointly.

The resulting equilibrium is characterised by three main features: the final joint effect is a compound of the outcomes of the disjoint simulations, but it is not a simple sum; there is a detectable and in some cases large interaction between the shocks impacting GDP. Changes in market services demand induced by change in tourism expenditure are by far the most important determinant of final effects. Let us consider these features one by one in detail.

not yield a net gain in terms of value of GDP: capital outflows and the decrease in disposable income due to negative transfers depresses internal prices and demand to an extent that more than compensate the improved position on international markets.

Compound of disjoint effects

The final equilibrium in the joint simulation follows qualitatively the patterns indicated by the disjoint outcomes. Taking GDP as an example (see figure 1) it can be appreciated that two negative performances in the disjoint cases translate always in a negative performance in the joint exercise. Analogously, when a positive and a negative effect are the respective outcomes of the disjoint simulations, in the joint simulation GDP takes the sign of the bigger of the two. Moreover in 8 regions over 16 the joint GDP effect is quite close to the sum of the disjoint effects (the percent difference between the composite GDP effect and the sum of the two separate GDP effects is lower than 2%).

Appreciable interaction

On the other hand, in many cases the final effects cannot be explained solely by ”adding” the disjoint effects. Sticking to the example provided by GDP (see fig. 1), in 8 regions of 16, the difference between the GDP effect in the joint-shock case and the sum of GDP effects in the two disjoint shock cases is larger than 2%. For SEA, SAM, MDE and CAN this difference, in absolute terms, is 4.2%, 8.8%, 33% and 75% respectively.
To understand if this difference is imputable to different initial shocks (recall that changes in tourism demand are indeed slightly different in the tourism alone and in the tourism + sea level rise simulations) or to an effective interaction between shocks, we compare the outcomes of the “diagnostic” simulation on tourism.

Figure 2 shows the percentage difference between real GDP in the joint shocks simulation and the sum of GDP outcomes obtained by the sea level and “diagnostic tourism” simulations.
This difference remains detectable (higher than 2%) in six regions (CAN, MDE, SAM, SAS, SEA and SSA) with a particularly sharp result for CAN and MDE highlighting an important role of shock interactions[11].

Prevalence of Tourism

Figures 2, 3 and 4 allow also to disentangle the role played by single shocks in the joint

[11]It is difficult to derive a “common rule” explaining these interactions, indeed joint effects can be bigger or smaller than the sum of the two disjoint effects, this depends on substitution mechanisms at play in the whole system. What emerges clearly is that effects do interact and that interactions can be quite relevant.

simulation. Due to the presence of shock interactions, this exploration gives just approximate indications whose reliability is inversely proportional to the relevance of the interactions themselves. Nevertheless, we have shown that in the case of GDP, which should summarise all possible economic interactions, these are quite limited in 12 out of 18 cases. Accordingly we think that the analysis of the disjoint simulations can still offer useful qualitative insights.

This analysis shows clearly that the impact of climate change on tourism expenditure largely dominates in economic terms that on the loss of productive land.

Firstly (see Figure 2), it can be noticed that real GDP changes in the "diagnostic tourism" simulation are usually larger (sometimes much larger) than those induced by sea level rise alone. As a result, the combined impact and the sum of the impacts is very similar to the impact of tourism only. The synergistic effect, that is, the difference between the combined impact and the sum of the impacts, is of the same order as the impact of sea level rise only. Figure 3 underlines this. It compares the effect of adding tourism to sea level rise to tourism only; the biases of ignoring sea level rise are small, except in Canada (-150%), South East Asia (18.2%). Middle East (-16.6%) and South America (11%). Figure 4 compares the effect of add sea level rise to tourism to sea level rise only; the biases of ignoring tourism are generally and substantially larger, peaking to -250% for Japan and South Korea. This is as expected: Combining a small impact and a large one does not influence the large impact, but it does affect the small impact.

Finally consider the behavior of the price of land in the two disjoint simulations[12] (see Table 7). The increase in the land price induced directly by land scarcity due to sea level rise is substantially smaller than that induced indirectly by changes in market services' demand relative to changes in tourism flows. We recall that in this specific case a decrease in market services' demand is partly compensated by an increase the demand of all other goods and services including agricultural commodities with a subsequent increase in the price of the land endowment[13].

This outcome is an evidence of the importance of the service sector in the total economic activity and of tourism activities in the service sector. It also shows the importance to conduct a general equilibrium exercise able to report not only direct costs, but also higher order

[12] Regarding land prices the effect of interactions is much limited than in the case of GDP. Indeed, the percent differences between land prices in the joint simulation and that of the sum of the two disjoint simulations is always lower than the 1.5%.

[13] Note that land prices increases also in CAN and WEU where tourism and thus market services demand increase. But here the aggregate effect of increasing GDP prevails on the sectoral re-composition effect of demand.

effects.

6. Conclusions

This study uses a CGE model to evaluate the economic implications of two specific consequences of climate change: sea level rise and change in tourism flows. In addition to the economic evaluation proper, this exercise aims firstly to highlight the economic adjustments triggered by the initial shocks, key in driving the final result and secondly, to disentangle the role of possible interactions originated by the coexistence of different impacts. To do so, impacts have been considered initially in isolation, successively jointly, and finally the respective outcomes have been compared.

As far as single impacts are concerned, the main outcome is that final effects on GDP are quite limited, unambiguously negative in the case of sea level rise, with slight gains for Western Europe, Japan and Korea, in the case of tourism. Distributional effects are more interesting. In the case of sea level rise, developing countries are the more penalized: higher dependence on land, difficulty in substituting the land lost with other production factors and capital outflows driven by reduced rate of returns explain the result. In the case of tourism, the effects on regional economies are consistent with the shocks on tourism demand. This general pattern is reinforced by the changes in income flows used to capture the changes in expenditures of international tourists, which tend, for most variables, to overshadow the impact of general equilibrium adjustments. This notwithstanding, demand re-composition do play a role, and occasionally general equilibrium effects are large enough to result in regional impacts which contrast with the general pattern just described. Again, developing countries are more severely affected; in this case this is not due to the dependence from a vulnerable sector, but, more directly, to the magnitude of the negative shocks imposed on their economies. It is worth noting, moreover, that in this case the shocks have more substantial effects on prices than on quantities, as a comparison of real and nominal GDP changes in Table 5 clearly illustrates.

Considering impacts jointly, the key message is that effect interactions do play a role. In 6 cases out of 16 there is a detectable difference between the sum of the outcomes in the disjoint and those of the joint simulations. Indeed, as long as additional exogenous shocks are imposed, factor and good substitution possibilities in the economic system are increasingly constrained (or expanded). Thus adjustments to each of the single shocks composing the set of

the joint perturbations become more (or less) costly than they would be if only one shock at a time were considered.

Finally, it has been also possible to determine the relative contribution of the different impacts to the final results. In economic terms, changes in tourism flows seem to be substantially more important than land loss. The change in demand scale and demand recomposition affecting the important sector of market services is by far more relevant than the relatively small supply side shock on land which prevalently affects agricultural industries.

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Tables and Figures

Tab 1: Market services demand

	SLR&TOU (1)	TOU (2)	% Difference (1)-(2)
USA	-0.866	-0.874	-0.870
CAN	0.506	0.459	10.211
WEU	0.941	0.883	6.615
JPK	5.516	5.639	-2.176
ANZ	-1.514	-1.530	-1.040
EEU	-3.124	-3.172	-1.485
FSU	-0.002	-0.024	-93.305
MDE	-5.951	-5.974	-0.385
CAM	-5.527	-5.519	0.156
SAM	-1.513	-1.521	-0.552
SAS	-1.529	-1.532	-0.228
SEA	-5.412	-5.452	-0.728
CHI	-7.043	-6.777	3.927
NAF	-3.215	-3.204	0.359
SSA	-3.057	-3.068	-0.349
ROW	-12.265	-12.251	0.115

All values, expressed as % changes w.r.t. 2050 baseline "without climate change"

Tab. 2: Sea-Level rise: main economic indicators

	Land loss	Direct costs: value of land lost		GDP	Terms of Trade	Invest. flows	CO2 Emiss.
		ml $	as % of GDP				
USA	-0.052	121	0.0002	-0.0013	-0.016	0.015	-0.002
CAN	-0.002	72	0.0017	-0.0004	0.029	0.032	0.001
WEU	-0.029	298	0.0005	-0.0019	-0.005	0.016	-0.002
JPK	-0.141	146	0.0004	-0.0018	0.006	0.011	0.025
ANZ	-0.010	237	0.0075	-0.0008	0.081	0.010	0.004
EEU	-0.041	45	0.0016	-0.0047	-0.001	-0.037	-0.004
FSU	0.000	0	0.0000	-0.0007	-0.005	0.010	0.007
MDE	-0.007	75	0.0011	-0.0045	0.000	-0.001	0.007
CAM	-0.120	182	0.0049	-0.0098	0.052	-0.023	-0.005
SAM	-0.041	647	0.0043	-0.0007	0.102	0.020	0.003
SAS	-0.396	6000	0.1180	-0.0649	0.078	-0.212	-0.065
SEA	-0.839	14913	0.1475	-0.1092	-0.032	-0.357	-0.150
CHI	-0.091	579	0.0063	-0.0303	-0.060	-0.236	-0.066
NAF	-0.039	1120	0.0548	-0.0036	0.012	0.039	-0.012
SSA	-0.130	8869	0.2359	-0.0094	0.100	-0.029	-0.009
ROW	-0.167	188	0.0220	-0.0189	-0.020	-0.086	-0.027

All values, except direct costs, expressed as % changes w.r.t. 2050 baseline "without climate change".

Tab. 3: Sea-level rise: price of primary inputs by region

	Land	Labour	Capital
USA	0.684	-0.034	-0.034
CAN	0.822	-0.013	-0.009
WEU	0.608	-0.035	-0.036
JPK	1.132	-0.034	-0.035
ANZ	0.967	-0.022	-0.028
EEU	0.629	-0.074	-0.079
FSU	0.613	-0.038	-0.040
MDE	0.998	-0.035	-0.044
CAM	0.806	-0.053	-0.059
SAM	0.742	0.005	0.007
SAS	1.420	-0.285	-0.292
SEA	2.372	-0.468	-0.504
CHI	0.521	-0.235	-0.260
NAF	0.795	-0.002	0.016
SSA	1.034	-0.055	-0.062
ROW	0.885	-0.162	-0.169

All values expressed as % changes w.r.t. 2050 baseline “without climate change”.

Tab. 4: Sea-level rise: world price index by industry

Rice	0.880
Wheat	0.340
CerCrops	0.455
VegFruits	0.465
Animals	0.392
Forestry	-0.116
Fishing	-0.073
Coal	-0.045
Oil	-0.035
Gas	-0.057
Oil_Pcts	-0.040
Electricity	-0.058
Water	-0.044
En_Int_Ind	-0.038
Oth_Ind	0.038
MServ	-0.040
NMServ	-0.037

All values expressed as % changes w.r.t. 2050 baseline “without climate change”.

Tab. 5: Tourism: main economic indicators

	Market services demand		Other goods/services dem.	Income transfers (% of GDP)	Real GDP	Nominal GDP	Terms of Trade	Invest. Flows	CO2 Emiss.
	Imposed	Endogenous							
USA	-0.874	-1.259	1.457	-0.365	-0.0015	-0.857	-0.511	-0.626	0.702
CAN	0.459	0.755	-1.381	0.211	-0.0004	-0.007	0.420	-0.116	-0.128
WEU	0.883	1.357	-2.287	0.378	0.0556	0.341	0.331	0.238	-0.064
JPK	5.639	8.096	-14.760	2.779	-0.1768	4.201	3.768	3.810	-2.106
ANZ	-1.530	-2.096	3.475	-0.696	0.0493	-0.846	-0.063	-0.654	2.012
EEU	-3.172	-4.683	3.255	-1.169	-0.1068	-1.726	-0.803	-0.999	1.131
FSU	-0.024	-0.073	0.052	-0.011	-0.0311	-0.543	-0.135	-0.390	-0.004
MDE	-5.974	-8.600	8.295	-2.074	0.0030	-3.070	-2.279	-1.960	1.919
CAM	-5.519	-7.980	7.518	-2.387	-0.1139	-2.644	-1.030	-1.805	1.844
SAM	-1.521	-2.015	1.583	-0.558	-0.0027	-1.337	-0.100	-1.161	0.636
SAS	-1.532	-1.794	1.102	-0.453	0.0251	-0.394	0.596	-0.507	0.404
SEA	-5.452	-7.057	6.854	-1.629	-0.0324	-1.382	-0.825	-0.620	1.365
CHI	-6.777	-8.020	2.731	-1.129	-0.0442	-0.641	-1.127	-0.854	-0.149
NAF	-3.204	-4.179	1.314	-0.646	-0.1614	-1.039	-0.795	-0.640	0.164
SSA	-3.068	-4.122	2.993	-1.053	-0.0079	-1.333	-0.359	-0.951	1.095
ROW	-12.251	-18.984	17.001	-5.990	-0.5330	-9.864	-7.522	-7.852	4.209

All values, except income transfers, expressed as % changes w.r.t. 2050 baseline “without climate change”.

Tab.6: Tourism: price of primary inputs by region

	Land	Labour	Capital
USA	5.443	-0.974	-1.070
CAN	4.463	-0.068	-0.125
WEU	1.343	0.296	0.412
JPK	-24.950	5.080	5.126
ANZ	6.277	-1.127	-1.194
EEU	7.731	-2.404	-2.569
FSU	4.145	-0.598	-0.729
MDE	17.249	-4.060	-3.500
CAM	10.249	-4.139	-3.461
SAM	6.656	-1.866	-1.745
SAS	4.298	-1.278	-1.172
SEA	9.197	-3.068	-2.869
CHI	5.042	-3.326	-3.508
NAF	6.912	-1.289	-1.026
SSA	8.491	-2.555	-1.973
ROW	34.194	-14.494	-15.333

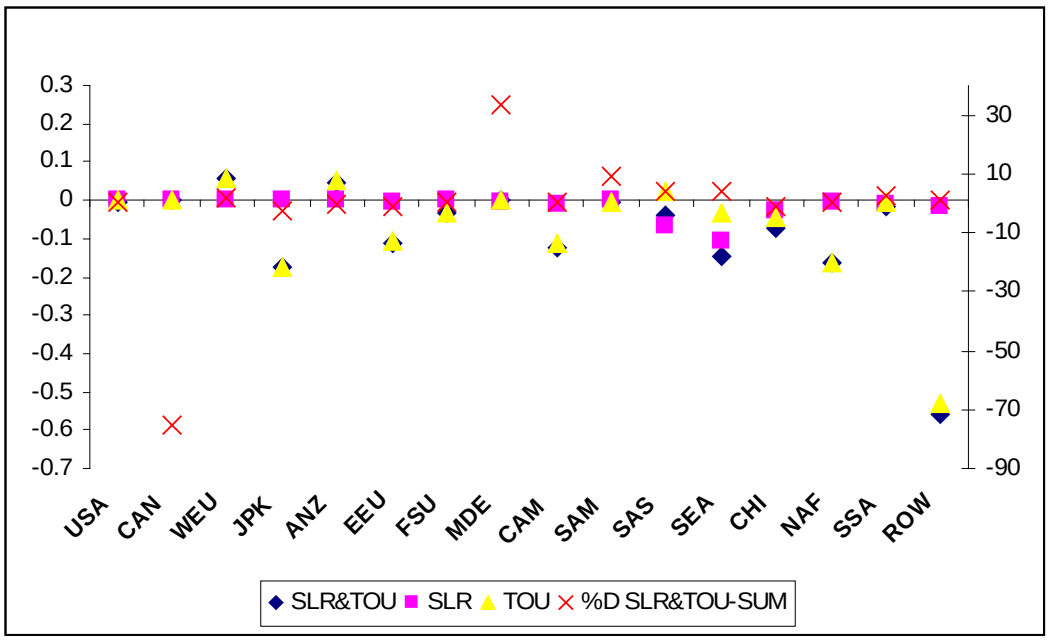
All values expressed as % changes w.r.t. 2050 baseline “without climate change”.

Tab 7: Land prices:

	SLR&TOU	SLR	TOU dia
USA	6.111	0.684	5.392
CAN	5.213	0.822	4.362
WEU	1.773	0.608	1.147
JPK	-23.550	1.132	-24.427
ANZ	7.239	0.967	6.232
EEU	8.264	0.629	7.594
FSU	4.684	0.613	4.039
MDE	18.199	0.998	17.082
CAM	11.065	0.806	10.198
SAM	7.378	0.742	6.589
SAS	5.747	1.420	4.270
SEA	11.661	2.372	9.125
CHI	5.687	0.521	5.155
NAF	7.702	0.795	6.828
SSA	9.511	1.034	8.411
ROW	35.257	0.885	34.210

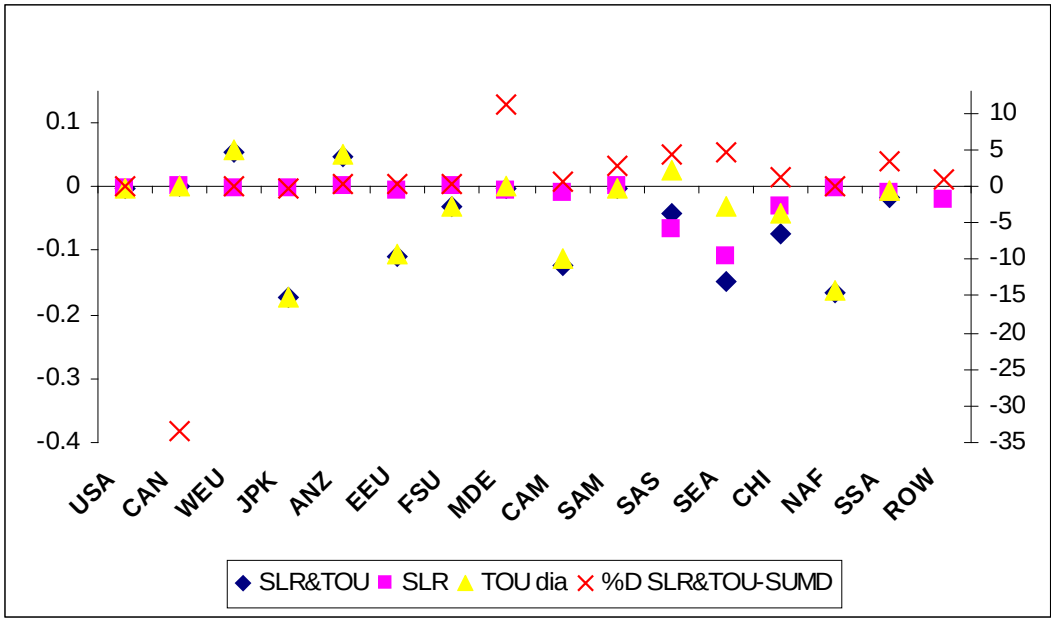
All values expressed as % changes w.r.t. 2050 baseline “without climate change”.

Figure 1: real GDP (A)



Impacts on GDP (in % changes wrt 2050 baseline "without climate change") of sea level rise (SLR), tourism (TOU) and of sea level rise and tourism jointly (SLR&TOU) are measured on the left axis; the percentage difference between the sum of the first two and the third (%D SLR&TOU-SUM) is measured on the right axis.

Figure 2: real GDP (B)



Impacts on GDP (in % changes wrt 2050 baseline "without climate change") of sea level rise (SLR), tourism "diagnostic"(TOU dia) and of sea level rise and tourism jointly (SLR&TOU) are measured on the left axis; the percentage difference between the sum of the first two and the third (%D SLR&TOU-SUMD) is measured on the right axis.

Figure 3: Real GDP. The impact of tourism when added to the impact of sea level rise relative to the impact of tourism

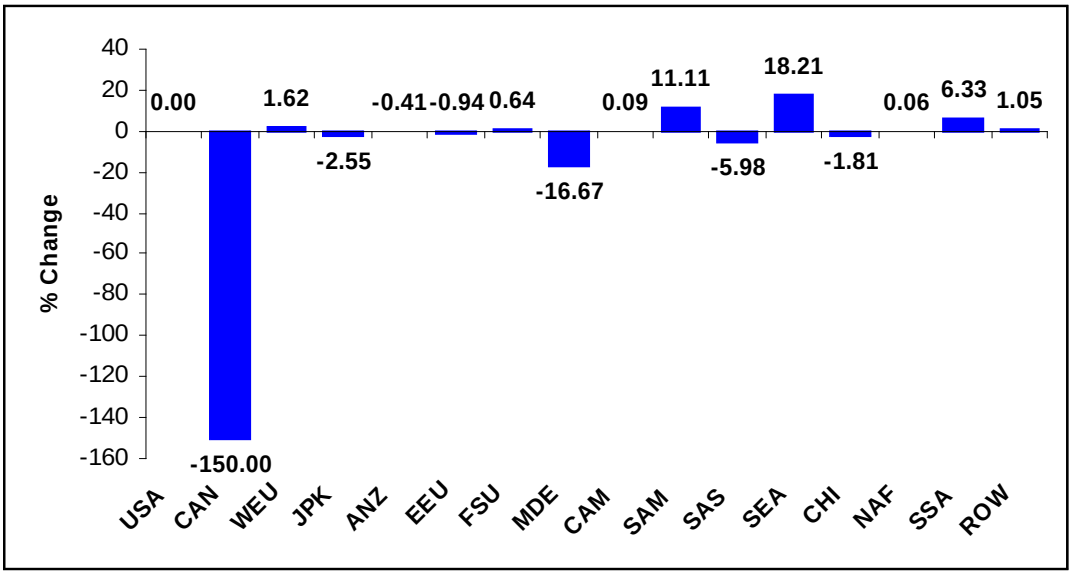
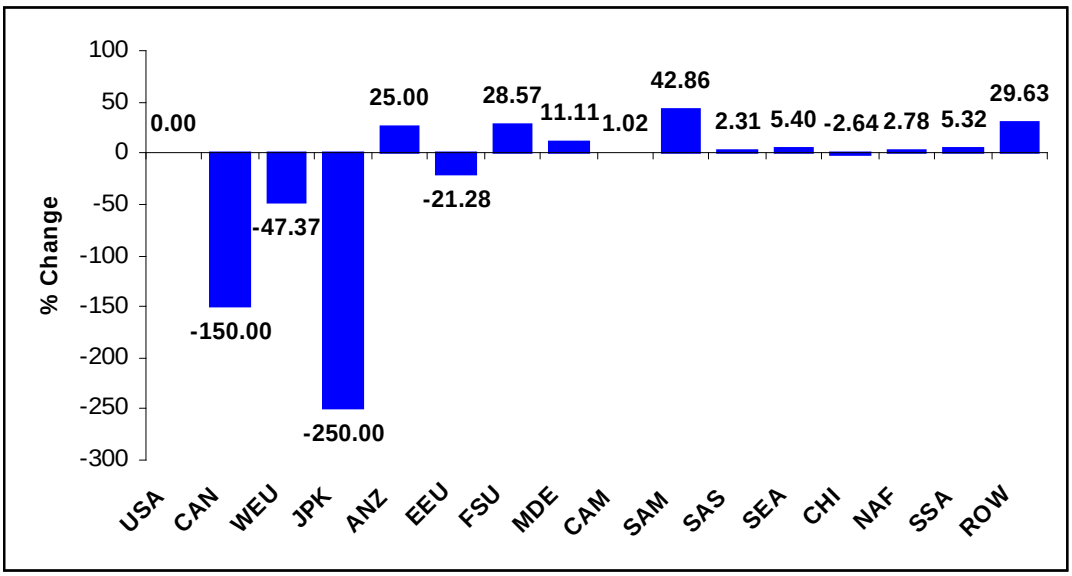


Figure 4: Real GDP. The impact of sea level rise when added to the impact of tourism relative to the impact of sea level rise



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 - amongst others - 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.

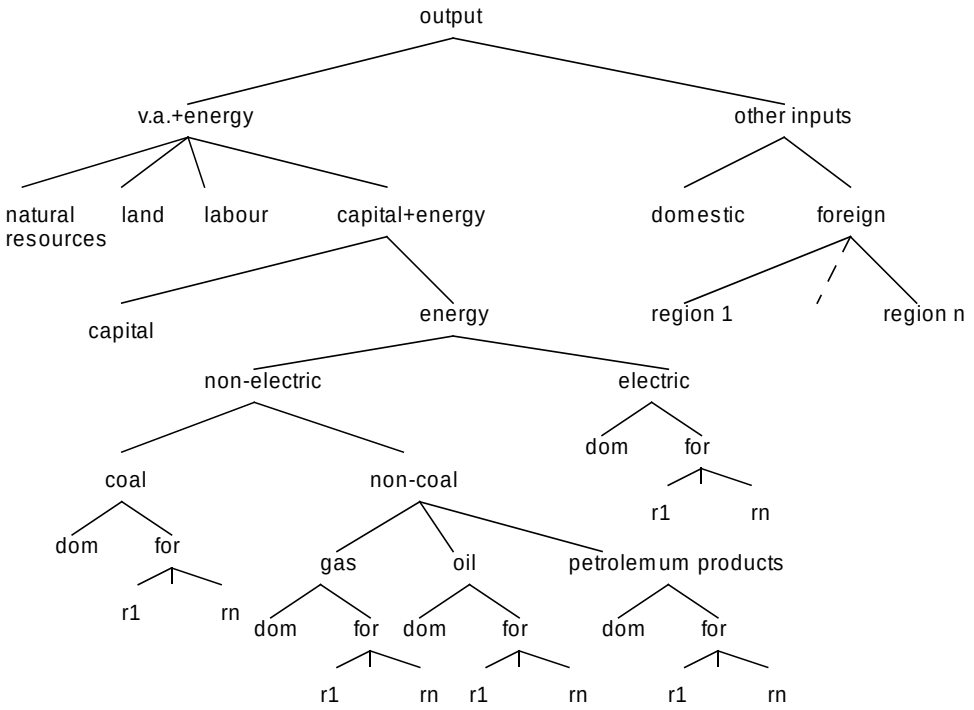


Figure A1 – Nested tree structure for industrial production processes

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 saying 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, viz. international transport and international investment production.

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.

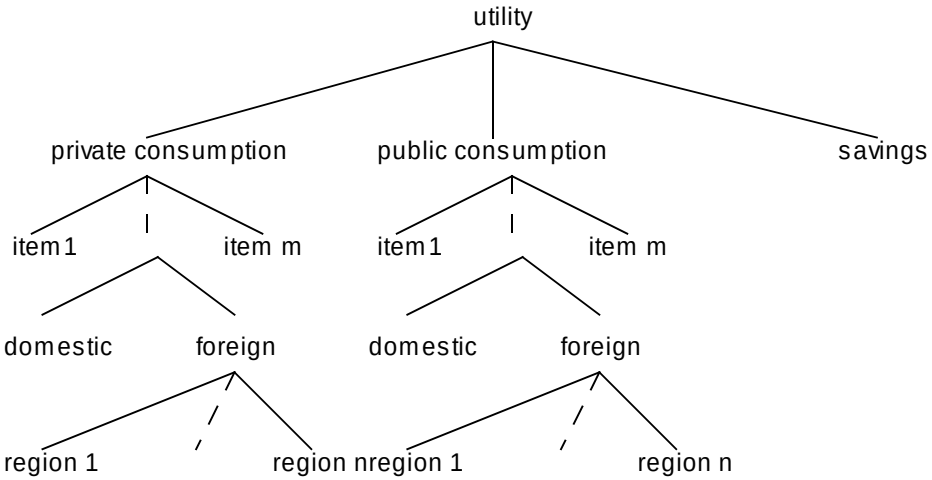


Figure A2 – Nested tree structure for final demand

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.

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