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 population growth, economic growth, and climate change on tourism. Model extensions are the explicit modelling of domestic tourism, the inclusion of tourist expenditures. Furthermore, the model is used to examine the impact of sea level rise on tourism demand. 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.

Keywords: Climate change, international tourism, domestic tourism

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1 Introduction

Climate is an important factor in the destination choice of tourists. Hamilton et al. (2005*a*,*b*)found that climate change shifts international tourism flows towards higher altitudes and latitudes. The redistribution of tourism flows could negatively affect countries and regions that depend heavily on income from tourism. On the other hand, it could also bring benefits to places that are currently not popular with tourists. The size of this impact is potentially important economically; tourism and recreation is, after health care, the second largest economic activity in the world. Certainly, the media shows a greater interest in tourism than in other aspects of our climate impact work. Tourism is omitted in estimates of the economic impact of climate change, and this may bias cost-benefit and other decision analysis of mitigation policy. Tourism does feature in discussions on adaptation policy, but competition between resorts is typically ignored. This paper does not inform those debates directly, but it does provide an updated set of estimates of the impact of climate change on international tourism and includes, for the first time, tourist expenditures, domestic tourism, and sea level rise.

Quantitative studies that examine the impact of climate change on tourism use a variety of approaches, and they are carried out at different levels of spatial resolution. Approaches include: estimating changes to the supply of tourism services (e.g. Elsasser & Messerly, 2001), estimating changes in the climatic attractiveness as measured by comfort indices (e.g. Scott et al., 2004) and estimating the statistical relationship between tourism demand and climate (e.g. Lise & Tol, 2002). The first of these approaches is typically carried out at the scale of a region within a country or even for particular resorts. The extensive data requirements restrict the index studies to focussing on smaller regions or particular destinations within larger areas (see below for the exception). The statistical demand studies have been carried out for tourists from particular countries travelling to the rest of the world. Hamilton & Tol (In press.) review the literature on tourism, recreation, climate, and climate change.

The lack of a global overview and the inclusion of substitution between destinations, both aspects that have been overlooked in the studies of the impact of climate change on tourism, were motivating factors behind the design and development of HTM. The HTM is a global model of tourism demand that does not look into detail at any one country let alone at any tourism resort. HTM does, however, allow for a synoptic overview, including the most important interactions. Apart from the previous versions of HTM, another study examines the impact of climate change on tourism at the global scale. Amelung (2006) depicts comfort index scores for the world on a 0.5 x 0.5 degree grid, and Amelung et al. (2007) use this to study the potential impact of climate change. Unfortunately, tourism data are not available at such a scale, making it difficult to connect tourism demand with the associated index value.

Domestic tourism accounts for 86% of total tourism (Bigano et al., 2007). Despite its size in comparison to international tourism, there are relatively few studies that analyse domestic tourism demand. These often focus on domestic

tourists of one country or in one region of a particular country (for example, Coenen & Eekeren, 2003; Seddighi & Schearing, 1997). Furthermore, domestic tourism has been overlooked in the research on climate change and tourism. On the whole the focus has been on international tourism; or tourism is examined in general not distinguishing between the two types of tourism. There are three reasons why analysts have focussed on international tourism rather than domestic tourism. Firstly, foreign holidays capture the imagination. Secondly, international tourism brings foreign currency and foreign income to the destination country. Thirdly, international tourists are readily counted as they pass through transport and customs bottlenecks. This paper is a small step towards restoring this bias.

In particular, substitution between domestic and international tourism needs to be examined. In the previous versions of HTM it is assumed 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., 2007) allows us to consider this aspect and explicitly model the trade-off between holidays in the home country and abroad.

Another major shortcoming of earlier versions of HTM was that it stopped at tourist numbers and at the examination of the impact of climate change purely in terms of a change in temperature. 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. Berritella et al. (2006) do this using HTM, version 1.0, and a computable general equilibrium model (CGE), but only for six world regions. Our economic approach is far simpler, but it does include all countries individually, which is impractical with a CGE. Bigano et al. (2006a) use results of the current version of HTM in a 16-region CGE. In addition, we use the HTM to examine the impact of sea level rise on domestic and international tourism. This extends, for the first time, the analysis beyond temperature change to the indirect impacts of climate change.

Goessling & Hall (2006) list five major weaknesses of current models, of which HTM is one, in predicting tourism flows. These points serve as caveats to the results presented below.

1. Data are weak. Particularly, data are not homogenous, different types of travel are grouped together, and the data are too coarse geographically and temporally. This is surprising, as tourism is so important in the economy. The data used in this study are the best data available.

2. Temperature is assumed to be the only important climate variable. There are two reasons for this. Firstly, many climate parameters are strongly correlated to temperature, so that switching variables would not change much, while statistical procedure cannot distinguish one effect from the other. This is particularly the case for temperature extremes, but also for such things as cloudiness, humidity, and weather predictability. Secondly, temperature is the only climate variable for which there are reliable data

and future projections with a large spatial coverage. Precipitation, particularly, has a high spatial variability, while climate model strongly disagree on future projections. Note that this study adds sea level rise to the list of drivers of the attractiveness of destinations to tourists.

3. The role of weather information in decision-making is unclear. While this is true in detail, empirical studies show that climate and weather have explanatory power for tourist destination choice (e.g. Maddison, 2001; Lise & Tol, 2002). Although it is unclear how the British know that it is warmer on Ibiza than it is on the Isle of Man, it is clear that they do and flock to Ibiza partly for this reason. Nonetheless, the model used in this paper is phenomenological—relationships are postulated, rather than derived from well-established laws or axioms, and assumed to be constant over time.

4. Future drivers are uncertain, such as disposable income, time budget, and travel costs. This problem is intrinsic in all predictions. Extensive sensitivity analyses are needed, and indeed reported in this and related papers.

5. Besides the uncertainty about the trends, there is stochasticity as well. Natural disasters, terrorism, and sport events are examples. Such events may wreck short-term predictions, but their effect on long-term trends is much smaller. See Bigano et al. (2006b) for a further discussion.

The paper proceeds as follows. Section 2 discusses the data. Section 3 presents the model, its calibration and validation. The model and all necessary input data can be downloaded at http://www.fnu.zmaw.de/fileadmin/fnu-files/models-data/htm/HTM11.zip. 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 briefly describe and discuss the data and the procedures to fill missing observations.

2.1 International arrivals and departures

The main data are on international arrivals and departures of tourists. A tourist stays at least one night, and at most one year. Tourists include holiday makers, visitors to friends and family, and pilgrims. Business travellers and migrant workers are excluded (unless they claimed to be tourists). The source and the limitations of the dataset on international arrivals and departures for 1995, and the subsequent estimation of missing data points are described in Hamilton et al. (2005a). For completeness, the equations used to estimate arrivals and

Table 1: Definition of the variables

Variable	Description
A	Total arrivals per
G	Land area (km^2)
T	Annual average temperature (℃)
C	Length of coastline (km)
Y	Per capita income
D	Total international departures per year
P	Population (in thousands)
B	The number of countries with shared land borders
H	Total domestic tourist trips per year
S	Average length of stay of international
E	Average expenditure of international tourists per day
L	Equal to 1 when "the length of stay" is for hotels only, otherwise 0
X	The ratio of purchasing power parity to the market exchange
d	The destination country
o	The origin country

departures are presented again here. First, the equation for arrivals (see Table 1 for a description of the variables used):

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

and second, the equation for departures:

$$(2) \quad \begin{aligned} \ln \frac{D_o}{P_o} = \underset{17,05}{1.51} - \underset{0.17}{0.18} T_o + \underset{16.82}{4.83} \cdot 10^{-3} T_o^2 \\ - \underset{4.22}{5.56} \cdot 10^{-2} B_o + \underset{0.09}{0.86} \ln Y_o - \underset{0.33}{0.23} \ln G_o \end{aligned} \qquad \begin{aligned} N = 99 \\ R_{adj}^2 = 0.66 \end{aligned}$$

Note that these equations are also the basis of the model. All data are annual. Summer tourism dominates winter tourism in most countries in reality, and in all countries in the model. Other explanatory variables are either insignificant (e.g., number of World Heritage Sites) or not available (e.g., number of hotel beds). Only total arrivals are counted, rather than arrivals from a particular origin.

2.2   Domestic tourism

The model has been extended to not only cover international tourism flows but also domestic tourism. This requires an extensive global database of the amount of domestic tourism trips per country in the base year.

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 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 population of the origin country. 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, they are endowed with plenty of opportunities for domestic tourism and they are large (or at least medium-sized). This definition fits in particular to the Scandinavian countries (e.g., 4.8 domestic tourists per resident in Sweden) but also Canada, Australia, and the USA[1]. In the USA, the combination of a large national area, a large number of tourist sites and high income per capita 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

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

Note that Equation 3 is not limited from above; we capped Equation 3 at 12 holidays per person per year. 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 in countries with an income of \$10,000 per person per year, the average number of trips taken per person is one per year.

The ratio of domestic to total holidays was interpolated using

$$(4) \quad \begin{aligned} \ln \frac{H_o}{D_o + H_o} &= -3.75 + 0.083 \ln G_o + 0.093 \ln C_o + 0.016 T_o \qquad N = 63 \\ & {}_{1.19} \quad {}_{0.42} \qquad {}_{0.30} \qquad {}_{0.32} \\ &\quad - 2.9 \cdot 10^{-4} T_o^2 + \left(0.16 - 4.43 \cdot 10^{-7} Y_o\right) \ln Y_o \qquad R^2_{adj} = 0.36 \\ & {}_{1.11} \qquad\quad {}_{0.12} \quad {}_{1.24} \end{aligned}$$

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 Equation 3 and Equation 4. The income elasticity of

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[1] Poland, ranking 8th, is particularly active notwithstanding substanially lower per capita income than the rest of the top 10 countries.
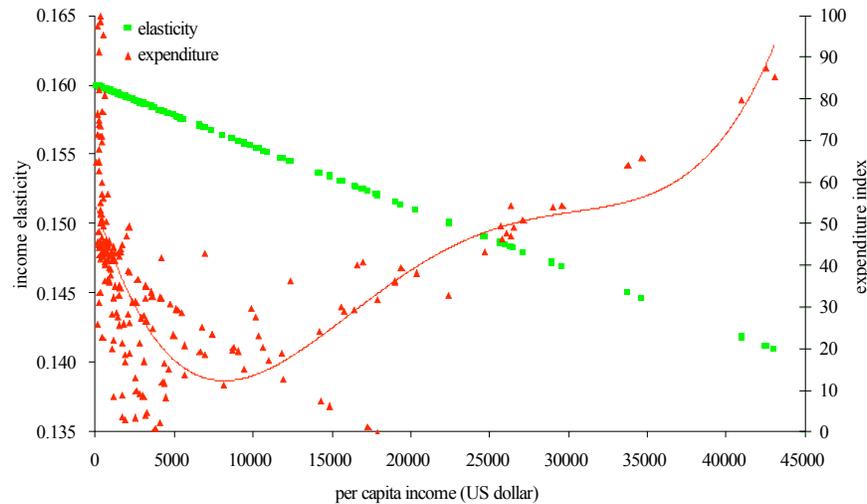
Figure 1: The income elasticity of the ratio of domestic to total tourists (left axis)
and expenditures per tourist per day as a function (indexed, right axis) of per
capita income

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 average income exceeds $360,000. This is a high number that
is well outside the sample, and that is never attained in any scenario. That is,
the share of domestic in total holidays never falls in the model. 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 Equation 2 can be used to derive international departures, just
like Equation 3 and Equation 4 can. The correlation coefficient between these
two alternatives is 99.8% (for 1995). Equation 2 was used in version 1.0 and 1.1
of HTM. Here, we use Equation 3 and Equation 4. In the new specification, we
have the total number of holidays as well as the trade-off between holidays at
home and abroad. In Equation 2, the number of international holidays goes up

with a constant income elasticity of 0.86. In Equation 3 and Equation 4, the income elasticity is 0.80 at a (hypothetical) zero income, rising to 0.93 at an income of \$36,000, and to 1.00 at an income of \$53,000. In the new specification, the number of international holidays accelerates faster.

2.3 Economic impacts

As well as simulating the changes in tourist numbers, the model has been extended to include the direct economic impacts of tourism, that is through the simulation of the length of stay and the average expenditure per day. The WTO (2002) provides data on the number of nights international tourists stay in selected countries. Dividing the number of nights by the number of international tourists leads to the average length of stay of international tourists, S. This can be modelled as

$$(5) \quad \begin{aligned} S_d &= \underset{0.61}{2.13} - \underset{0.62}{2.58}L_d - \underset{0.79}{1.91} \cdot 10^{-6}G_d \qquad && N = 55 \\ &+ \underset{0.40}{0.206}T_d + \underset{0.78}{1.72} \cdot 10^{-4}C_d \qquad && R^2_{adj} = 0.40 \end{aligned}$$

where L is a dummy (1 for tourists staying in hotels only, 0 for tourists in all establishments). All parameters are significantly different from zero. The income per capita in the destination country does not affect the length of stay. The interpretation of Equation 5 is that tourists stay longer in hotter countries, in smaller countries and in countries with longer coasts but 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 total expenditures by the number of arrivals and their length of stay yields expenditure per international tourist per day, E, which can be modelled as

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

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[2] 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 Equation 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 destination countries ranked by per capita income—see Figure 1—Equation 6 says that expenditures per tourist per day

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[2]Note that the average income of tourists is not observed. We used the bilateral matrix of tourist flows in the model to construct the average income of tourists.

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 expen-
sive in the poorest countries, probably because international tourists tend to be
restricted to luxury resorts—we are not aware of any study comparing tourist
expenditures between poor and rich destinations. Note that we use Equation 6
to *change* expenditures; expenditures in the calibration year are as observed.

3   The model

The Hamburg Tourism Model, version 1.0, is specified and applied in Hamilton
et al. (2005*a*), and HTM1.1 is specified and applied in Hamilton et al. (2005*b*).
The current version (1.2) of the model explicitly considers domestic tourism and
includes tourist expenditures.

  The goal of our model is to describe, at a high level of geographic disaggre-
gation, 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 input data to the model are a mix of observa-
tions and interpolations (see above). The equations in the model are based on
the regressions shown above, but they are not identical. This is because the
regressions are about the column and row totals, whereas the model is about
the bilateral flow matrix. This also implies that the model has to be calibrated.

  The data concern 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 $1.7 \cdot 10^{-4}$ (after Lise & Tol, 2002), 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 in-
ternational 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. This restriction is effective. Note also that the
temperature parameters of Equation 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 pa-
rameters of Equation 4 with those of Equation 2—both equations are about

foreign holidays—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, 2001; Nakicenovic & 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 & Williams, 1998).

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, because that is the year 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 countries of the OECD (the regions at the bottom of the graph) dominate 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
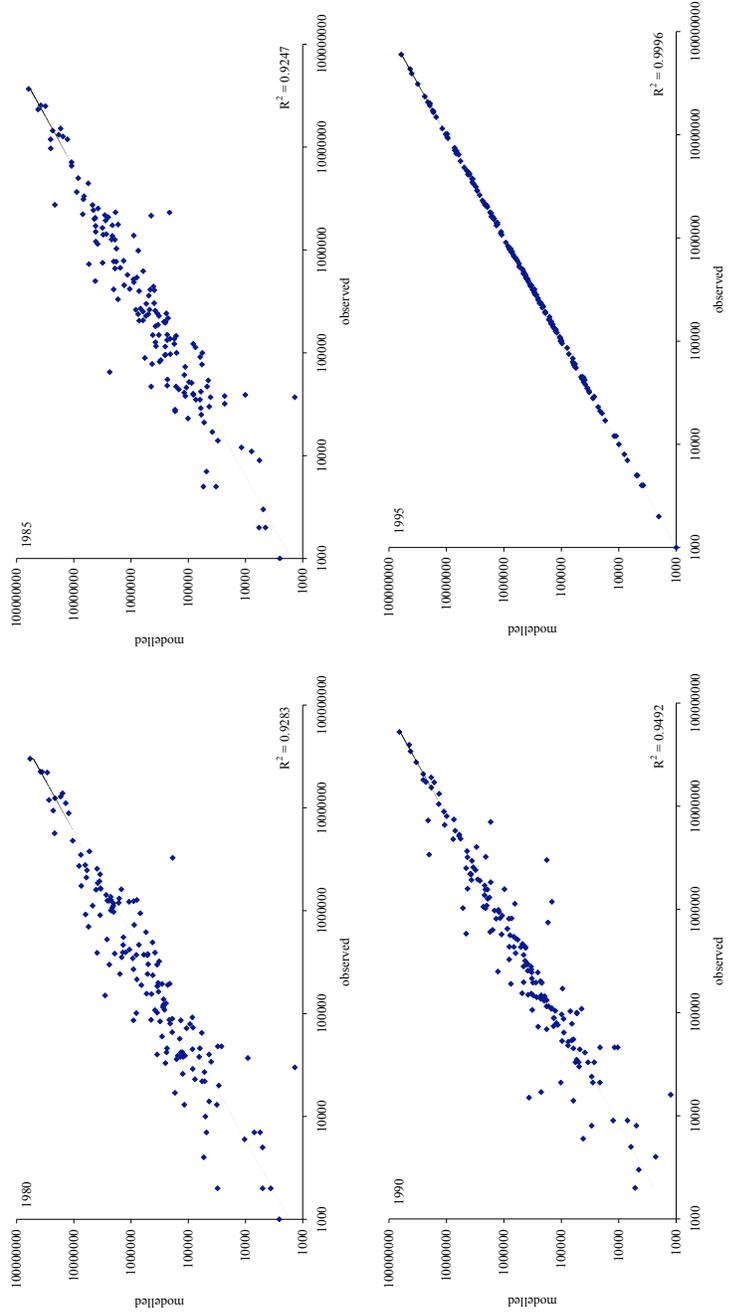
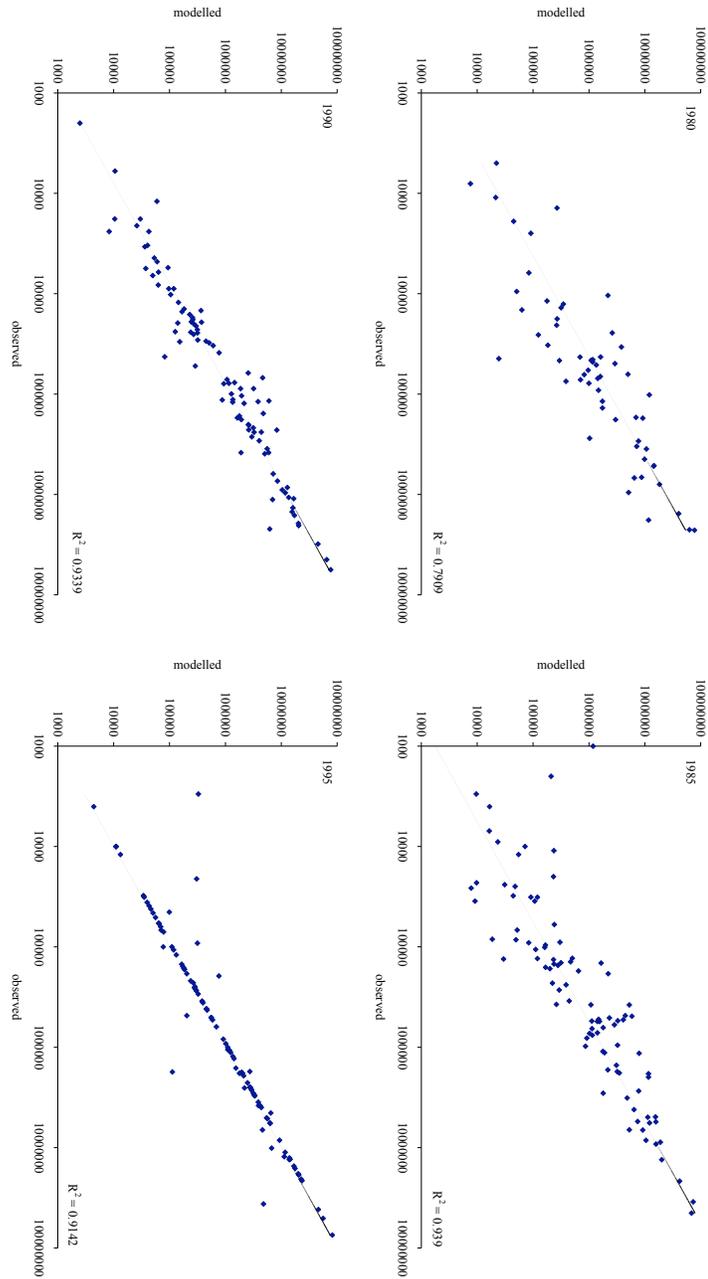**Figure 2:** Observed versus modelled international arrivals in 1980, 1985, 1990 and 1995

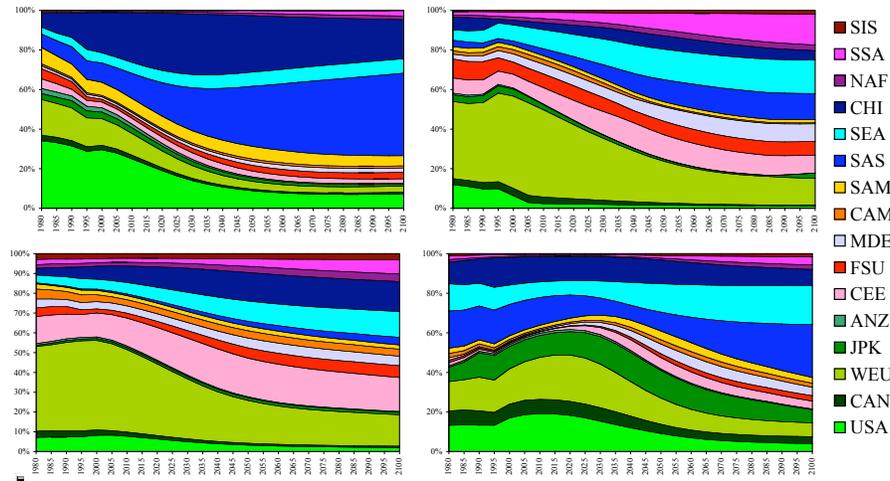**Figure 3:** Observed versus modelled international departures in 1980, 1985, 1990 and 1995

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.

the 21st century, tourists 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. This is partly because of Europe, which has a relatively large number of relative small countries. Asia (Africa) has a smaller (bigger) share of international tourism than of domestic tourism, because it has 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. Our projections are consistent with those of the WTO (2001) until 2020. We are not aware of other tourism projections beyond 2020.

The impact of climate change on domestic tourist numbers, both over time and over space is shown in Figure 5. The world aggregate number of domestic tourists hardly changes due to climate change, partly because positives and negatives cancel each other in the average, and partly because the ratio of domestic to total tourism is at its upper bound in some countries. However,

individual countries may face dramatic impacts that grow rapidly over time. By 2100, domestic tourist numbers may be up by 100% (Mongolia) or down by 30% (Mali). Roughly speaking, currently colder countries will see an increase in domestic tourism; warmer countries will see a reduction. Exceptions to this are countries at high altitudes surrounded by lower lying countries (e.g., Zambia, Zimbabwe). While colder than their neighbouring countries, they are projected to face roughly the same, absolute warming and therefore break the smooth pattern of the lower panel 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 maximum decrease 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. By 2100, for individual countries, international arrivals may fall by up to 60% of the base value or increase by up to 220% of the base value.. Climate change increases the attractiveness of cooler countries, and reduces that of warmer ones. Climate change has an impact on total tourism expenditures both over time and over space. This is shown in Figure 7. World aggregate expenditures hardly change, first rising slightly and then falling slightly. The situation is different for individual countries; the impact of climate change ranges from a reduction of 50% to an increase of 130% by 2100. As expected colder countries can expect to receive more tourism money because of climate change, and warmer countries can expect to receive 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. (2005a,b) report extensive sensitivity analyses on the behaviour of international tourists. These analyses do not harbour any 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
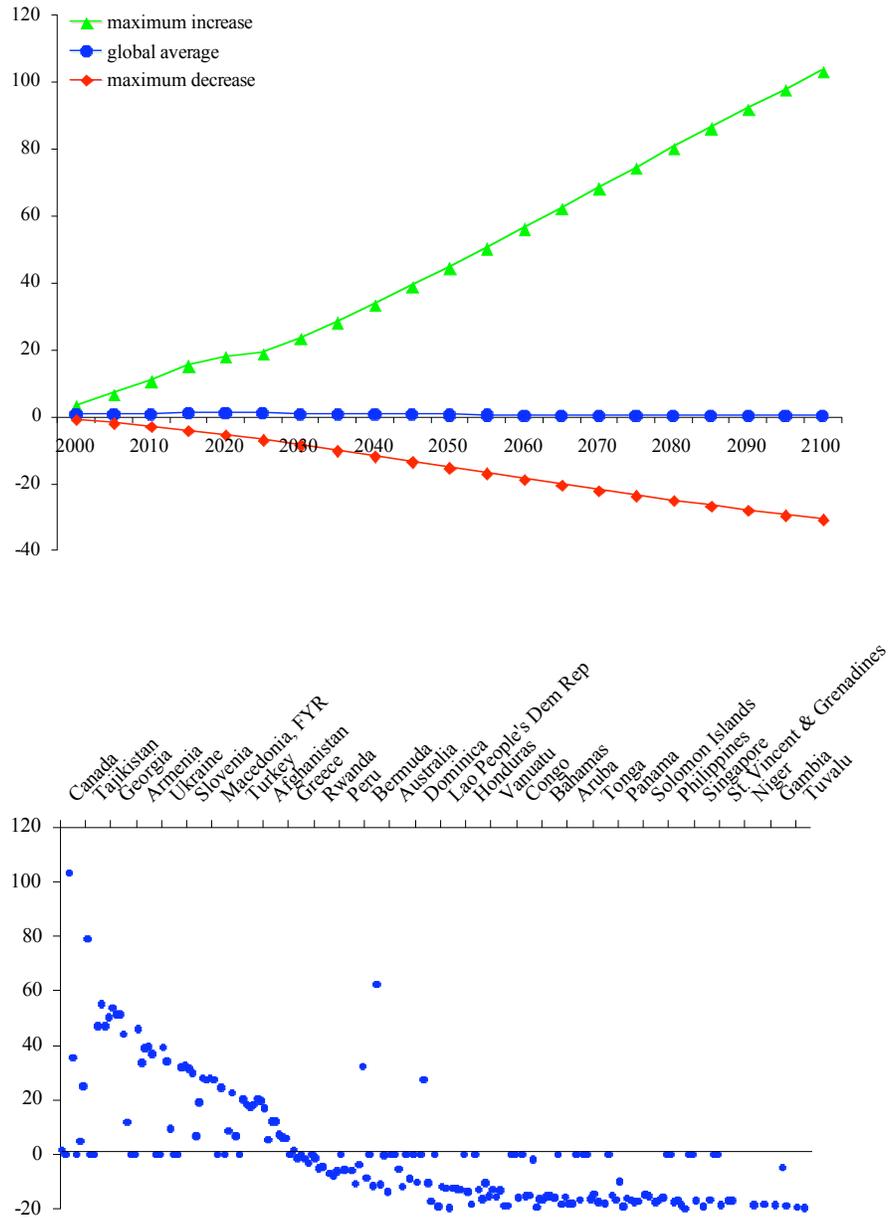
Figure 5: The effect of climate change on domestic tourist numbers, as a percentage of the numbers without climate change; top panel: world average, maximum increase (positive), and maximum decrease (negative); bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.
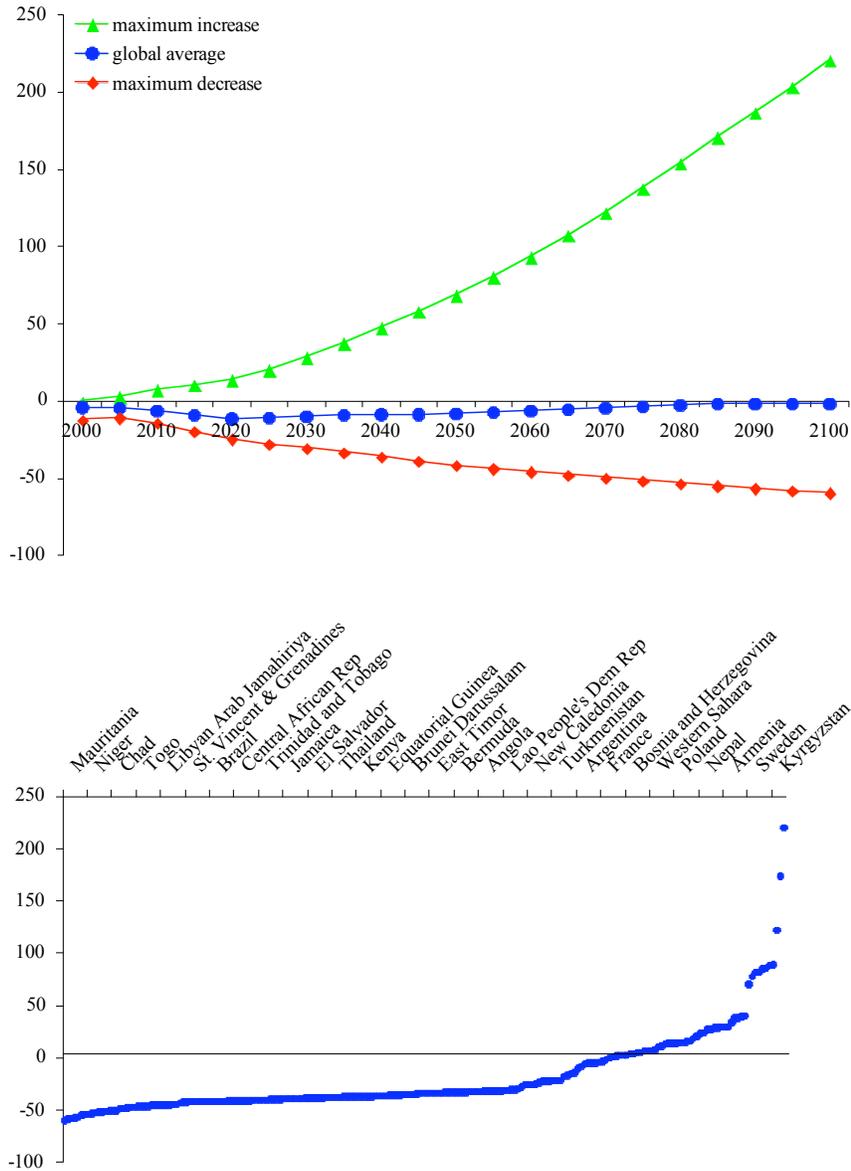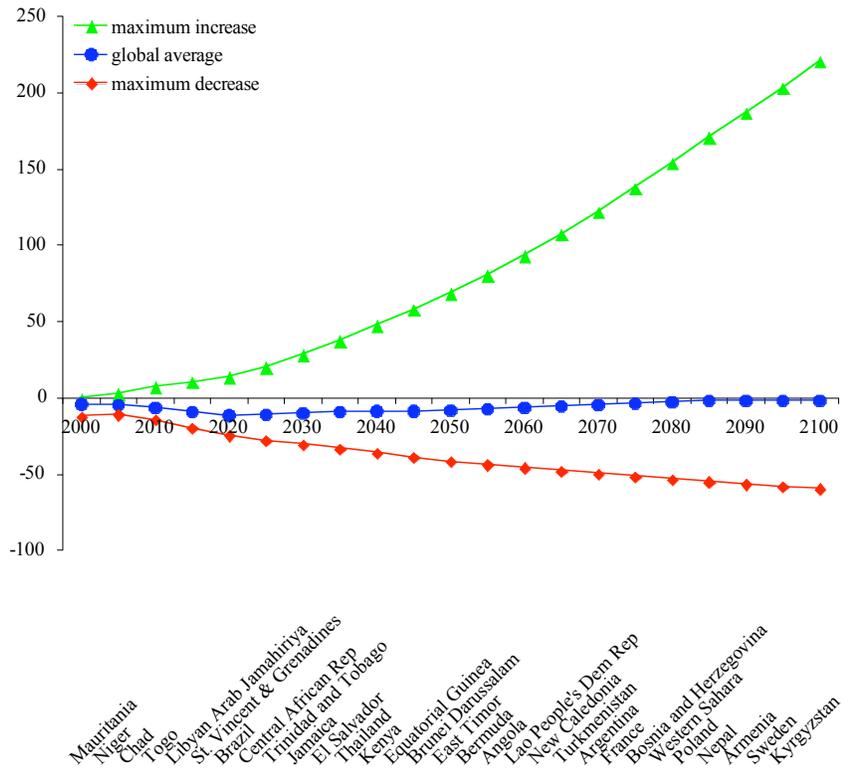
Figure 6: The effect of climate change on international tourist arrivals, as a percentage of the numbers without climate change; top panel: world average, maximum increase, and maximum decrease; bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.

Figure 4. The effect of climate change on international tourist arrivals, as a percentage of the numbers without climate change; top panel: world average, maximum increase, and maximum

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 increase, and maximum decrease; bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.

sensitivity analyses reported here focus on domestic tourists and on sea level rise, as these issues were not explored in previous papers.

The effect of altering the income elasticity in Equation 4 for the year 2100 is shown in Figure 8. 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 \$360,000). 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 plots the impact of climate change on arrivals and expenditures, expressed as a percentage increase or decrease, for the base income elasticity against the impact of climate change under the alternative elasticity. The closer the points lie to the straight line in Figure 8 the lesser the estimated impact of the parameter change. Points above the line indicate an increase in the tourism variable under consideration; points below indicate the line a decrease. (Figure 9 and Figure 10 function in the same way). 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 sensitivity of the demand for international tourism. We use the parameters that were originally estimated for Equation 4 rather than those of Equation 2 (see Section 3). Two things happen: firstly, the optimal temperature for domestic holidays increases from 18 extdegree C to 30 extdegree C. This increases domestic tourism at the expense of international tourism. Secondly, the spread around the optimum is much shallower; 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.

We can also use the model to examine the impact the sea level rise will have on tourism. 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); 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 (as the scenario says), then its domestic to total tourism ratio and its international attractiveness index both fall by 78%.[3] Figure 10 shows the effect on domestic tourism and on international arrivals of including sea level rise. In

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[3]On the one hand, this underestimates the impact of sea level rise on tourism, because both tourism and land losses are heavily concentrated on the coast. On the other hand, by excluding coastal protection, impacts are overestimated. It is not clear whether the relationship between tourist numbers and land loss is linear.
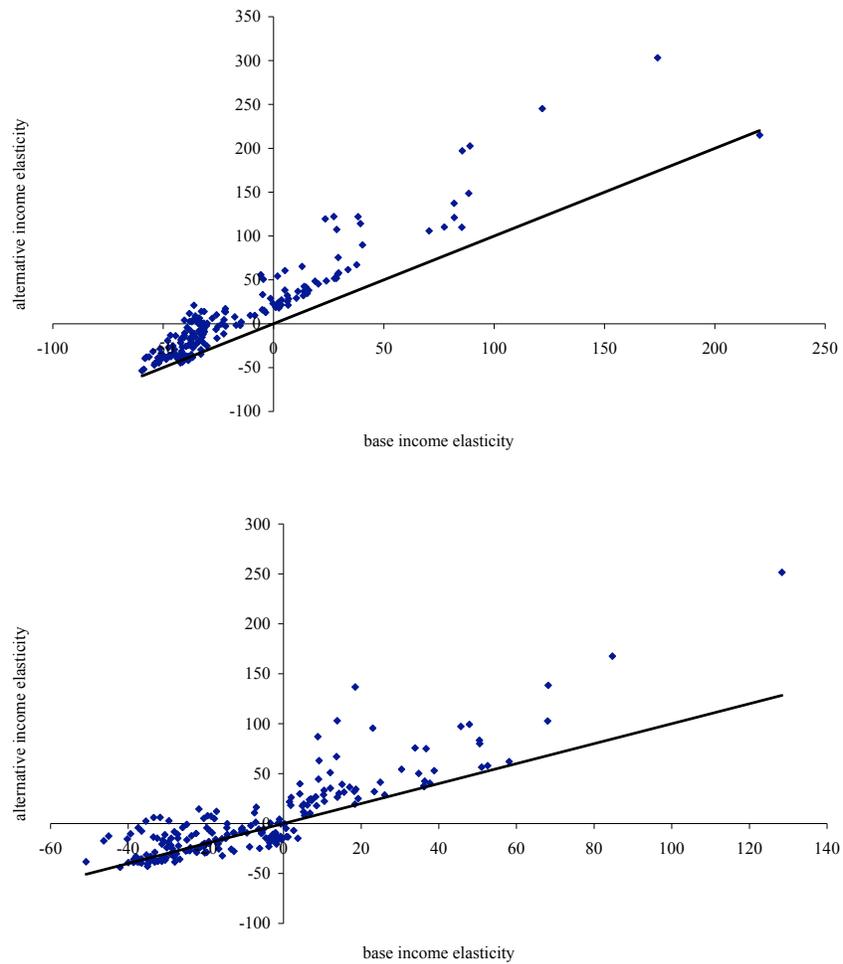
Figure 8: The effect of changing the income elasticity of Equation 4 on the impact of climate change on international arrivals (top panel) and tourism expenditures (bottom panel) in the year 2100; change is measured as percentage deviation from the case without climate change.
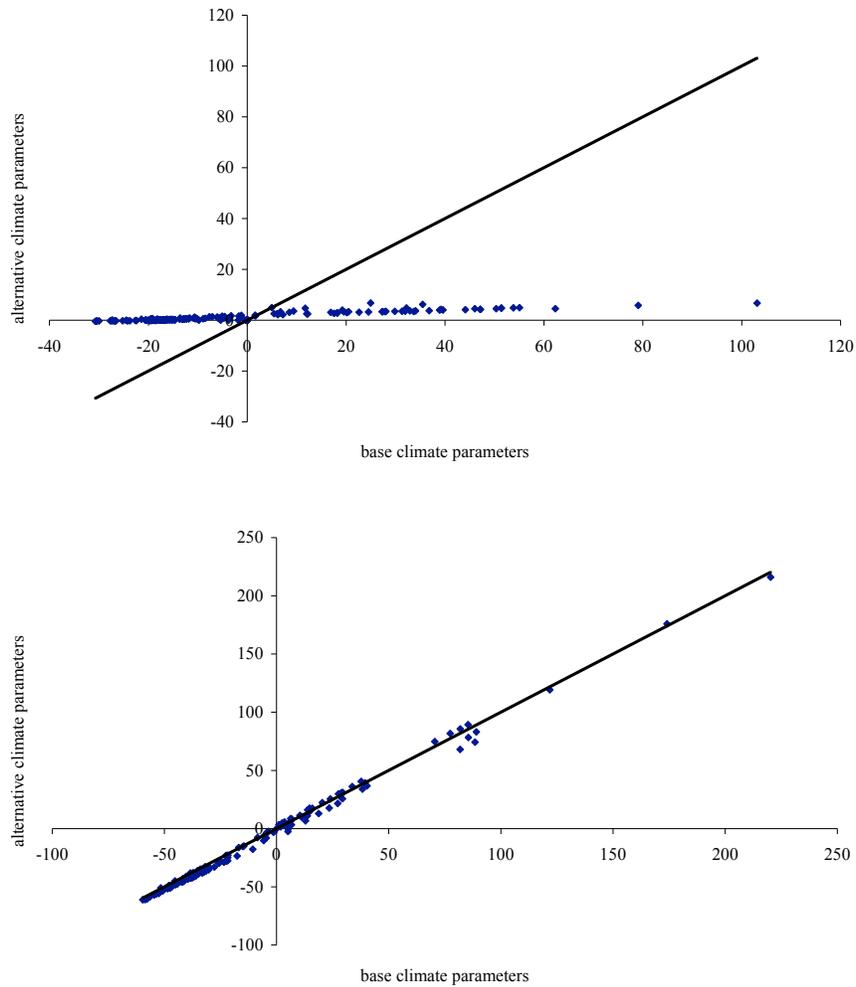
Figure 9: The effect of changing the temperature parameters of Equation 4 on the impact of climate change on domestic tourists (top panel) and international arrivals (bottom panel) in the year 2100; change is measured as percentage deviation from the case without climate change.

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. 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.

5   Discussion and conclusion

We present a changed and extended version of the Hamburg Tourism Model (HTM). Specifically, we now model total holiday demand, and the trade-off between domestic and international holidays. We added the direct economic cost of changes in tourism. As in earlier papers (Hamilton et al., 2005*a,b*), 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. Particularly important are the parameters that drive the trade-off between domestic and foreign holidays. Unfortunately, these parameters are also particularly uncertain, as the literature has focussed on the easy-to-observe international tourists. The qualitative pattern of international tourist arrivals and expenditures is robust, however. Interestingly, we find that climate change has a greater impact on tourism than sea level rise does, because the latter heavily affects only a few places.

In the ideal case, HTM would be based on behavioural equations that are consistent with economic theory and estimated using micro-data. Unfortunately, micro-data on tourist behaviour are available for only a handful of countries, so that we had to rely on aggregate tourist flows. Micro-data are also hard to analyse, because so many decisions are made simultaneously (when to go, where to go, how long to go, who to go with, what to do, and how much to spend on holiday) and different people would make these decisions in a different order and under different constraints (for example, a family with school-going kids is more constrained than a retired couple or a bachelor, unless the holiday is with the grandchildren or the bachelor is a school teacher in an unregistered relationship). Nonetheless, future research should make better use of the available micro-data, and future versions of HTM will apply such insights as they come available.

A potential further application of the model is to sustainability analysis. On
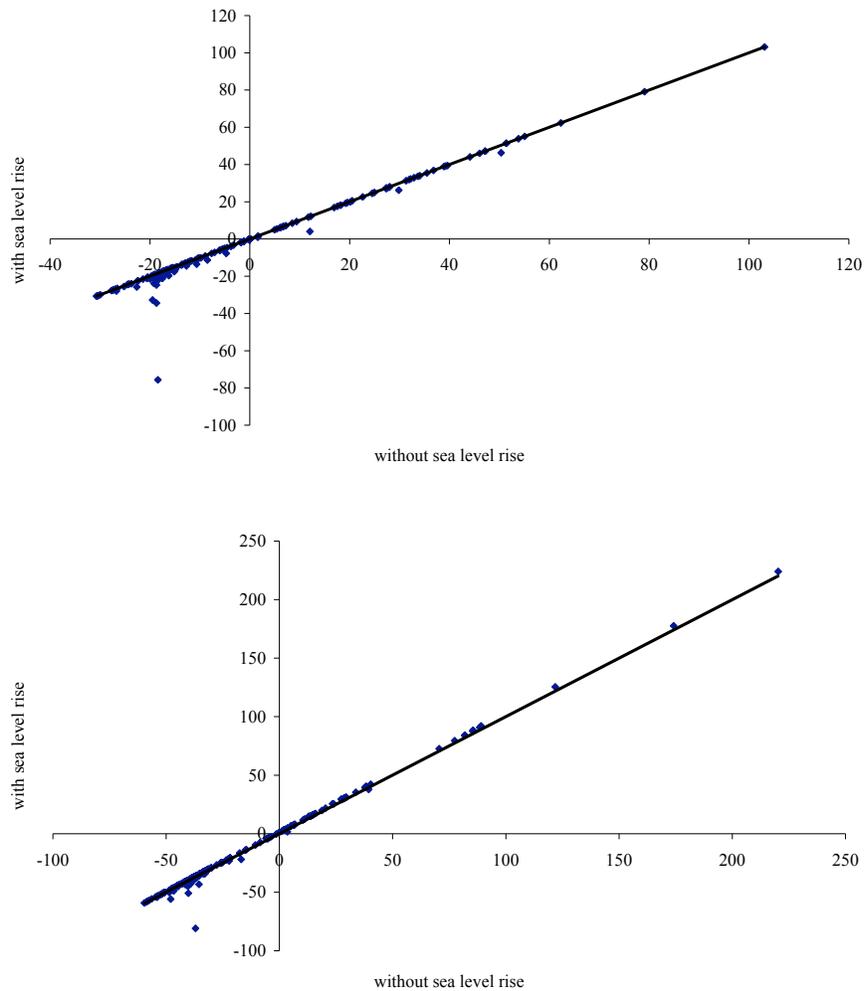
Figure 10: The effect of including sea level rise on the impact of climate change on domestic tourists (top panel) and international arrivals (bottom panel) in the year 2100; change is measured as percentage deviation from the case without climate change.

the one hand, tourists exert substantial pressure on the environment (Goessling, 2002) while ecotourism supports conservation (Goessling, 1999; Wilson & 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. (2005*b*), 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.

6 Acknowledgements

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