THE EFFECTS OF CLIMATE CHANGE ON INTERNATIONAL TOURISM

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Abstract

We present a simulation model of the flow of tourists between 207 countries. The model almost perfectly reproduces the calibration year 1995, and performs well in reproducing the observations for 1980, 1985 and 1990. The model is used to generate scenarios of international tourist departures and arrivals for the period 2000-2075, with particular emphasis on climate change. The growth rate of international tourism is projected to increase over the coming decades, but may slow down later in the century as demand for travel saturates. Emissions of carbon dioxide would increase fast as well. With climate change, preferred destinations would shift to higher latitudes and altitudes. Tourists from temperate climates would spend more holidays in their home countries. As such tourists currently dominate the international tourism market, climate change would decrease worldwide tourism. The effects of climate change, however, are small compared to the baseline projections.

Key words

International tourism, climate change impacts, carbon dioxide emissions, scenarios

JEL Classification

L83, Q25

1. Introduction

Climate is one of the main drivers of international tourism as tourists seek to relax in the sun or the snow. Nevertheless, climate plays only a minor role in the tourism literature (e.g., Witt and Witt, 1995), perhaps because it so trivial, perhaps because climate is believed to be constant or beyond control. Climate, however, is changing because of human intervention, and it is likely to continue to change for decades to come. Climate change would substantially affect tourism, something that is largely ignored in the climate change impacts literature (e.g., Smith et al., 2001), even though tourism is now the largest industry in the world and is still growing fast. Because tourism is so big, it also has a large impact on the environment (Goessling, 2002); tourism also has a substantial impact on climate, not just through the emissions of carbon dioxide of, particularly, air travel but also through the direct impact of flight (e.g., contrails).

One can approach the relationship between tourism and climate (change) in two different ways. Firstly, one can look at tourists, what they prefer (e.g., Matzarakis, 2003) or how they behave (e.g., Maddison, 2001). Secondly, one can look at destinations, how their attractiveness changes with climate and management (e.g., Abegg, 1996). However, tourism, like any market, is defined by supply and demand, by push and pull factors. Destinations compete for the most lucrative tourists, and tourists compete for the best deals. The best way to study tourism is by using a comprehensive model of tourists and destinations. As tourism is so international, this implies a global model.

We draw on a recent study by Hamilton et al. (2003). They present the first version of the Hamburg Tourism Model, an econometric simulation model of the travel patterns of tourists from 207 countries enjoying their holidays in one of the other 206 countries. They find that climate change affects international tourism, but that this effect is small compared to the other changes in the industry. They find that currently cool places would attract more tourists under global warming, and that currently warm places would attract fewer tourists. This supply side effect, however, is dominated by a demand side effect: Currently cool places would generate less outbound tourists, and currently warm places more. Because of this, total tourism numbers would fall (relative to a rapidly rising baseline without climate change), and so would total distance travelled.

In this paper, we extend the model. First, we take a closer look at the model and its ability to predict observations that were not used in the calibration; this leads to a few adjustments in the parameterisation. Second, we estimate emissions of carbon dioxide from international tourism for various scenarios. Third, we study the implications of changes in international tourism for domestic tourism.

The following section presents the model, its calibration and its validation. Section three shows scenario analyses. Sensitivity analyses are presented in section four and section five concludes.

2. The model

We use the Hamburg Tourism Model, version 1.1. HTM models international tourist flows from 207 countries to 207 countries. The purpose of the HTM is *not* to understand the current pattern of international tourism; for that, we need more detailed information than is available to us. Rather, the purpose of the model is to analyse how the current pattern may change under not-implausible scenarios of future population growth, economic growth and, particularly, climate change. The inputs to the patterns and their changes are the empirical regularities reported in Hamilton *et al.* (2003). The details are given below.

The basis of the model is the matrix of bilateral tourism flows. This matrix is perturbed with scenarios of population growth, economic growth and climate change. The perturbations on the supply side are perturbations on the *relative attractiveness* of holiday destinations. The perturbations on the demand side are perturbations on the *number of tourists* from origin countries. For these perturbations, we used the same relationships as we used to construct the bilateral tourism flow matrix.

The model is calibrated against the international arrivals and departures data of 1995 contained in the World Resources Databases (WRI, 2000).[1] There are three 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, the data are total arrivals and total departures; there is no data on the origin of the arrivals or the destination of the departures. We therefore need to construct a database on bilateral tourism flows for all pairs of countries. Thirdly, there are missing observations, particularly with regard to departures.

For arrivals, we filled the missing observations with a statistical model, viz.

(1)
$$\ln A_i = \underset{0.97}{5.97} + \underset{0.96}{2.05} \cdot 10^{-7} Area_i + \underset{0.07}{0.22} T_i - \underset{2.21}{7.91} \cdot 10^{-3} T_i^2 + \underset{3.03}{7.15} \cdot 10^{-5} Coast + \underset{0.09}{0.80} \ln Y_i$$
$$N = 139; R_{adj}^2 = 0.54$$

where *A* denotes number of international arrivals; *Area* is area; *T* is the annual average temperature; *Coast* is the length of the coastline; *Y* is per capita income; and *i* denotes country. This model is the best fit to the observations for the countries for which we do have data.[3] The total number of tourists increases from 55.2 million (observed) to 56.5 million (observed + modelled).

For departures, we filled the missing observations with a statistical model, viz.

(2)
$$\ln \frac{D_i}{Pop_i} = \underset{17.05}{1.51} - \underset{0.17}{0.18} T_i + \underset{16.82}{4.83} \cdot 10^{-3} T_i^2 - \underset{4.22}{5.56} \cdot 10^{-2} Border + \underset{0.09}{0.86} \ln Y_i - \underset{0.13}{0.23} \ln Area_i$$
$$N = 99; R_{adj}^2 = 0.66$$

Again, this model is the best fit to the observations for the countries for which we do have data,[4] but although the fit is better than for arrivals, the uncertainty about the parameters is larger. This leads to a total number of departures of 48.2 million, so we scaled up *all* departures[5] so that the total number of observed and modelled departures equals the total number of observed and modelled arrivals.

Bilateral tourism flows were derived as follows. In keeping with the model described below, we constructed a *general attractiveness index* for each country.[6] The tourists of each country are allocated to other countries according to an index that is proportional to the *general attractiveness index times the distance* between the two capital cities raised to the power -$1.7 \cdot 10^{-4}$. In this manner, the model reproduces the 1995 pattern of total departures and arrivals (see Figures 1, 2 and 3). As a comparison of the two maps shows, the model is well calibrated.

There is only weak empirical support that tourists are attracted to places with low or high population densities. Population growth is therefore assumed to affect international tourism as a proportional increase in departures. As population growth is not uniform over the globe and

[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 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.
[4] The data on the number of land borders were taken from CIA (2002).
[5] Scaling up only the interpolated departures leads to distortions, as many small countries do not report departures data.
[6] In the first iteration, the attractiveness index equals the market share of each country in world tourism. The ratio between predicted and observed tourist arrivals was used to adjust the attractiveness index.

tourism is partly determined by distance, this simple assumption already creates a shift in the pattern of international tourism (see Hamilton *et al.*, 2003).

Economic growth is assumed to affect tourism according to Equations (1) and (2). That is, a country becomes more attractive as it grows richer, with an elasticity of 0.80. A country generates more tourists as it become richer, with an elasticity of 0.86. The population and economic scenarios together produce a marked shift of international tourism towards Asia (see Hamilton *et al.*, 2003). The number of international trips per person is capped at four per year, or one per season; in 1995, the observed annual maximum was in Bermuda (1.57) with Austria (1.55) and Switzerland (1.47) following close; all three countries are small and rich.

WRI (2001) presents tourism data for the period 1980-1998. 1995 is the calibration year, and the model operates in time steps of five year[7], so we used the model to "predict" tourist numbers for the years 1980, 1985, and 1990. The model does not have differential equations, so time can be readily inverted. There are many missing observations in 1980, so calibrating the model to 1980 and "predicting" the following 20 years is not an option. Running the model back in time requires data on population and per capita income. Population data are readily available from WRI (2000), except for a few small or new countries; for these countries, we used the population growth rates of nearby countries and the growth rate of the original country. Per capita income is more problematic. WRI (2000) has many missing observations, which we filled with the indicative national growth rates from the World Bank website (www.worldbank.org) "Countries at a glance".[8]

Comparing the model outcomes to the past observations, it turned out that the 1995 cross-section income elasticity of international tourism demand (0.86) is too low. Cross-section may not be the best way of estimating income elasticities, anyway. The best fit to the observations of 1980/1985/1990 is an income elasticity of 2.57. Crouch (1995) reports the results of a meta-analysis of tourism demand. He finds an income elasticity of 1.86, with a standard deviation of 1.78, encompassing both 0.86 and 2.57. The adjustment of the income elasticity is the only adjustment made to the model. Figure 2 compares modelled arrivals to observed arrivals. Figure 3 compares departures. As already seen from Figure 1, the model reproduces the observations for 1995 rather well; the R^2 is 1.00 (or 0.9995 to be precise); 1995 is the year of calibration, however. The model is also capable of "predicting" arrivals in the other years; the R^2 does not fall below 0.77; there are of course mismatches, but by and large the model gets the overall pattern correct.

Figure 3 shows that departures are reproduced well for 1995, the calibration year; the R^2 is 0.97. Moreover, the years 1990 and 1985 are replicated well, with R^2s of 0.88 and 0.85, respectively. For 1980, deviations between model and observations are much larger: the R^2 is only 0.47. This is partly due to imperfections in the model, but also because the income data on 1980 are sparse; some countries report tourist departures but not income. Moreover, only about half of the modeled departures can be compared to observations. Overall, version 1.1 of the Hamburg Tourism Model has a reasonable performance in reproducing observations.

3. Scenario analysis

Scenarios of population and economic growth are taken from the 17-region IMAGE 2.2 implementation (IMAGE Team, 2001) of the SRES scenarios (Nakicenovic and Swart, 2001). More people implies more tourists (Equation (2)). A higher per capita income implies that

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[7] for reasons of data management and storage

[8] Data for the former Yugoslavia were taken from the Penn World Tables. Data for North Korea from www.inform.umd.edu/econdata/WorkPaper/INFORUM/wp97008.pdf

people travel more (Equation (2)) and that a country becomes relatively more attractive (Equation (1)).

Climate change scenarios are taken from country-specific output of the COSMIC model (Schlesinger and Williams, 1998). We use the average of the 14 GCMs as our middle scenario. The effect of climate change follows from Equations (1) and (2), both of which have a quadratic specification. That is, if a cool country gets warmer, it first attracts more tourists, until it gets too warm and starts attracting less tourists. The turning point lies at 14°C (annual 24-hour average). Similarly, if a cool country gets warmer, it first generates less tourists until it gets too warm and starts generating more tourists. The turning point lies at 18°C (annual 24-hour average).

Figure 4 compares the growth rates of international tourism for three scenarios. In the first scenario, tourism demand *does not* saturate; the growth rate of numbers of international tourists goes up to more than 14% per year in 2025, and then gradually falls as population and economic growth slow; the average number of pleasure trips in foreign countries reaches about 100 per person per year in 2075. As these results are hard to imagine, the second scenario assumes that demand for foreign travel *does* saturate, at four trips per year. The number of international tourists rises rapidly in this scenario as well, but not as fast as without saturation; the growth rate is around 10% per year between 2015 and 2035; these additional tourists are primarily from Asia. After 2035, the market saturates, and growth falls rapidly. In the third scenario, we add climate change. As is shown in Hamilton *et al.* (2003), climate change perturbs the socio-economic scenario, but does not dominate it. Until 2020, climate change slows the growth of international tourism, as tourists from temperate and cool countries, particularly in Europe, stay within their own country. After 2020, more tourists originate in hot countries, and tourism numbers go up as they seek to spend their holiday at cooler destinations.

Figure 5 shows the change in departures and arrivals in 2025 for the arbitrary, but realistic, climate change scenario of 1°C global warming. As expected, climate change would lead to a poleward shift of tourism. However, not only would countries closer to the poles become more attractive for tourists, but also would those countries generate less international tourists – as these countries would become more attractive to their own citizens as well. Figure 5 also shows that there will be a shift from lowland to highland tourism; the tourism sectors in Zambia and Zimbabwe, for instance, would benefit greatly from climate change. Figure 6 plots the change in departures and arrivals due to climate change for 2050, as a function of the initial annual mean temperature. Figure 6 confirms the messages of Figure 5.

The distances between the capital cities of the countries of origin and destination are used in the estimation of bilateral tourism flows. The distance travelled also determines energy use and carbon dioxide emissions. We use an emission coefficient of 112 gCO_2 per passenger kilometre for 2000 (Becken, personal communication), falling at 1% per year. Figure 7 shows the carbon dioxide emitted by international tourists with and without climate change, for the A1B scenario. Without climate change, carbon emitted inceases rapidly at first, in fact even more rapidly than the tourism numbers, but stabilises later as the tourism market saturates. At present, international air travel accounts for some 2% of global CO2 emissions; even with an optimistic rate of technical progress of 1%, this share increases to over 35% in 2050 in the IMAGE2.2 A1B scenario. If we assume that the demand for tourism saturates at two (rather than four) international trips per year, then the share of tourism emissions in total CO_2 emissions is capped at 20%.[9] With climate change, the upward trend is slightly slower – again largely because the heavy travellers from Northwest Europe stay closer to home. The effect of climate change is in the order of 1%. This effect is similar for high and low saturation.

[9] The emissions scenarios were built without explicit attention to international tourism.

4. Sensitivity analyses

The model and the results presented above depend on a number of parameters, each of which is uncertain. In Hamilton *et al.* (2003), we report a sensitivity analysis on the distance parameter, simulating a scenario in which travel would become cheaper over time. This greatly affects travel patterns in the baseline scenario, but does not much affect the impact of climate change. Similarly, we show there that variations in the income elasticity have a large impact on the baseline scenario, but much less so on the relative impact of climate change.

Figure 8 shows the effects of varying climate change. In the base case, we use the geographic pattern of temperature change that is the average of 14 GCMs (Schlesinger and Williams, 1998). As sensitivity analyses, we use that average plus one times the standard deviation over the 14 GCMs and minus half the standard deviation. This roughly corresponds to varying the climate sensitivity from 2.5˚C to 1.5˚C and 4.5˚C, respectively. The results are as expected. Slower climate change leads to lower impacts of climate change, and faster climate change to higher impacts.

Figure 9 compares the relative impact of climate change on arrivals and departures between the base case, with tourism demand saturating at four trips per year, and the case in which tourism demand saturates at two trips per year. Although these two scenarios considerably differ in absolute numbers of international tourists (cf. Figure 7), the relative impact of climate change is very similar.

The current version of the model is restricted to international tourism. Domestic tourism is not included because of the limited data availability. International departures, however, are included, and responsive to climate change and scenarios. We can therefore calculate the number of people that would have travelled abroad but did not. If we assume that the tourists not travelling abroad add to domestic tourism, we get a better idea of the real changes in tourism. Figure 10 plots the change in international arrivals as a function of the initial annual mean temperature (as in Figure 6) and adds the number of tourists not travelling abroad. Almost everywhere, the tourists not travelling abroad amplify the change in tourist arrivals, in a fair number of cases substantially so. Figure 10 also shows the ratio of the change in international tourist arrivals and the number of tourists not travelling abroad, again as a function of the initial temperature. In one-third of the cases, the number of tourists not travelling abroad is greater than the change in international tourist arrivals. In one-tenth of the cases, the number of tourists not travelling abroad has a different sign than the change in tourist arrivals. This happens in the countries that have an initial temperature between 11˚C and 18˚C. This reflects the difference in optimal temperature for departures and arrivals (see above).

5. Discussion and conclusion

We present a simulation model of international tourism, and develop scenarios of changes in international arrivals and departures because of changes in population numbers, per capita income, and climate change. A model like this tests sensitivities rather than making predictions. Although the model does well in predicting out of sample, the validation period is short compared to the "forecasting" period.

The model shows that the past growth of international tourism may well continue unabated in the medium term, but will saturate in the long term. The main driver is economic growth, and the growth of international tourism will therefore be concentrated in those regions with the highest economic growth. Although intercontinental tourism will also grow, mass tourism is likely to continue to prefer destinations closer to home.

Climate change would lead to a gradual shift of tourist destinations towards higher latitudes and altitudes. Climate change would also imply that the currently dominant group of international tourists – sun and beach lovers from Western Europe – would stay closer to home, implying a relative fall of total international tourist numbers. The changes induced by climate change are generally much smaller than those resulting from population and economic growth.

The model described in this paper is, to our knowledge, the first 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 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 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). Improving on all this is deferred to future research.

The paper is a convincing demonstration 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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References

Abegg, B. (1996) *Klimaänderung und Tourismus – Klimafolgenforschung am Beispiel des Wintertourismus in den Schweizer Alpen*. Zurich: vdf Hochschuleverlag an der ETH

Central Statistical Office Poland (2002) *Tourism statistics.* Online documents at URL http://www.stat.gov.pl/english/serwis/polska/rocznik11/turyst.htm

CIA (2002) *The World Factbook 2002*. Central Intelligence Agency, Washington, D.C., Online documents at URL http://www.cia.gov/cia/publications/factbook

Crouch, G.I. (1995) A meta-analysis of tourism demand. *Annals of Tourism Research* 22 (1), 103-118

Goessling, S. (2002) Global environmental consequences of tourism. *Global Environmental Change* 12, 283-302.

IMAGE Team (2001) *The IMAGE 2.2 Implementation of the SRES Scenarios: A Comprehensive Analysis of Emissions, Climate Change and Impacts in the 21st Century*. RIVM CD-ROM Publication 481508018. Bilthoven: National Institute for Public Health and the Environment

Matzarakis, A. (2002) Examples of climate and tourism research for tourism demands, 15th Conference on Biometeorology and Aerobiology joint with the International Congress on Biometeorology. 27. October to 1. November 2002, Kansas City, Missouri, pp 391-392

Nakicenovic, N. and Swart, R.J. (2001) *IPCC Special Report on Emissions Scenarios*. Cambridge: Cambridge University Press

Schlesinger, M.E. and Williams, L.J. (1998), *COSMIC 1.1 Country-Specific Model for Intertemporal Climate*. Palo Alto: Electric Power Research Institute

Smith, J.B., H.-J. Schellnhuber, M.M.Q. Mirza, S. Fankhauser, R. Leemans, E. Lin, L. Ogallo, B. Pittock, R.G. Richels, C. Rosenzweig, R.S.J. Tol, J.P. Weyant and G.W. Yohe (2001), 'Vulnerability to Climate Change and Reasons for Concern: A Synthesis', Chapter 19, pp. 913-967, in J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White (eds.), *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge: Cambridge University Press,

Witt, S.F. and Witt, C.A., 1995, Forecasting tourism demand: A review of empirical research. *International Journal of Forecasting* 11, 447-475

World Bank (2003) Countries at a glance. Online documents at URL www.worldbank.org

WRI (2000) *World Resources Database 2000-2001.* Washington, D.C: World Resources Institute

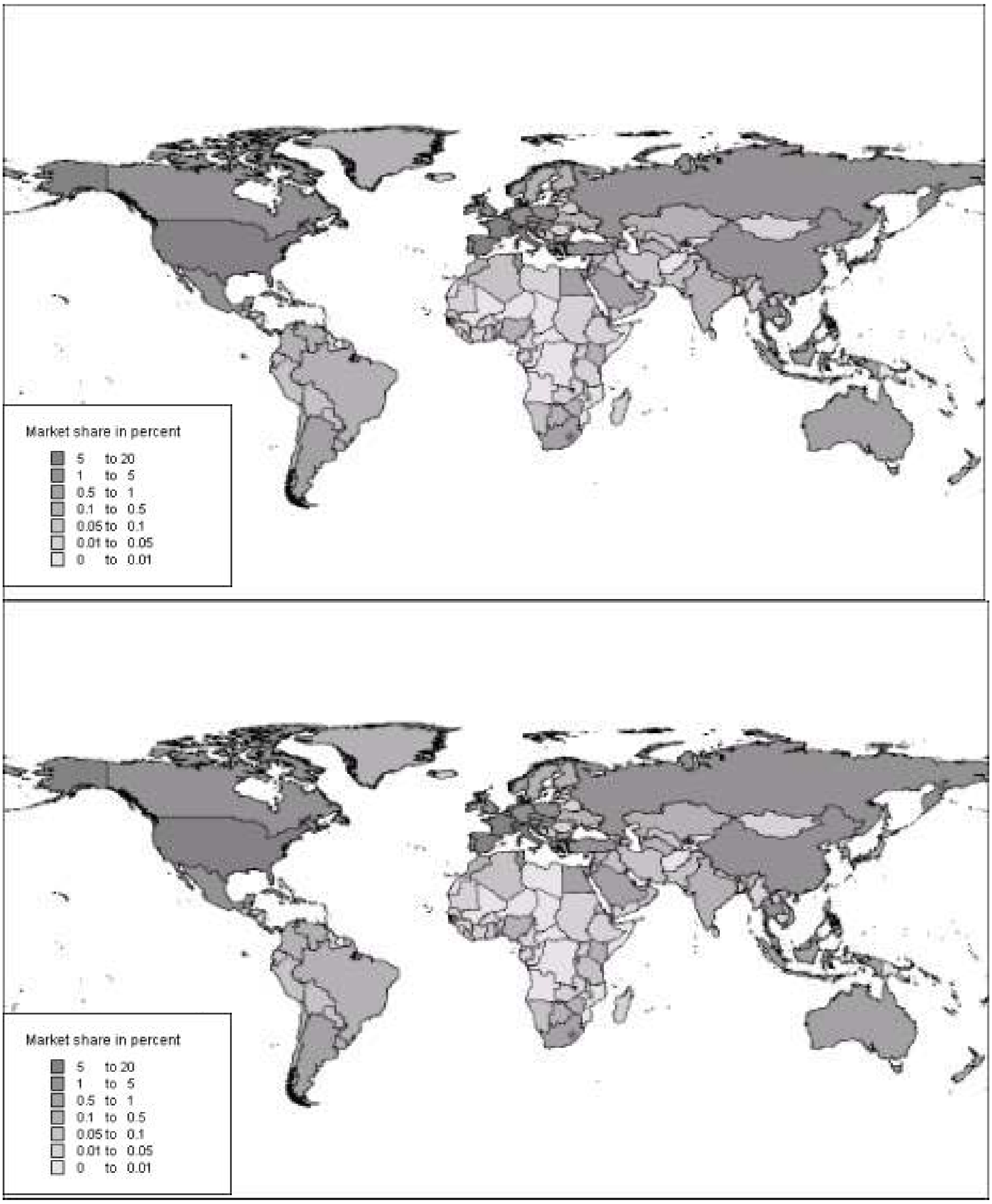


Figure 1. The share of arrivals per country as observed (top) and modelled (bottom) in 1995.

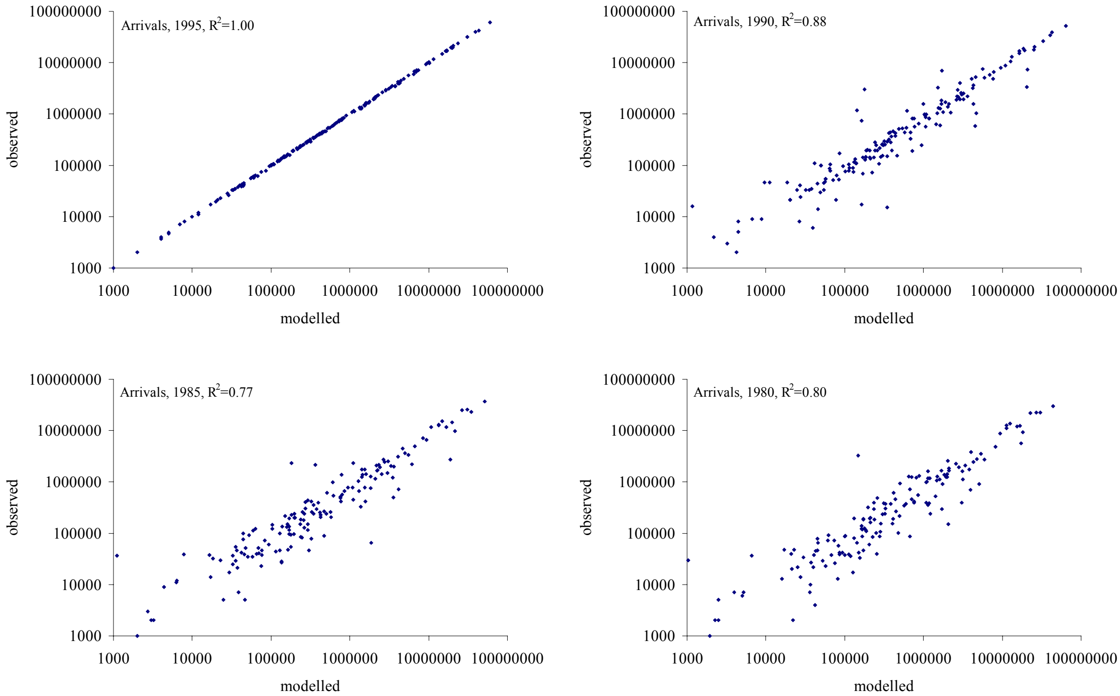


Figure 2. Observed versus modelled number of tourist arrivals for 1980, 1985, 1990, and 1995.

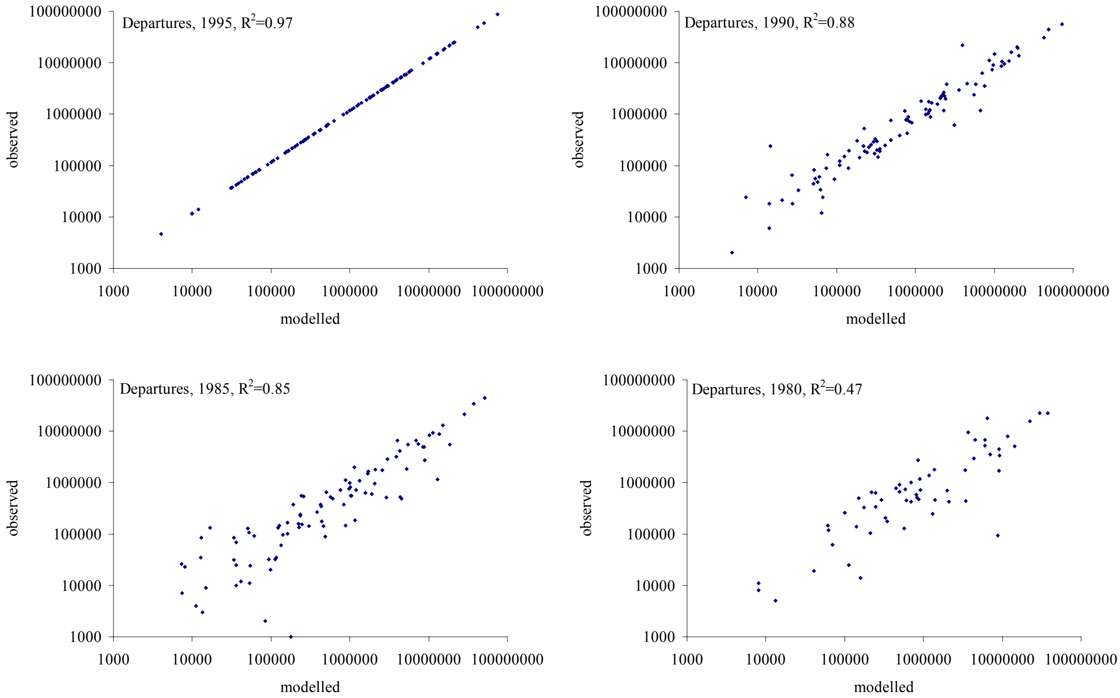


Figure 3. Observed versus modelled number of tourist departures for 1980, 1985, 1990, and 1995.

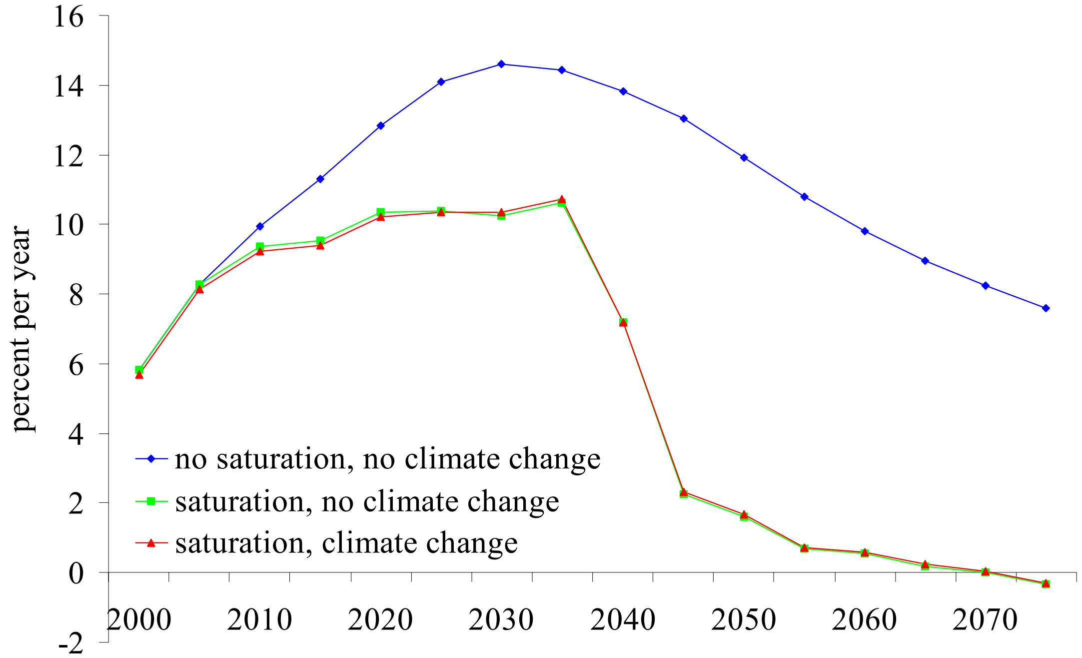
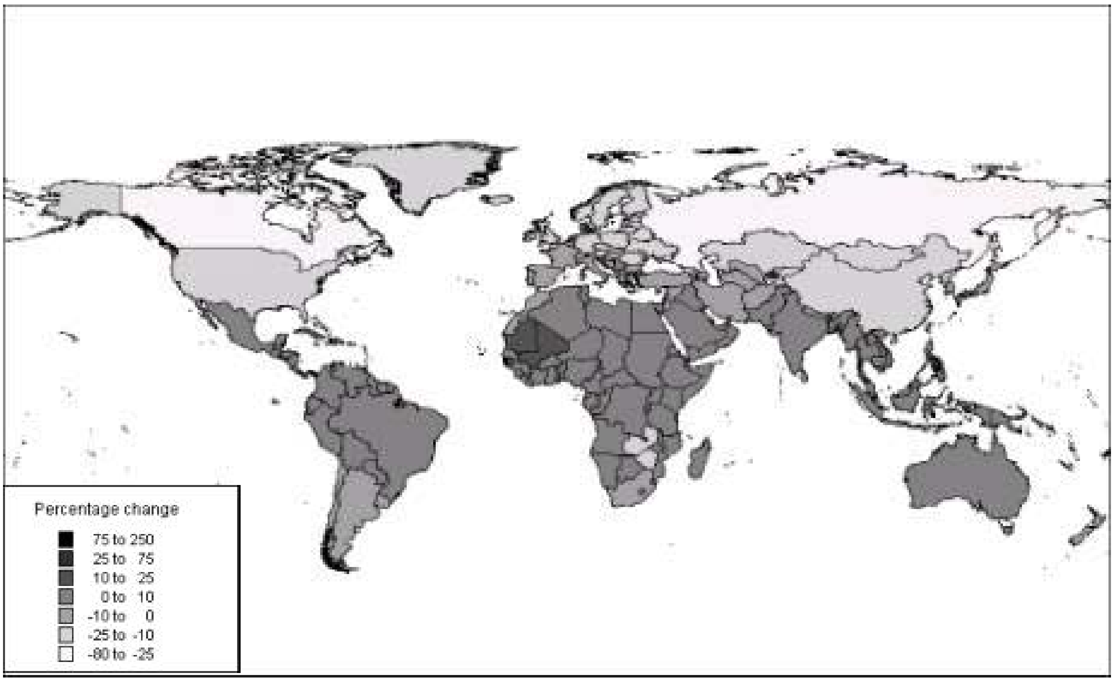


Figure 4. The growth rate of international tourism according to three scenarios.



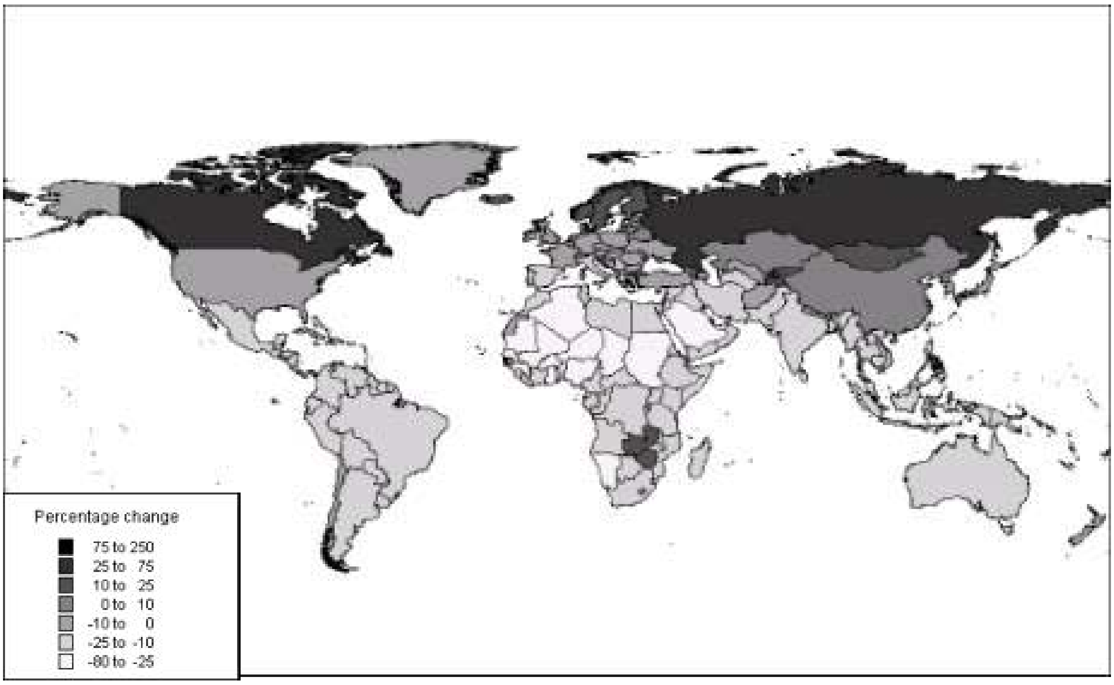


Figure 5. The change in departures (top) and arrivals (bottom) as a result of a 1°C global warming in 2025.

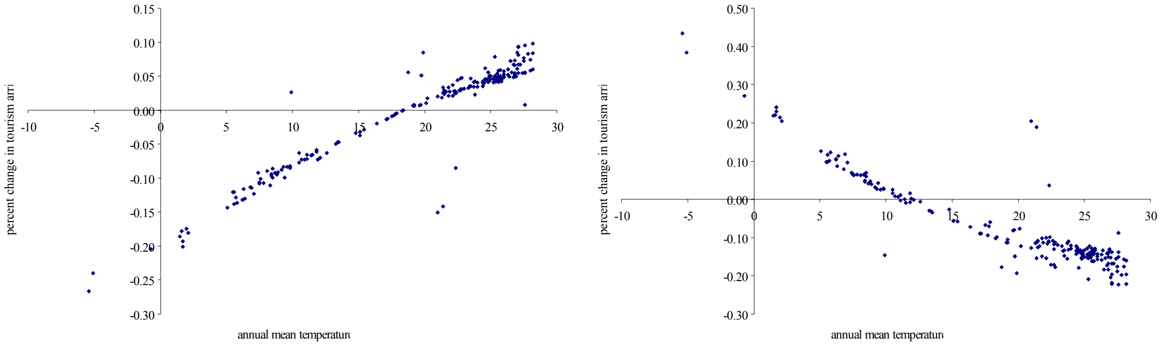


Figure 6. The change in tourism departures (left panel) and arrivals (right panel) in 2050 (percentage of tourist numbers without climate change) as a function of the annual mean temperature.

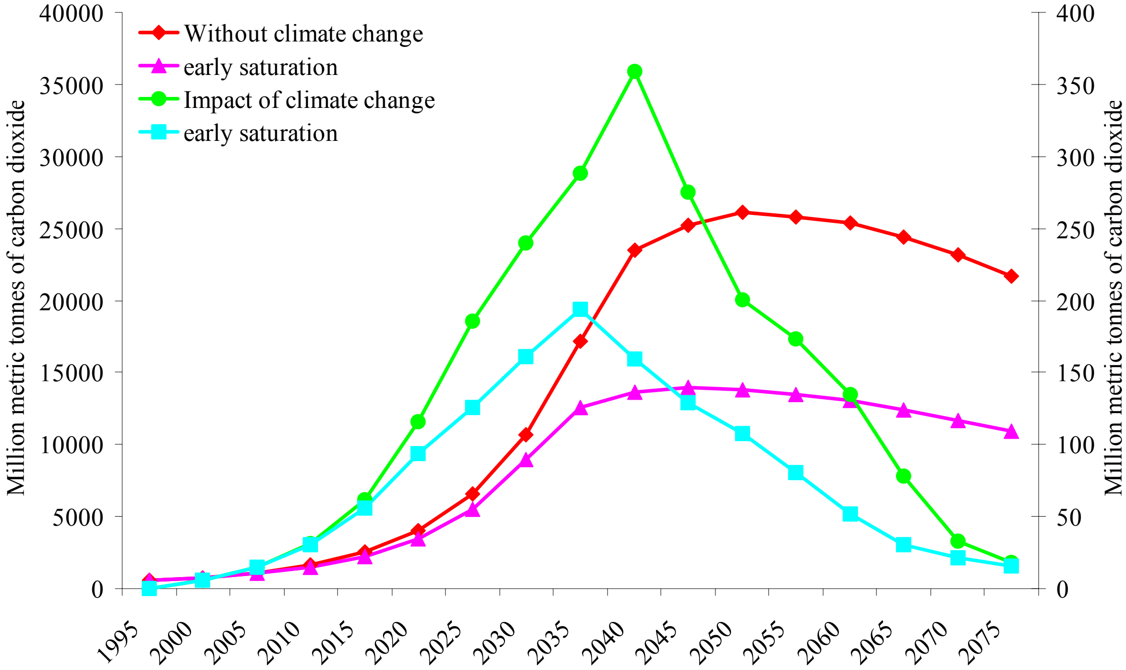


Figure 7. The total carbon dioxide emitted by international tourism without climate change (left axis) and the difference induced by climate change (right axis); results are for the A1B scenario; in the base scenario, tourism demand saturates at 4 trips per year, in the early saturation scenario, demand saturates at 2 trips per year.

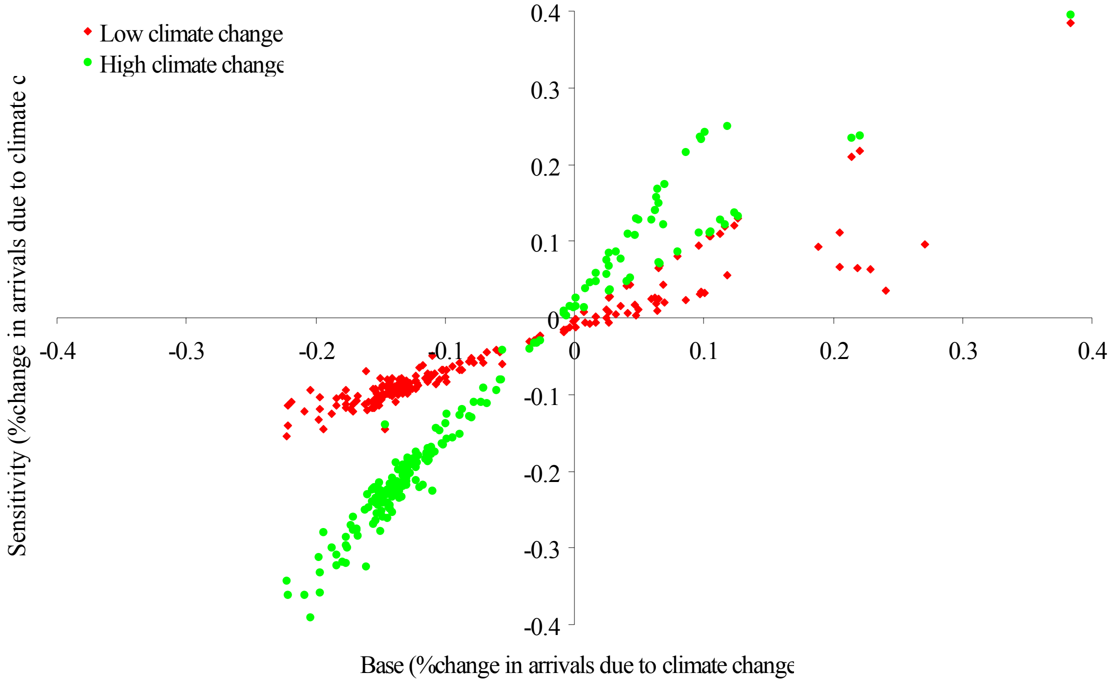


Figure 8. Climate change induced change to tourist arrivals per country in 2050 (A1B) for medium climate change versus high and low climate change.

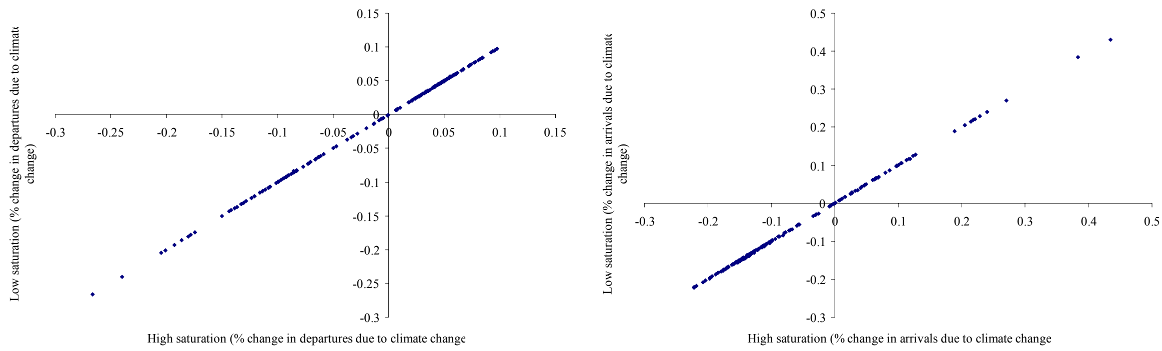


Figure 9. The relative change in the number of departures (left panel) and arrivals (right panels) in 2050 (A1B scenario); base case (demand saturates at four trips per year) compared to alternative (demand saturates at two trips per year).

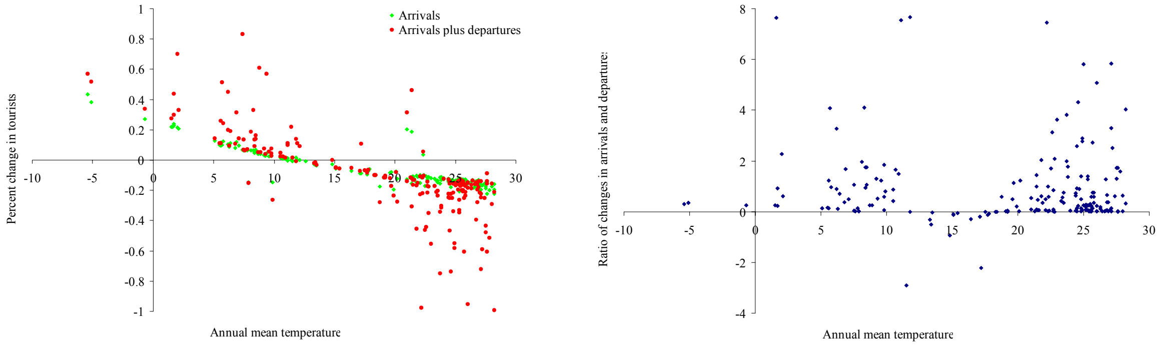


Figure 10. The change in tourism arrivals (diamonds, left panel) plus the number of tourists not travelling abroad (circles, left panel) in 2050 (percentage of tourist numbers without climate change) as a function of the annual mean temperature; the right panel shows the ratio of the change in tourist arrivals and the number of tourists not travelling abroad as a function of the annual mean temperature.

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Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – An Assessment of Structural Impacts on Decision-making Processes*, **FNU-28** (submitted)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – A Unique Approach?*, **FNU-27** (*China Environment Series,* Issue 6, pp. 120-124; http://www.wilsoncenter.org/topics/pubs/7-commentaries.pdf)

Roson, R. and R.S.J. Tol (2003), *An Integrated Assessment Model of Economy-Energy-Climate – The Model Wiagem: A Comment*, FNU-26 (submitted to *Integrated Assessment*)

Yetkiner, I.H. (2003), *Is There An Indispensable Role For Government During Recovery From An Earthquake? A Theoretical Elaboration*, **FNU-25**

Yetkiner, I.H. (2003), *A Short Note On The Solution Procedure Of Barro And Sala-i-Martin for Restoring Constancy Conditions*, **FNU-24**

Schneider, U.A. and B.A. McCarl (2003), *Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry*, **FNU-23** (submitted)

Zhou, Y. and Tol, R.S.J. (2003), *The Implications of Desalination to Water Resources in China - an Economic Perspective*, FNU-22 (forthcoming in *Desalination*)

Yetkiner, I.H., de Vaal, A., and van Zon, A. (2003), *The Cyclical Advancement of Drastic Technologies*, **FNU-21**

Rehdanz, K. and Maddison, D. (2003) *Climate and Happiness*, **FNU 20** (submitted)

Tol, R.S.J., (2003), *The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties*, **FNU-19** (submitted).

Lee, H.C., B.A. McCarl, U.A. Schneider, and C.C. Chen (2003), *Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation*, **FNU-18** (submitted).

Schneider, U.A. and B.A. McCarl (2003), *Implications of a Carbon Based Energy Tax for U.S. Agriculture*, **FNU-17** (submitted).

Tol, R.S.J. (2002), *Climate, Development, and Malaria: An Application of* FUND, **FNU-16** (submitted).

Hamilton, J.M. (2003), *Climate and the Destination Choice of German Tourists,* **FNU-15** (revised and submitted).

Tol, R.S.J. (2002), *Technology Protocols for Climate Change: An Application of* FUND, **FNU-14** (submitted to *Climate Policy*).

Rehdanz, K (2002), *Hedonic Pricing of Climate Change Impacts to Households in Great Britain*, **FNU-13** (submitted to *Climatic Change*).

Tol, R.S.J. (2002), *Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of* FUND, **FNU-12** (submitted to *Environment and Development Economics*).

Rehdanz, K. and Tol, R.S.J. (2002), *On National and International Trade in Greenhouse Gas Emission Permits*, **FNU-11** (submitted).

Fankhauser, S. and Tol, R.S.J. (2001), *On Climate Change and Growth*, **FNU-10** (submitted to *Resource and Energy Economics*).

Tol, R.S.J.and Verheyen, R. (2001), *Liability and Compensation for Climate Change Damages – A Legal and Economic Assessment*, **FNU-9** (forthcoming in *Energy Policy*).

Yohe, G. and R.S.J. Tol (2001), *Indicators for Social and Economic Coping Capacity – Moving Toward a Working Definition of Adaptive Capacity*, **FNU-8** (*Global Environmental Change*, **12** (1), 25-40).

Kemfert, C., W. Lise and R.S.J. Tol (2001), *Games of Climate Change with International Trade*, **FNU-7** (forthcoming in *Environmental and Resource Economics*).

Tol, R.S.J., W. Lise, B. Morel and B.C.C. van der Zwaan (2001), *Technology Development and Diffusion and Incentives to Abate Greenhouse Gas Emissions*, **FNU-6** (submitted to *International Environmental Agreements*).

Kemfert, C. and R.S.J. Tol (2001), *Equity, International Trade and Climate Policy*, **FNU-5** (*International Environmental Agreements*, **2**, 23-48).

Tol, R.S.J., Downing T.E., Fankhauser S., Richels R.G. and Smith J.B. (2001), *Progress in Estimating the Marginal Costs of Greenhouse Gas Emissions*, **FNU-4**. (*Pollution Atmosphérique – Numéro Spécial: Combien Vaut l'Air Propre?*, 155-179).

Tol, R.S.J. (2000), *How Large is the Uncertainty about Climate Change?*, **FNU-3** (*Climatic Change*, **56** (3), 265-289).

Tol, R.S.J., S. Fankhauser, R.G. Richels and J.B. Smith (2000), *How Much Damage Will Climate Change Do? Recent Estimates*, **FNU-2 (***World Economics,* **1** (4), 179-206)

Lise, W. and R.S.J. Tol (2000), *Impact of Climate on Tourism Demand*, **FNU-1** (*Climatic Change*, **55** (4), 429-449).