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THE IMPACT OF CLIMATE CHANGE ON DOMESTIC AND INTERNATIONAL TOURISM: A SIMULATION STUDY

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Abstract

We use an updated and extended version of the Hamburg Tourism Model to simulate the effect of development and climate change on tourism. Models extensions are the explicit modelling of domestic tourism, and the inclusion of tourist expenditures. Climate change would shift patterns of tourism towards higher altitudes and latitudes. Domestic tourism may double in colder countries and fall by 20% in warmer countries (relative to the baseline without climate change). For some countries international tourism may treble whereas for others it may cut in half. International tourism is more (less) important than is domestic tourism in colder (warmer) places. Therefore, climate change may double tourist expenditures in colder countries, and halve them in warmer countries. In most places, the impact of climate change is small compared to the impact of population and economic growth.The quantitative results are sensitive to parameter choices, both for the baseline and the impact of climate change. The qualitative pattern is robust, however. Climate change is more important to tourism than is sea level rise, because the latter heavily affects only a few places where beach nourishment is a viable option.

Key words

Climate change, international tourism, domestic tourism

1. Introduction

Climate is an important factor in the destination choice of tourists. Climate change is therefore likely to alter tourism patterns towards the poles and up the mountains (Hamilton *et al.*, 2004, forthcoming). This could negatively affect countries and regions that depend heavily on incoming tourists, but it could also bring benefits to places currently shunned by tourists. The impact of climate change on tourism is qualitatively clear. It is also, potentially important economically; tourism and recreation is, after health care, the second largest economic activity in the world. However, quantitative studies of the impact of climate change on tourism are rare. This paper tries to fill this gap, extending earlier work to domestic tourism and tourist expenditures.

Climate change impact studies for tourism use a variety of approaches. Some studies use physiological models of comfort levels as a function of weather and climate, either in great detail in a limited space (e.g., Matzarakis, 2002) or globally with a cruder approach (Amelung and Viner, forthcoming). Some studies focus on tourist resorts (e.g, Elsasser and Bürki, 2002; Perry, 2003), others on the behaviour of groups of tourists (Maddison, 2001; Lise and Tol, Hamilton, 2003). The market for tourism is a global one, however, and shaped by both demand and supply. The Hamburg Tourism Model (HTM) was designed with these requirements in mind. A global model of demand and supply, it does not look into detail in any one country, let alone tourism resort, either at the demand or the supply side. HTM does, however, allow for a synoptic overview, including the most important interactions.

In Hamilton *et al.* (2004, forthcoming), we use earlier versions of HTM, a model for international tourism. However, domestic tourism is not explicitly modelled there. In fact, these papers assume that the change in the absolute numbers of domestic tourists equals the change in the absolute numbers of international departures, without considering the actual number of domestic tourists. Recently collected data on domestic tourism (Bigano *et al.*, 2004) allows us to consider this aspect and explicitly model the trade-off between holidays in the home country and abroad. Domestic tourists comprise 86% of the total tourist numbers.

Another major shortcoming of earlier versions of HTM was that it stopped at tourist numbers. In this paper, we extend the model to include tourist expenditures. This allows us to estimate the economic implications of climate-change-induced changes in tourism. Berrittella *et al.* (2004) do this for HTM, version 1.0, but only for six world regions, using a computable general equilibrium model. Our economic approach is far simpler, but it does include all countries individually.

The paper proceeds as follows. Section 2 discusses the data. Section 3 presents the model, its calibration and validation. Section 4 shows the base results and sensitivity analyses. Section 5 concludes.

2. The data

Data are crucially important to a simulation model like HTM. In this section, we describe and discuss the data and the procedures to fill missing observations.

2.1. International arrivals and departures

The data on international arrivals and departures for 1995 are taken from the World Resources Databases (WRI, 2000).[1] There are two major problems with this dataset. Firstly, for some countries, the reported data are arrivals and departures for tourism only. For other countries, the data are arrivals and departures for all purposes. Unfortunately, it is impossible to correct for this.[2] Secondly, there are missing observations, particularly with regard to departures.

For arrivals, 181 countries have data but 26 do not. We filled the missing observations with a statistical model, viz.,[3]

[1] The reported departures from the Czech Republic were divided by 10; comparison to earlier and later years shows that the 1995 data have a typographical error.
[2] However, we did correct the Polish departure data. According to Statistic Poland, only 12% of the reported international departures are tourists (Central Statistical Office Poland, http://www.stat.gov.pl/english/serwis/polska/rocznik11/turyst.htm)
[3] The numbers below the parameter estimates are their standard deviations.

$$(1)\quad \begin{array}{l} \ln A_d = \underset{0.97}{5.97} + \underset{0.96}{2.05}\cdot 10^{-7} G_d + \underset{0.07}{0.22} T_d - \underset{2.21}{7.91}\cdot 10^{-3} T_d^2 + \underset{3.03}{7.15}\cdot 10^{-5} C_d + \underset{0.09}{0.80} \ln Y_d \\ N = 139; R_{adj}^2 = 0.54 \end{array}$$

where A denotes total arrivals, G is land area (in square kilometres); T is annual average temperature for 1961-1990 (in degrees Celsius) averaged over the country, Ct is length of coastline (in kilometres), and Y is per capita income. d indexes the country of destination. This model is the best fit[4] to the observations for the countries for which we do have data.[5] The total number of tourists increases from 55.2 million (observed) to 56.5 million (observed + modelled). The 26 missing observations constitute only 2% of the international tourism market.

For departures, the data problem is more serious: 107 countries report but 99 do not[6]; 46.5 million departures are reported, against 56.5 million arrivals, so that 18% of all international tourists have an unknown origin. We filled the missing observations with a statistical model, viz.,

$$(2)\quad \begin{array}{l} \ln \frac{D_o}{P_o} = \underset{17.05}{1.51} - \underset{0.17}{0.18} T_o + \underset{16.82}{4.83}\cdot 10^{-3} T_o^2 - \underset{4.22}{5.56}\cdot 10^{-2} B_o + \underset{0.09}{0.86} \ln Y_o - \underset{0.13}{0.23} \ln G_o \\ N = 99; R_{adj}^2 = 0.66 \end{array}$$

where D denotes departures (in number), P denotes population (in thousands) and B is the number of countries with shared land borders. o indexes the country of origin. This model is the best fit[7] to the observations for the countries for which we do have data.[8] This leads to a total number of departures of 48.2 million, so we scaled up *all* departures[9] by 17% so that the total number of observed and modelled departures equals the total number of observed and modelled arrivals.

2.2. Domestic tourism

For most countries, the volume of domestic tourist flows is derived using 1997 data contained in the Euromonitor (2002) database. For some other countries, we rely upon alternative sources, such as national statistical offices, other governmental institutions or trade associations. Data are mostly in the form of number of trips to destinations beyond a non-negligible distance from the place of residence, and involve at least one overnight stay. For

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[4] The estimation procedure started with a large number of explanatory variables, including precipitation, number of world heritage sites, political stability and a range of other indicators. Explanatory variables that are individually and jointly insignificant were eliminated. The shown specification results. We experimented with different representations of temperature (e.g., temperature of the hottest month); the annual average temperature describes the data best.

[5] The data on per capita income were taken from WRI (2000), supplemented with data from CIA (2002); the data on area and the length of international borders are from CIA (2002); the data on temperature from New *et al.* (1999). All data can be found at http://www.uni-hamburg.de/Wiss/FB/15/Sustainability.

[6] These are mostly African countries and small dependencies; however, data from Pakistan and Taiwan are also missing. Luxemburg is the only OECD country without departures data.

[7] The estimation procedure started with a large number of explanatory variables. Explanatory variables that are individually and jointly insignificant were eliminated.

[8] The data on population were taken from WRI (2000), the data on the number of land borders were taken from CIA (2002).

[9] Scaling up only the interpolated departures leads to distortions, as many small countries do not report departures data. Besides, countries have less of an interest in counting departures than in counting arrivals, so departures are probably underreported even if there are data available. Note that by equating total arrivals and total departures numbers, we assume that tourists visit one country per trip only.

some countries, data in this format were not available, and we resorted to either the number of registered guests in hotels, campsites, hostels etc., or the ratio between the number of overnight stays and the average length of stay. The latter formats underestimate domestic tourism by excluding trips to friends and relatives; nevertheless, we included such data for completeness, relying on the fact that dropping them did not lead to any dramatic change.

In general, the number of domestic tourists is less than the regional population. However in 22 countries, residents were domestic tourists more than once per year. An examination of the characteristics of such countries shows that these are in general rich countries, endowed with plenty of opportunities for domestic tourism and large (or at least medium-sized). This definition fits in particular Scandinavian countries (e.g., 4.8 domestic tourists per resident in Sweden) but also Canada, Australia, and the USA.[10] In the USA, the combination of a large national area, a large number of tourist sites, high income per capita and a willingness to travel long distances contribute to explain why, on average, an average American took a domestic holiday 3.7 times in 1997. Distance from the rest of the world is also important, and this is most probably the explanation for the many domestic holidays in Australia and New Zealand.

We filled the missing observations using two regressions. We interpolated total tourist numbers, $D+H$, where H is the number of domestic tourists, using

$$\ln \frac{D_o + H_o}{P_o} = -\underset{0.83}{1.67} + \underset{0.10}{0.93} \ln Y_o \qquad (3)$$
$$N = 63; R^2_{adj} = 0.60$$

Note that (3) is not limited from above. The number of tourists may exceed the number of people, which implies that people take a holiday more than once a year. Note that we measure population numbers in thousands. The parameters imply that people with an income of \$10,000 per person per year take one holiday per year.

The ratio of domestic to total holidays was interpolated using

$$\ln \frac{H_o}{D_o + H_o} = -\underset{1.19}{3.75} + \underset{0.42}{0.83} \cdot 10^{-1} \ln G_o + \underset{0.30}{0.93} \cdot 10^{-1} \ln C_o + \underset{0.32}{0.16} \cdot 10^{-1} T_o - \underset{1.11}{0.29} \cdot 10^{-3} T_o^2$$
$$+ \left(\underset{0.12}{0.16} - \underset{1.24}{4.43} \cdot 10^{-7} Y_o \right) \ln Y_o \qquad (4)$$
$$N = 63; R^2_{adj} = 0.36$$

The individual temperature parameters are not statistically significant from zero at the 5% level, but they are jointly significant. “Observations” for 1995 were derived from 1997 observations by dividing the latter by the population and per capita income growth between 1995 and 1997, correcting the latter for the income elasticity of (3) and (4). The income elasticity of domestic holidays is positive for countries with low incomes but falls as income grows and eventually goes negative. See Figure 1. Qualitatively, this pattern is not surprising. In very poor countries, only the upper income class have holidays and they prefer to travel abroad, also because domestic holidays may be expensive too (cf. Equation 6). As a country gets richer, the middle income class have holidays too, and they first prefer cheap, domestic holidays. The share of domestic in total holidays only starts to fall if the lower income class are rich enough to afford a holiday abroad; with the estimates of Equation (4), this happens if

[10] Poland, ranking 8th, is particularly active notwithstanding substantially lower per capita income than the rest of the top 10 countries.

average income exceeds $360,000, a high number. We perform sensitivity analysis on this specification below.

For the total (domestic and foreign) number of tourists, the world total is 12.0% higher if we include the interpolated tourist numbers, that is, 4.0 billion versus 3.6 billion tourists. The observed world total includes those countries for which we have observed both domestic tourists and international arrivals. For domestic tourists only, the observations add up to 3.1 billion tourists, and 3.5 billion tourists with interpolation, a 12.1% increase.

Note that Equations (3) and (4) can be used to derive international departures, just like Equation (2). The correlation coefficient between these two alternatives is 99.8%. We prefer (2) for its simplicity.

WTO (2002) contains data on the number of nights foreign tourists stay in selected countries. Dividing by the number of foreign tourists, this leads to the average length of stay, *S*. This can be modelled as

$$S_d = \underset{0.61}{2.13} - \underset{0.62}{2.58} E_d - \underset{0.79}{1.91} \cdot 10^{-6} G_d + \underset{0.40}{2.06} \cdot 10^{-1} T_d + \underset{0.78}{1.72} \cdot 10^{-4} C_d \qquad (5)$$
$$N = 55; R^2_{adj} = 0.40$$

where *E* is a dummy for measurement in hotels only (as opposed to all establishments). All parameters are significantly different from zero. The income per capita in the destination country does not affect the length of stay. Equation (5) says that tourists stay longer in hotter countries, in smaller countries and in countries with longer coasts; tourists spend less time in the destination country if they are accommodated in a hotel.

WRI (2002) has data on the total expenditures of international tourists. Dividing by the number of arrivals and their length of stay, this yields expenditure per tourist per day, *E*, which can be modelled as

$$E_d = -\underset{200}{611} + \underset{0.007}{0.029} Y_d + \underset{71}{295} X_d \qquad (6)$$
$$N = 47; R^2_{adj} = 0.31$$

where *X* is the ratio of the purchasing power parity exchange rate to the market exchange rate. Expenditures increase linearly with the average per capita income in the holiday country. This is as expected. Surprisingly, there is no significant relationship between the average income of the tourists and their expenditures. There is also no significant relationship between expenditures and income distributions, a measured by the Gini coefficient, in either the destination or the origin country. Per capita income is measured in market exchange dollars. The second explanatory variable in (6) is the ratio of purchasing power and market exchange rates. This ratio is high (up to 5) for the least developed countries and around 1 for developed economies. If we combine the two effects, plotting expenditures against countries ranked by per capita income – see Figure 1 – Equation (6) says that expenditures per tourist per day first *fall* with per capita income, then *increase* linearly with per capita income if the latter is above $10,000 per person per year. The increase is as expected, as per capita income is a rough proxy for price levels. Holidays are more expensive in poorer countries, probably because international tourists tend to be restricted to luxury resorts.

3. The model

We here present the Hamburg Tourism Model, version 1.2. HTM, version 1.0, is specified and applied in Hamilton *et al.* (forthcoming), HTM1.1 in Hamilton *et al.* (2004). The current version of the model explicitly considers domestic tourism and extends to tourist expenditures.

The goal of our model is to describe, at a high level of geographic disaggregation, the reactions to climate change of tourist behaviour, both in terms of changes in their (domestic and international) numbers and in terms of changes in their expenditure decisions. This has been performed through the following steps. First, we construct a matrix of tourism flows from one country to the next. Second, we perturb this matrix with scenarios of population, income, and climate change. Third, we compute the resulting changes in the average length of stay and expenditures.

The data concerns the number of domestic tourists, international departures, and international arrivals per country. For international tourism, we also need the matrix of bilateral flows of tourists from one country to the next. That matrix is largely unobserved. In order to build this matrix, we take Equation (1), multiply it with the distance (in kilometres) between the capital cities raised to the power $1.7 \cdot 10^{-4}$, and allocate the tourists from a particular country to all other countries proportional to the result. This procedure delivers the results for the base year 1995.

For other years, we use a similar approach. The total number of tourists per country follows from Equation (3). This is divided into domestic and international tourists using Equation (4), holding everything constant except for temperature and per capita income. Note that the ratio of Equation (4) is not necessarily smaller than unity; we restrict the ratio of domestic to total tourists to lie between 0.01 and 0.99. Note also that the temperature parameters of (4) are highly uncertain. The domestic to total tourist ratio is at a maximum at a temperature of 30°C. This would imply that, except for in the very hottest countries, global warming would result in more and more domestic holidays. We therefore replace the temperature parameters of (4) with those of Equation (2), which imply that the domestic-to-international ratio is at a maximum at 18°C. We perform sensitivity analysis on this specification below.

For the simulation years, we allocate international departures in the same way as we build the matrix of bilateral tourist flows, keeping everything as in 1995 except for per capita income and temperature. We also keep area constant. Tol (2004) argues that full coastal protection against sea level rise would be economically viable, even for small island countries. We perform a sensitivity analysis below in which sea level rise erodes beaches.

The change in the length of stay follows readily from (5). The change in expenditure per tourist per day follows from (6). Following Tol (2004), we let the ratio of purchasing power to market exchange rate fall with per capita income, using an income elasticity of 0.28. We put a lower bound on (6) which equals the observed lower bound in 1995.

Scenarios for population and per capita income growth are taken from the *IMAGE* 2.2 implementation of the IPCC SRES scenarios (IMAGE Team, 2002; Nakicenovic and Swart, 2001). The original scenarios are specified for 17 world regions. The growth rates of countries in each region are assumed equal to the regional growth rate. Scenarios for the global mean temperature are derived from the *FUND* model (Tol, 2002), using the same population and economic scenarios and the corresponding scenarios for energy efficiency improvements and decarbonisation. The global mean temperature change is downscaled to national means using the *COSMIC* model (Schlesinger and Williams, 1995).

The 1995 model values for the total number of tourists, the number of domestic tourists, the length of stay, and the expenditures are as observed. We do not have data for other years to validate this part of the model. We can validate international arrivals and departures, however. Figure 2 compares the model results for international arrivals to the observations for 1980, 1985, 1990, and 1995. The correlation between observed and modelled international arrivals in 1995 is almost perfect, largely because of calibration. For the other years, the correspondence between observations and modelled values is never below 92%.

Figure 3 compares model results and data for international departures. Between 1985 and 1995, the correspondence between observations and model results is between 91 and 94%. For 1980, this drops to 79%, which is still a reasonable performance given the fact that data are patchy, not just for international tourism, but also for per capita income.

4. Results

4.1. Base results

Figure 4 shows some characteristics of the A1B scenario without climate change for 16 major world regions. Currently, the OECD (the regions at the bottom of the graph) dominates tourism, with over half of world tourists but only a fraction of the world population. However, the OECD share has been declining over the last 20 years, and will continue to do so. For most of the 21st century, tourism will be predominantly Asian. Within Asia, East Asia leads first, but South Asia will take over after a few decades. The dominance of the rich countries in international departures is stronger than it is in domestic holidays, and this dominance will decline more gradually. Asia (Africa) has a smaller (bigger) share of international tourism than of domestic tourism, because it has so a number of big (many small) countries. The difference between Europe and North America has the same explanation. The pattern of international arrivals is similar to, but smoother than the pattern of international departures; international tourists cross borders, but prefer to travel not too far. The pattern of receipts from domestic and international tourists is different. Here, the OECD first expands its market share as expenditures per tourist per day fall as the poorer countries grow richer – see Equation (6). After 2030, however, the other regions, but particularly Asia, capture a larger share of the market.

Figure 5 shows the impact of climate change on domestic tourism numbers, both over time and over space. While the world aggregate number of domestic tourists hardly changes due to climate change, individual countries may face dramatic impacts that grow rapidly over time. By 2100, domestic tourism numbers may be up by 100% or down by 30%. Roughly speaking, currently colder countries see an increase in domestic tourism. Colder countries see an increase in domestic tourism, warmer countries a reduction. Exceptions to this are countries at high altitudes surrounded by lower lying countries. While colder than their neighbouring countries, they are projected to face roughly the same, absolute warming and therefore break the smooth pattern of Figure 5. Because tourists prefer to stay close to home, high altitude countries (surrounded by low altitude countries) have an advantage over low altitude countries (surrounded by other low altitude countries) with a similar initial climate, because the neighbouring countries of the former are hotter than the neighbouring countries of the latter. Countries at the minimum (0.01) or maximum (0.99) share of domestic tourism in total tourism, are not affected by climate change.

Figure 6 shows the impact of climate change on international tourism arrivals, both over time and over space. Aggregate international tourism falls because of climate change, reaching a minimum of 10% below the scenario without climate change around 2025, and edging towards zero after that. Aggregate international tourism falls because more tourists stay in their home country (cf. Figure 5), particularly tourists from Germany and the UK, who make up a large part of international tourism; tourists from hot countries would increasingly prefer international over domestic holidays, and the share of such tourists gradually increases throughout the century. For individual countries, international arrivals may fall by up to 60%, or increase by up to 220% in 2100. Climate change increases the attractiveness of cooler countries, and reduces that of warmer ones.

Figure 7 shows the impact of climate change on total tourism expenditures, both over time and over space. World aggregate expenditures hardly change, first rising a bit and then falling a bit. The situation is different for individual countries, with a range of a negative 50% to a positive 130% by 2100. As expected colder countries can expect to receive more tourism money because of climate change, and warmer countries less. The relationship between current climate and impacts of climate change, however, is a lot noisier for expenditures than for international arrivals and domestic tourists.

4.2. Sensitivity analysis

Hamilton *et al.* (2004, forthcoming) report extensive sensitivity analyses on the behaviour of international tourists. These analyses do not harbour major surprises. If climate change is more severe, so is its impact. The uncertainty about the baseline is large (if there are more and richer people, there would be more tourism), but the effect on the *relative* impact of climate change is minor (although the effect on the *absolute* impact is large). The impact of climate change is sensitive to the specification of the climate preferences, and to whether tourism demand saturates or not. Similar results hold for the current version of the model. The sensitivity analyses reported here focus on domestic tourists and on sea level rise, issues unexplored in previous papers.

Figure 8 shows the effect for the year 2100 of altering the income elasticity in Equation (4). Specifically, the first (second) parameter was reduced (increased) by one standard deviation. With these parameters, the share of domestic in total tourism starts falling at an annual income of $71,000 per person (rather than $361,000). As a result, international tourism grows at the expense of domestic tourism. As international tourism is more sensitive to climate change than is domestic tourism, this increases the impact of climate change. Figure 8 shows the effects on arrivals and expenditures. Altering the income elasticity as described, the climate change impacts on arrivals increase everywhere. The climate change impacts on expenditures fall in some places, as the loss of domestic tourism outweighs the gain in international tourism; the climate change impact on global expenditure switches from a negative 2% in the base case to a positive 8% in the alternative case.

Figure 9 shows the effect of changing the temperature parameters in Equation (4); in fact, we use the parameters of Equation (4) rather than those of Equation (2). Two things happen. Firstly, the optimal temperature for domestic holidays increases from 18°C to 30°C. This increases domestic tourism at the expense of international tourism. Secondly, the spread around the optimum is much more shallow; this reduces the effect of climate change. The second effect dominates, as is shown in Figure 9. The impact of climate change on domestic tourism is much reduced. The impact on international arrivals is much smaller; the global number of international tourists is only slightly different between the two cases, as in both cases the increases in domestic tourism almost cancel the decreases.

Figure 10 shows the effect of including sea level rise. We take the sea level rise scenario that corresponds to the temperature scenario used elsewhere in this paper. We take the national land losses, without coastal protection, from Hoozemans *et al.* (1993; see also Tol, 2004). We use the proportional land loss to scale both domestic tourism and the attractiveness to international tourists. That is, if the Maldives loses 78% of its territory to sea level rise (this is what the scenario says), than its domestic to total tourism ratio and its international attractiveness index both fall by 78%. This crude approach serves only to illustrate the qualitative effect of sea level rise; more sophisticated analyses would take account of the interaction of beach and sun, and deliberate efforts to maintain commercially attractive beach in the face of sea level rise induced erosion. In most countries, the effect of sea level rise on domestic tourism is minimal, as the land loss is minimal. In some countries, however, the effect is dramatic. The same pattern can be seen in international arrivals; most countries gain a little, and some lose a lot. No country gains particularly from the partial loss of the small island states.

5. Discussion and conclusion

We present an updated and extended version of the Hamburg Tourism Model (HTM). As in earlier papers (Hamilton *et al.*, 2004, forthcoming), we find that climate change would shift patterns of tourism towards higher altitudes and latitudes. Domestic tourism may double in colder countries and fall by 20% in warmer countries (relative to the baseline without climate change). For some countries international tourism may treble whereas for others it may cut in half. International tourism is more (less) important than is domestic tourism in colder (warmer) places. Therefore, climate change may double tourist expenditures in colder countries, and halve them in warmer countries.

However, in most places, the impact of climate change is small compared to the impact of population and economic growth.

The quantitative results are sensitive to parameter choices, both for the baseline and the impact of climate change. The qualitative pattern is robust, however. Interestingly, we find that climate change is more important to tourism than is sea level rise, because the latter heavily affects only a few places and beach nourishment for tourism is a viable option in many countries.

The model described in this paper is, to our knowledge, one in its kind. As all early models, it leaves much to be desired. Although the model is reasonably good at reproducing current and past patterns of international tourism, long-term and global studies of tourism demand are rare – and the empirical basis of the model is therefore weak. This is even truer for the effects of climate change on tourist destination choice, where the model is based on only a few studies from a limited set of similar countries. The projections neglect that changes in preferences, age structure, working hours and life styles would also affect tourist behaviour. The spatial resolution (national) of the model is crude, as is the temporal resolution (annual). A seasonal resolution would allow for the separate analysis of sun and snow seekers, and would allow tourists to shift their holidays not only in space (as they do in the current model) but also in time (from summer to spring and autumn). The economic impact does not extend beyond tourist expenditures. Improving on all this is deferred to future research. The results presented here demonstrate that this is a fruitful line of research.

Another potential application of the model is to sustainability analysis. On the one hand, tourists exert substantial pressure on the environment (Goessling, 2002) while ecotourism supports conservation (Goessling, 1999 and Wilson and Tisdell, 2001). Immediate applications include an analysis of the relocation effects due to restrictions on tourist numbers in a particular country (e.g., Bhutan). In Hamilton *et al.* (2004), we project carbon dioxide emissions from international travel, but other emissions and resource use can be readily added (if the data are available) now that the model includes the length of stay as well. The implications of constraints on emissions and resource use could then be analysed too. In this paper, the attractiveness of a tourist destination consists of a climate component, which changes, and a second, unspecific component, which is kept constant. Splitting the latter would allow for the analysis of other environmental changes – for example, the establishment of national parks. The analysis of price instruments to change the behaviour of tourists would require adding costs to the attractiveness index, and splitting "distance" into its price and time components. These are important topics for future research.

The paper demonstrates that, erratic as individual tourists may be, mass tourist movements can be modelled and projected into the future. As tourism is an important driving force of global environmental change, this is a step towards the prediction of human impacts on the environment and, via climate change for example, of environmental change on human behaviour.

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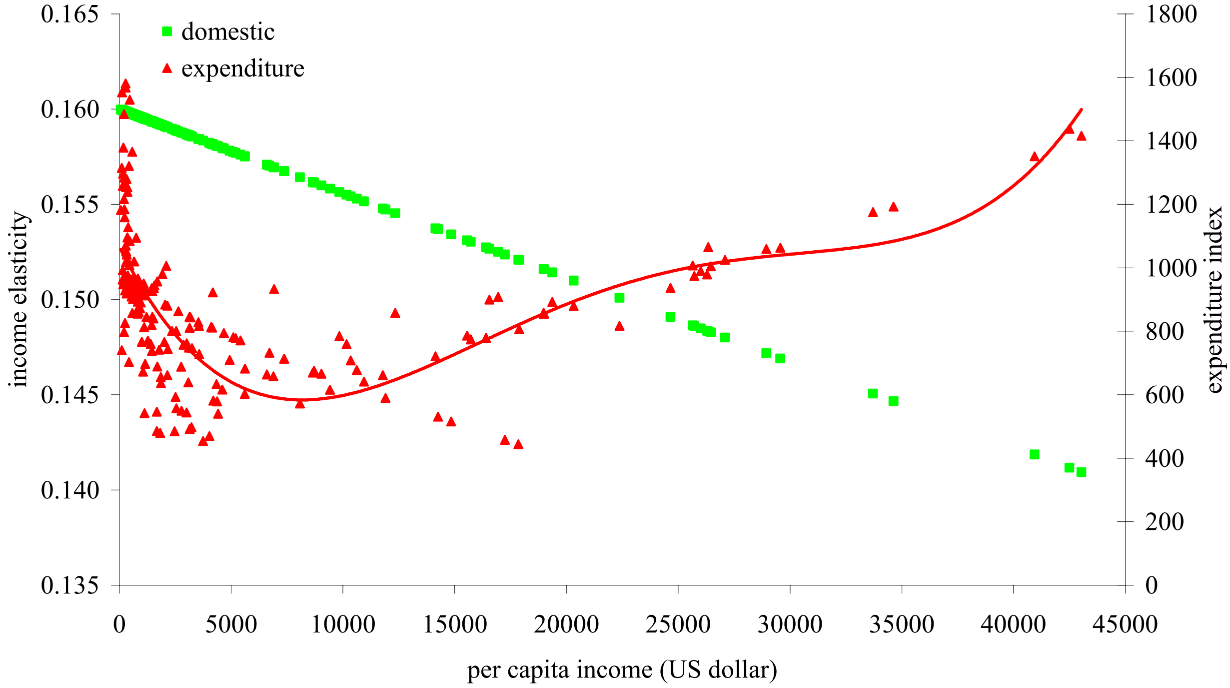
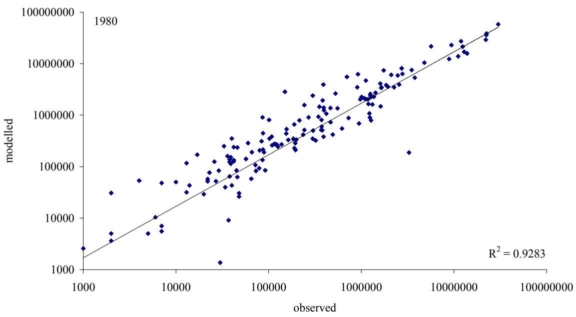


Figure 1. The income elasticity of the ratio of domestic to total tourists, and expenditures per tourist per day as a function of per capita



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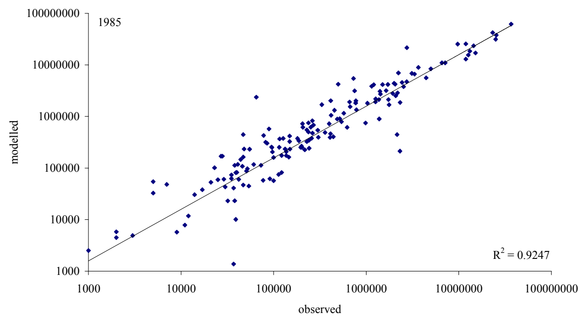

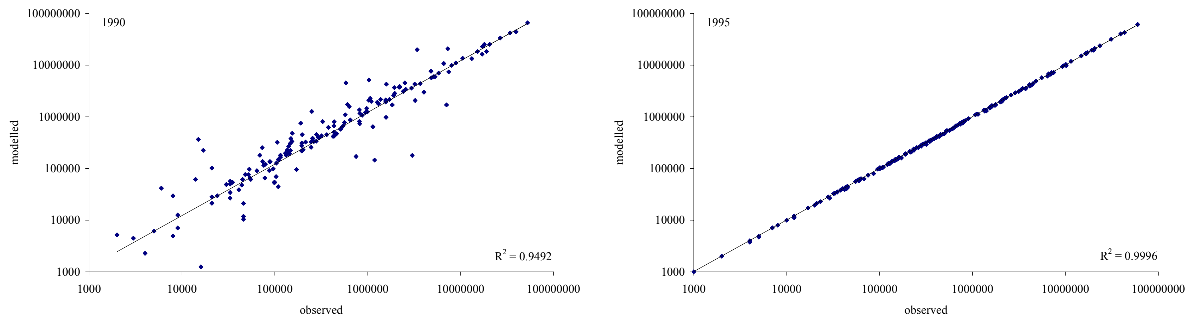

Figure 2. Observed versus modelled international arrivals in 1980, 1985, 1990 and 1995.

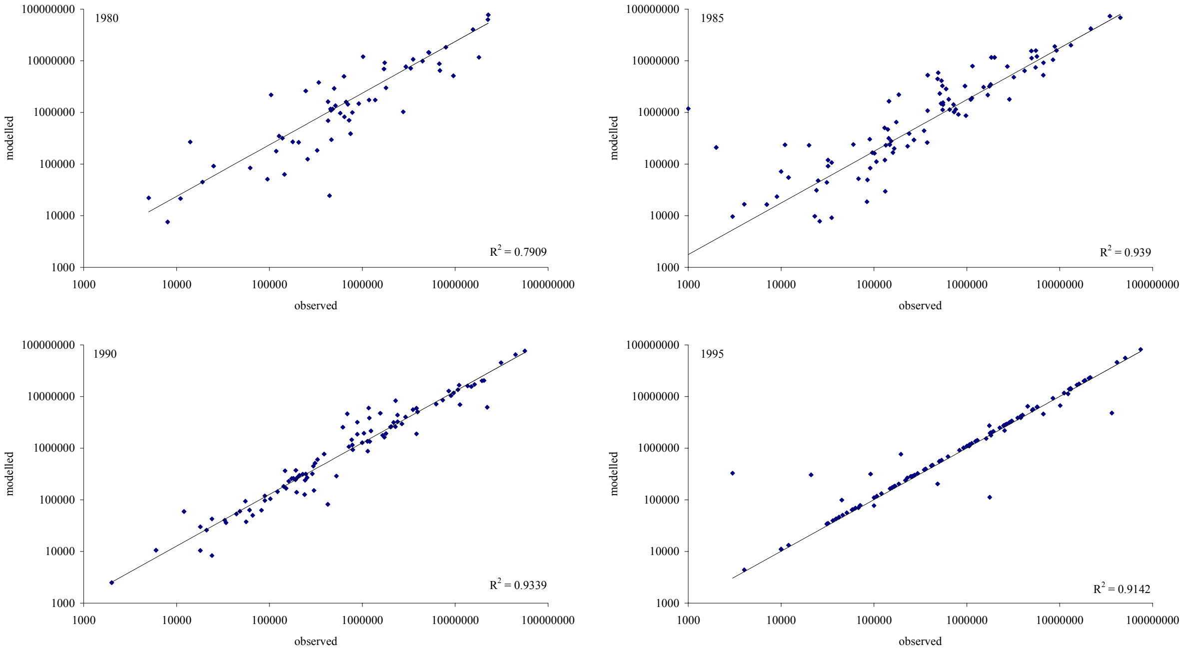

Figure 3. Observed versus modelled international departures in 1980, 1985, 1990 and 1995.

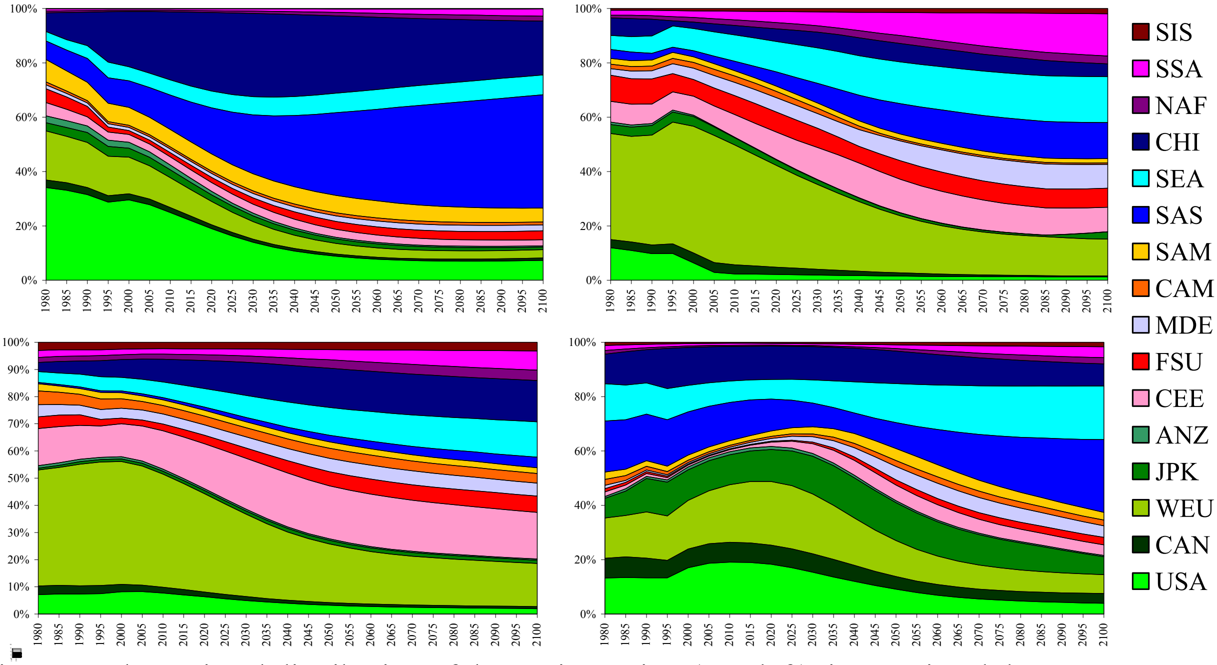

Figure 4. The regional distribution of domestic tourists (top, left), international departures (top, right), international arrivals (bottom, left) and tourism receipts (bottom, right) for the A1B scenarios without climate change. The regions are, from top to bottom: Small Island States; Sub-Saharan Africa; North Africa; China, North Korea and Mongolia; South East Asia; South Asia; South America; Central America; Middle East; Former Soviet Union; Central and Eastern Europe; Australia and New Zealand; Japan and South Korea; Western Europe; Canada, and the USA.

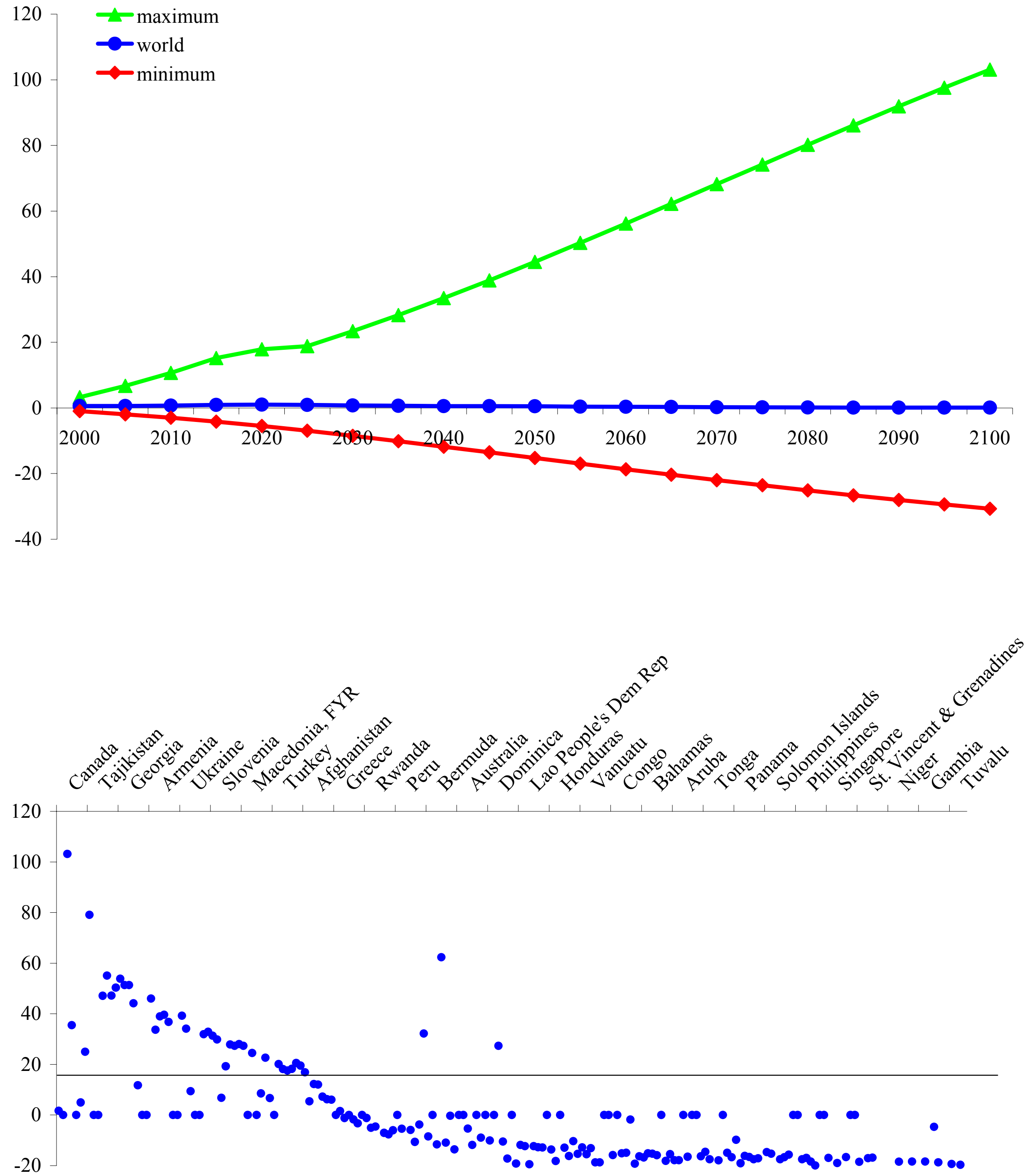

Figure 5. The effect of climate change on domestic tourist numbers, as a percentage of the numbers without climate change; top panel: world average, maximum impact (positive), and minimum impact (negative); bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.

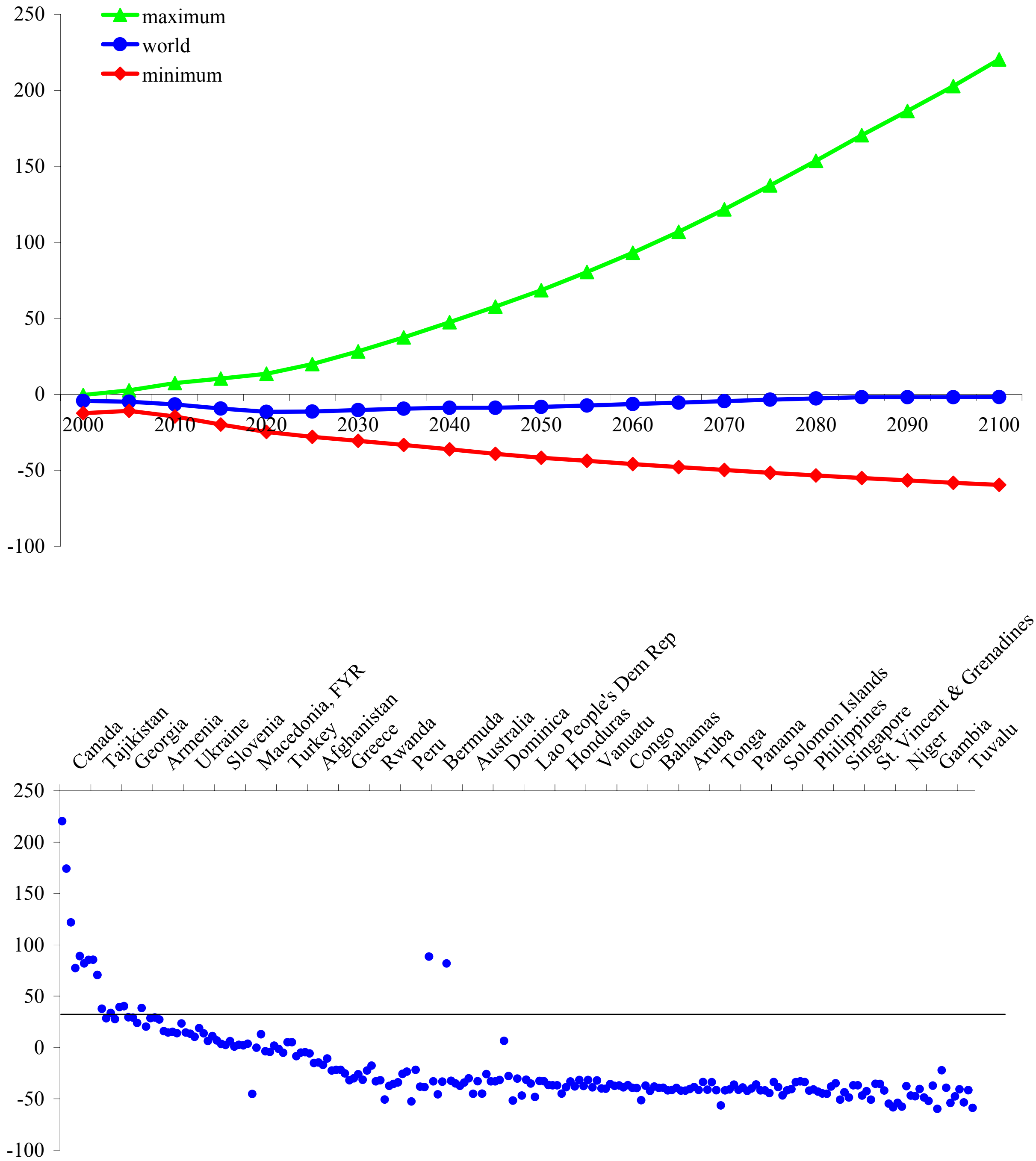

Figure 6. The effect of climate change on international tourist arrivals, as a percentage of the numbers without climate change; top panel: world average, maximum impact (positive), and minimum impact (negative); bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.

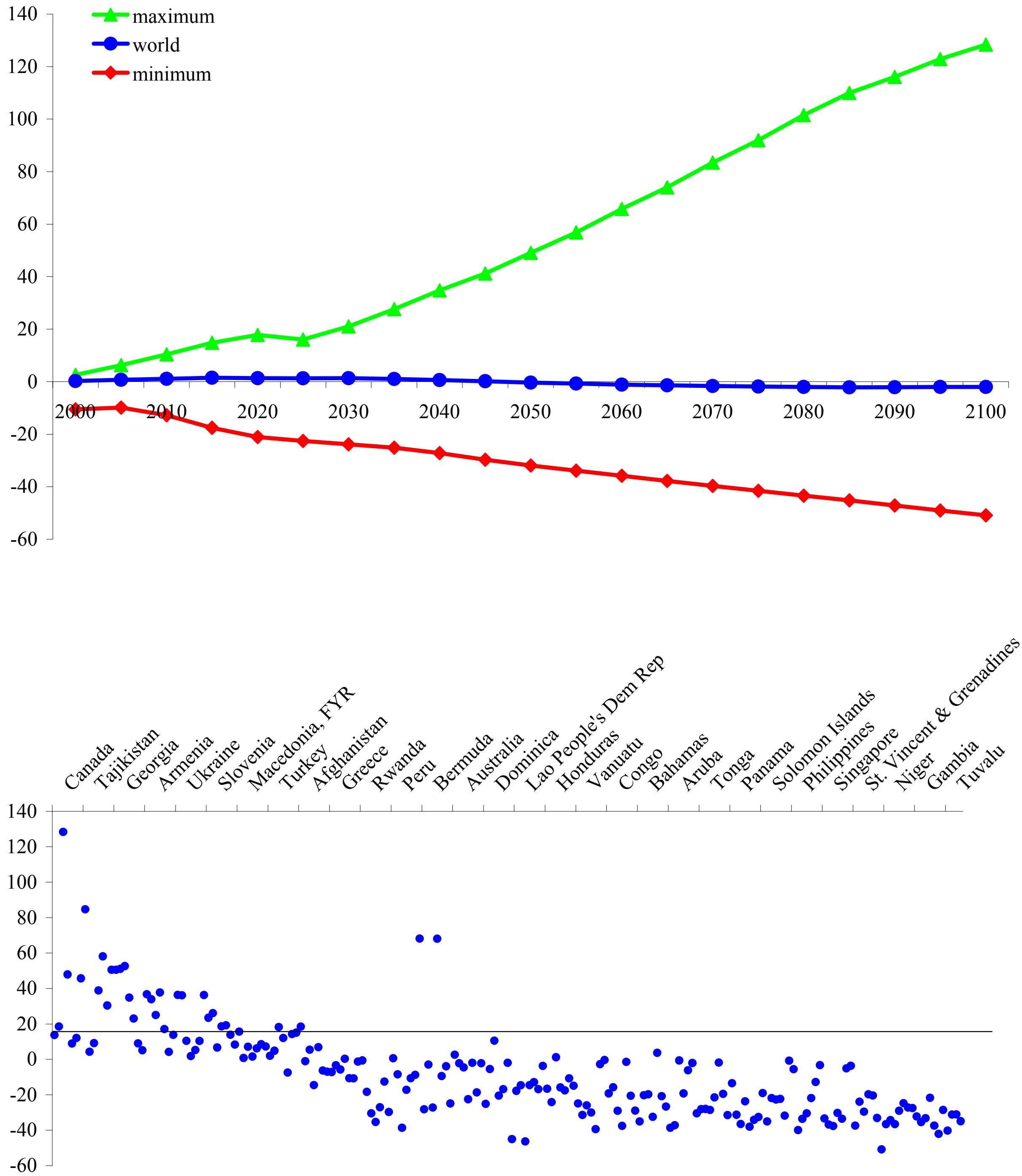

Figure 7. The effect of climate change on total tourism expenditures, as a percentage of the numbers without climate change; top panel: world average, maximum impact (positive), and minimum impact (negative); bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.

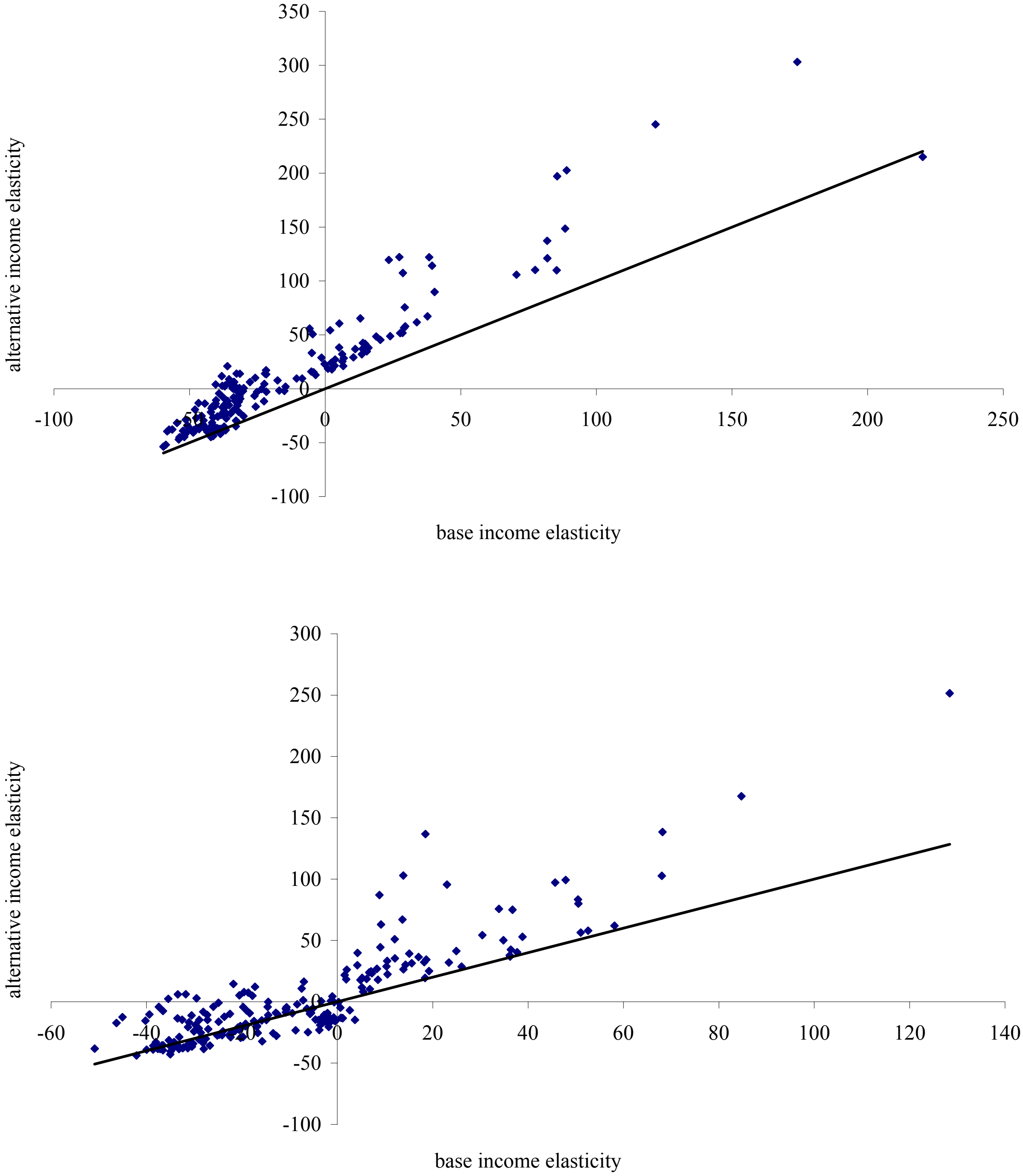

Figure 8. The effect of changing the income elasticity of Equation (4) on the impact of climate change on international arrivals (top panel) and tourism expenditures (bottom panel) in the year 2100.

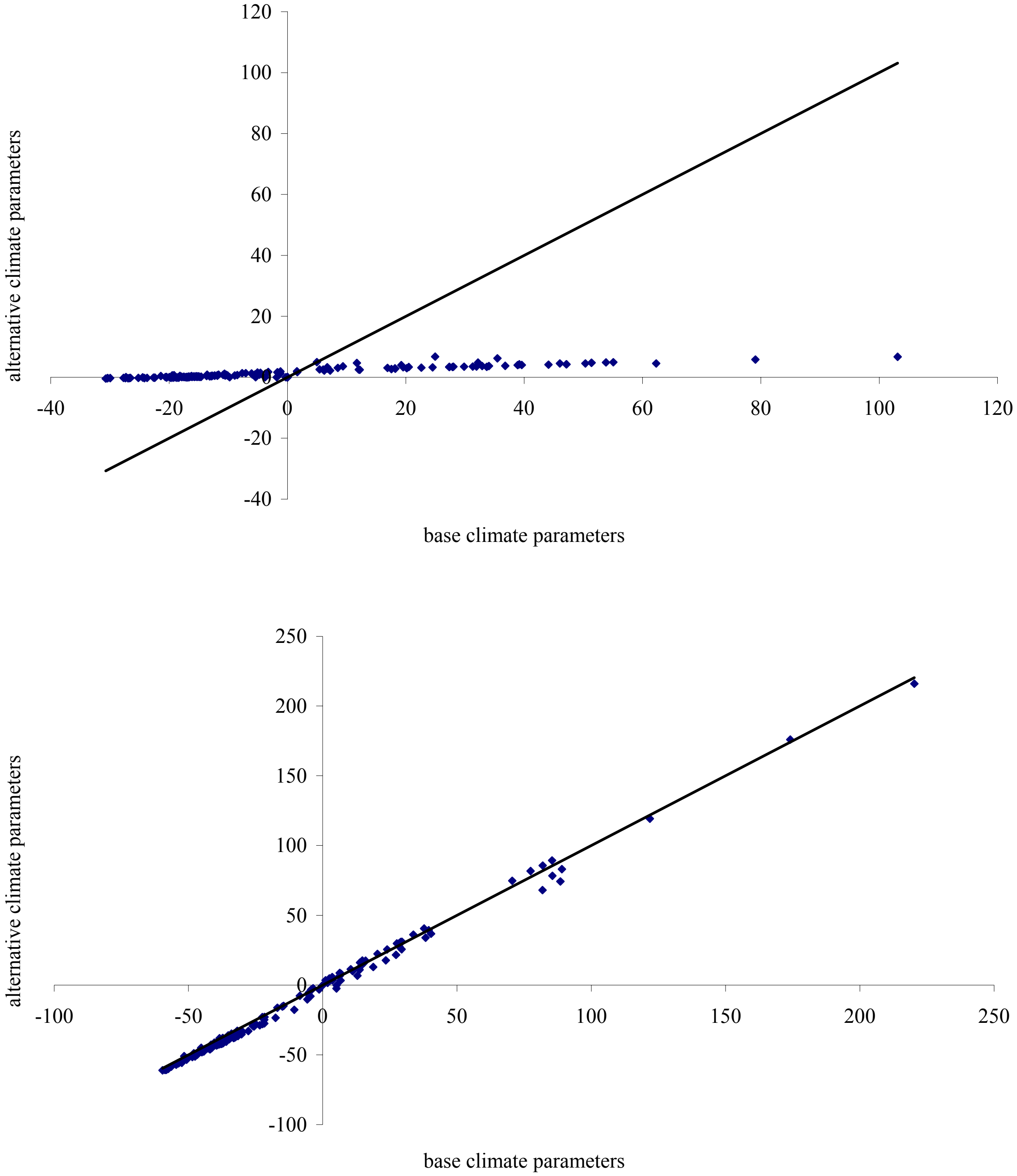

Figure 9. The effect of changing the temperature parameters of Equation (4) on the impact of climate change on domestic tourists (top panel) and international arrivals (bottom panel) in the year 2100.

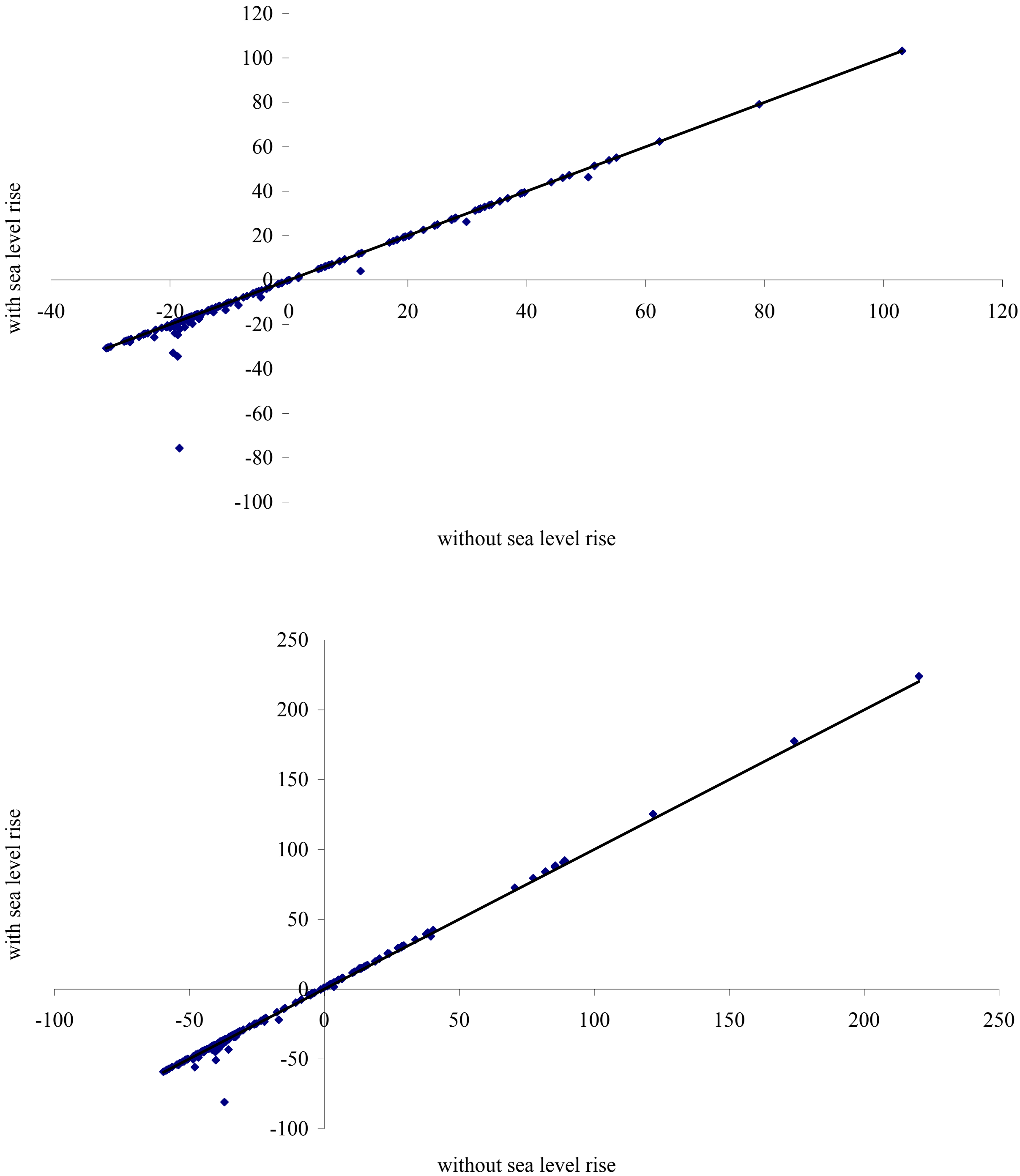

Figure 10. The effect of including sea level rise on the impact of climate change on domestic tourists (top panel) and international arrivals (bottom panel) in the year 2100.

Working Papers

Research Unit Sustainability and Global Change

Hamburg University and Centre for Marine and Atmospheric Science

Bigano, A., J.M. Hamilton and R.S.J. Tol (2005), *The Impact of Climate Change on Domestic and International Tourism: A Simulation Study*, **FNU-58** (submitted)

Bosello, F., R. Roson and R.S.J. Tol (2004), *Economy-wide estimates of the implications of climate change: Human health*, **FNU-57** (submitted)

Hamilton, J.M. and M.A. Lau (2004) *The role of climate information in tourist destination choice decision-making,* **FNU-56** (submitted)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2004), *The impact of climate on holiday destination choice*, **FNU-55** (submitted)

Bigano, A., J.M. Hamilton, M. Lau, R.S.J. Tol and Y. Zhou (2004), *A global database of domestic and international tourist numbers at national and subnational level*, **FNU-54** (submitted)

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Hamilton, J.M. and R.S.J. Tol (2004), *The Impact of Climate Change on Tourism and Recreation*, **FNU-52** (submitted)

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Rehdanz, K. and Maddison, D. (2004), *The Amenity Value of Climate to German Households*, **FNU-39** (submitted)

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