CLIMATE CHANGE AND TOURISM IN THE MEDITERRANEAN

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1. Introduction

Long term changes in the climate have already been observed and it is predicted that the climate will continue to warm over the 21st century. There is agreement that, on the whole, leisure tourism is climate sensitive. Although some tourists do not care about the climate at their destination, and other tourists give it only minor consideration, mass tourism is about sun, sea and sand – and this type of tourism dominates in the Mediterranean. There is a small but growing research field that has focussed on the questions of what sort of climate tourists prefer and on the impact that climate change will have on particular destinations or on source markets. The majority of impact studies, however, focus on particular countries or types of tourism and the global overview is neglected. Moreover, the possible substitution between countries has been ignored. Finally, domestic and international tourists are often lumped together although their behaviour and possible responses may be different and there may be substitution between domestic and international tourism.

The Hamburg Tourism Model (HTM) was developed to fill some of the aforementioned gaps. The model uses data from 207 countries and territories and a simulation programme to reproduce the flows between the 207 destination and origin countries. Then scenarios of economic and population growth and most importantly of climate change are fed into the model and used to simulate how tourism flows would change over the 21st century. Results of the simulation model were first presented in an article by Hamilton et al. (2005a). The model was then adapted to include the saturation of demand and to examine the impact of sea-level rise (Hamilton et al. 2005b). A recent development was to extend the model to include domestic tourism, expenditures on tourism and the length of stay (Bigano et al. 2007). It is this version of the model that will be discussed here. Subsequent developments of the model have focussed on examining the effects of various climate policies on the flows of tourists (Tol, 2007; Mayor and Tol, 2007).

2. Tourism and climate

Whether in the process of deciding on the destination and the right time for a holiday or in the daily choices made about recreation activities whilst on holiday, climate and weather play an important role (Hamilton and Lau, forthcoming). One would suspect that, “last minute” holidays and short breaks apart, tourist destination choice is affected by the expected weather (climate) rather than the actual weather. For daily recreation choices, actual weather is the decisive factor in decision-making. Climate’s importance for tourism has been classified by de Freitas (2003) according to its aesthetic, physical and thermal aspects. There is growing evidence, however, that climate has significant neurological and psychological effects (Parker 2001), which may also have some influence on the choice of holiday destination. In the literature, there are two broad types of study where the importance of climate and weather for tourism and recreation have been examined: attitudinal studies and behavioural studies.

2.1. Attitudinal studies

Two kinds of attitudinal studies were found, those that examine the subjective rating of climate compared to the ratings from indices of weather data and those that examine the significance of climate in the image and the attractiveness of particular destinations. Thermal comfort indices have been developed in order to capture the complexity of the thermal aspect of climate, which is argued to be a composite of temperature, wind, humidity and radiation. Special modifications of such indices have been used to assess the suitability of certain climates for tourism (e.g. Amelung and Viner, in press). The basis of these indices, however, is subjective and arbitrary according to de Freitas (2003). In a case study, carried out at a beach in Queensland, Australia on 24 days spread over a single year, de Freitas (1990) finds that the relationship between HEBIDEX, a body-atmosphere energy budget index, and the subjective rating of the weather by beach users is highly correlated. Furthermore, he finds that the optimal thermal conditions for beach users are not at the minimum heat stress level but at a point of mild heat stress. Using the thermal comfort index, predicted mean vote, Thorson *et al*. (2004) find a positive relationship between thermal comfort and urban park use for recreational activities in Göteborg, Sweden. They also find, however, that there is a discrepancy in the subjective rating of the weather and the rating of the weather according to the index. The majority of those surveyed said that the weather was “acceptable” when it was “warm” or “hot” according to the calculated index. These levels are associated with heat stress.

In spite of the popularity of studies of destination image in the tourism literature, only one of the 142 destination image papers that are reviewed by Pike (2002)[1] specifically deals with weather. This was a study by Lohmann and Kaim (1999), who note that there is a lack of empirical evidence on the importance of weather/climate on destination choice decision-making. Using a representative survey of German citizens, the importance of certain destination characteristics was assessed. Landscape was found to be the most important aspect even before price considerations. Weather and bio-climate were ranked third and eighth respectively for all destinations. Moreover, they found that although weather is an important factor, destinations are also chosen in spite of the likely bad weather. Measuring the importance of destination characteristics is also the focus of a study by Hu and Ritchie (1993). They review several studies from the 1970s and find that “natural beauty and climate” are of universal importance in defining destinations’ attractiveness. In their own study, they examine the image of Hawaii, Australia, Greece, France and China using a survey of Canadian citizens. They find that climate is the second most important characteristic for the group of tourists on a “recreational” holiday. Climate ranks 12th for the group of tourists taking an “educational” holiday. When the images of the countries are compared, Hawaii is found to have the most attractive climate. Climate and access to the sea are ranked the most important characteristics of destinations in a survey of German tourists, who were departing from the Hamburg area to various destinations abroad in the summer of 2004 (Hamilton and Lau, forthcoming).

[1] These were published in the period 1973 to 2000.

2.2. Behavioural Studies

Some behavioural studies examine daily recreational use patterns of particular sites in terms of weather data. For example, Dwyer (1988) has estimated a daily site use model, for an urban forest in Chicago, USA, using data on noon temperature, percentage sunshine, percentage rain and snow depth. In this study, data on wind-chill is not useful for estimating the use levels. Demand is highest on the sunniest days and on days that are exceptionally warm especially when these conditions occur in late spring or in early summer. High temperatures in July decrease demand. Brandenburg and Arnberger (2001) predict daily use levels of the Danube Flood Plains National Park in Austria. They find that using standard climate data does not produce any satisfactory results. Instead they use the Physiological Equivalent Temperature (PET), the occurrence of precipitation and cloud cover to estimate the number of visitors per day in total and for four groups: cyclists, hikers, joggers and dog walkers. The PET value is very important in determining the use levels, particularly for cyclists and hikers.

Other studies examine the statistical relationship between tourism demand and weather. For example, Agnew and Palutikof (2001) model domestic tourism and international inbound and outbound tourism using a time series of UK tourism and weather data. The results show that temperature is the strongest indicator of domestic demand. In contrast, wetter weather increases the demand for trips abroad in the current period and in the year following. Snow dependent activities are the focus of a survey of US college students carried out in 1997 and 1998 by Englin and Moeltner (2004). Using data on price, weekly conditions at ski resorts in California and Nevada and the participant's income they find that although demand increases as snow amount increases, trip demand is more responsive to changes in price. As said before tourism (as opposed to recreation) is likely to be affected by the expected weather (climate) rather than the actual weather.

Another set of studies uses climate data to capture the role of expected weather in destination choice and consequently demand. Lise and Tol (2002) study the holiday travel patterns of tourists from a range of OECD countries. The data and method are crude, but the results suggest that people from different climates have the same climate preferences for their holidays: The climate of Southern France and California is preferred by everyone, regardless of the home climate[2]. Bigano *et al.* (2006) confirm this result, using less crude econometrics for a much wider range of countries including African and Asian ones. However, Bigano *et al.* also find that people from hotter places tend to have sharper preferences. That is, while Southern France is preferred by people from both hot and cold places, people from hot places would feel much worse about going elsewhere than Southern France than would people from cold places (see Figure 1).

Also using climate data, the Pooled Travel Cost Model (PTCM) has been applied to the demand of tourists from the UK, the Netherlands and Germany for a range of countries (Maddison, 2001; Lise and Tol, 2002; Hamilton, 2003). Hamilton (2003) includes the possibility of taking a vacation in the origin country, whereas the other PTCM studies only examine outbound tourism. The studies include temperature and temperature squared in their estimation of demand. The estimated coefficients on these studies allow the optimal temperature to be calculated, that is, where demand is highest. Demand for a country by tourists from the UK is maximized when the quarterly maximum daytime temperature is 31°C; for tourists from Germany demand peaks where the mean monthly temperature is 24°C. In the Dutch study, the coefficients were not significant.

3. Tourism and climate change

Climate change impact studies can be categorized as qualitative and quantitative. Qualitative impact studies provide information about vulnerabilities and the likely direction of change; nevertheless,

[2] Of course, this does not apply that all tourists travel to these places; climate is not the only factor in tourist destination choice.

they do not provide estimates of changes in demand. Quantitative impact studies can be categorized further into four groups: first, studies that predict changes to the supply of tourism services; second, studies that use tourism climate indices to predict the change in climatic attractiveness; third, studies that use the statistical relationship between demand and weather or climate to estimate the changes in demand; and finally, simulation models of tourism flows.

3.1. Qualitative impact studies

Qualitative studies rely on experts' opinions on the likely impact of climate change. For example, Perry (2000) discusses the impact that climate change will have on tourism at the Mediterranean. The main impact caused by an increase in temperature will be a "doughnut" shaped pattern of demand: in the shoulder season there will be more visits than in the summer season. In addition, he expects that there will be an increase in the demand for long winter holidays particularly from the older generations. The indirect effect of enhanced beach erosion caused by sea level rise will reduce demand and increase the need for planning restrictions in the coastal zone. According to Gable (1997), Caribbean coastal areas will also experience a drop in demand through beach loss. Viner and Agnew (1999) describe the current climate and market situation for the most popular destinations of the British tourist. In addition, the consequences for demand for these destinations under a changed climate in the 2020s and 2050s are discussed. Currently warm resorts such as those in the Eastern Mediterranean are expected to become less attractive as temperature and humidity increase. As summer weather becomes more favourable and reliable in temperate countries, tourism is expected to increase. All of these studies rely on a synthesis of existing work on the physical impacts of climate change or on the expert opinion of the authors; a direct link with demand (or supply) of tourism is not made. Nevertheless, these studies highlight the range of impacts that climate change will have. One qualitative study, however, has involved the tourism industry. This a study by Krupp (1997), where tourism experts from the local tourist industry discussed the impact of climate change on tourism in the West coast of Schleswig-Holstein in Germany. Krupp finds that an increase in summer precipitation will reduce the willingness of the tourism industry to make new investments in tourism infrastructure and facilities.

3.2. Impact on the supply of tourism services

Predicting changes in the supply of tourism services has been applied to the winter sports industry. Breiling and Charamza (1999) analyze the impact of a 2°C change in temperature on seasonal snow-cover depth for all districts in Austria. They estimate that these changes will reduce ski season length and the usability of ski facilities. Warming will have strong impact on low altitude resorts, which the authors expect will disappear first and the remaining resorts will become more expensive. Similar studies have been carried out for winter sports tourism in Scotland (Harrison *et al.*, 1999), Switzerland (Abegg, 1996; Elsasser and Messerli, 2001), Finland (Kuoppamaeki, 1996) and Canada (Scott *et al.*, 2001). These studies find a general decline in natural skiing conditions, although this will be less of a problem at high altitude sites. Moreover, the use of snow making machines is also temperature dependent, which restricts the adaptation options available.

3.3. Impact on climatic attractiveness

The index approach, discussed above, has been used to examine the impact of climate change on the climatic attractiveness of tourist destinations. Scott and McBoyle (2001) apply the tourism index approach to the impact of climate change on city tourism in several North American cities. Cities are ranked according to their climatic appropriateness for tourism and the relationship between tourist accommodation expenditures is examined. Then this ranking is recalculated using data from scenarios of (the lower and middle bounds of) climate change for the 2050s and the 2080s. The attractiveness of the cities improves in both time slices. Improvements in spring are the largest of all the seasons. The authors predict an increase in revenue from tourist accommodation for Canadian cities. Amelung and Viner (in press) also use a tourism index to analyse tourism potential for Europe. The attractiveness of a location for tourists depends on temperature, precipitation, humidity and wind in a very non-linear way. They calculate the index values for spatial resolution of 0.5˚ x 0.5˚ using monthly data for the 2020s, 2050s and the 2080s. The results show that climate change would shift tourists towards higher latitudes and altitudes. In addition, there would be a shift from summer to spring and autumn in some destinations, and from spring and autumn to winter in other destinations.

3.4. The impact on demand

There are studies that examine the impact of climate change on recreation demand. For example, the impact of climate change in the US on eight recreation activities is examined by Loomis and Crespi (1999). They estimate demand equations relating the number of activity days to temperature and precipitation. Under a scenario of a +2.5°C change in temperature and a 7% reduction in precipitation in 2060, they predict sharp reductions in the number of skiing days (-52%) and increases in the number of days spent playing golf (14%), at the beach (14%) and at reservoirs (9%). Mendelsohn and Markowski (1999) estimate the impact of climate change on a range of recreation activities using the same climate change scenario and timeframe as Loomis and Crespi (1999). The aggregate impact is estimated in terms of welfare and ranges from a reduction of 0.8 billion 1991US$ to an increase of 26.5 billion 1991US$. Using the contingent visitation approach, Richardson and Loomis (2004) find that temperature is a positive determinant of demand for visits to the Rocky Mountain National Park in Colorado. Moreover, depending on the climate scenario, they estimate an increase in recreational visits from 9.9% to 13.6% in 2020. These three studies examine domestic demand within the United States either at site level or for each state, and although they refer to recreation tourist trips (involving an overnight stay) have been included in their data.

The following studies examine national demand for domestic and international tourism. In the study by Agnew and Palutikof (2001), a 1°C increase in the summer temperature leads to a 1%-5% increase in UK domestic demand. Maddison (2001) finds that the number of visits and the consumer surplus per year increase as the temperature increases although only until the optimal maximum daily temperature. More specifically, he finds that for a climate change scenario for the 2030s a temperature increase of 2°C and a reduction in precipitation of 15% in summer leads to a 1.3% reduction in trips from the UK to Greece and a 2.2% increase in trips to Spain. For the other seasons, there are increases in the number of trips and in the consumer surplus. Hamilton (2003) uses climate data and the coefficients on the climate variables from the statistical estimation of the demand of German tourists to construct a climate index. For a selection of European countries, the climate index is calculated for the period 1961-1991, and for an arbitrary scenario for August, new climate index values were calculated. For the observed data, Spain, Portugal and Greece have the most attractive climate in August. Under the scenario of climate change (a 2°C temperature increase, a 15% decrease in precipitation and a 10% decrease in the number of wet days per month), however, the value of the climate index actually falls for these countries: it has become too hot. Germany’s climate in August increases in attractiveness. Thus, according to this study, we can expect a shift away from Mediterranean holidays in the summer months to domestic holidays

3.5. Impact on global tourism flows

In the impact studies reviewed so far, the following gaps are evident. Firstly, the possibility of substitution between destinations has been neglected in all studies. Secondly, the studies have focused on particular areas or particular origin nationalities; the global picture has yet to be filled in. Thirdly, climate as a "push" factor has also been overlooked. With this, we mean that the climate of the tourists' home country motivates them to take a holiday to somewhere with a climate that they prefer. This may be to escape the heat of summer months or to get away from a cold and wet winter (or even summer). This is important as climate change may reduce (or increase, when countries get too hot) the need to go elsewhere to spend time in a suitable climate. Hamilton *et al.* (2005a,b) and Bigano et al. (2007) seek to fill these gaps with the Hamburg Tourism Model (HTM), which is a global model of flows from and to 207 countries that includes the climate of countries as a factor in both the estimation of demand to travel as well as the demand for a particular destination.

The model is calibrated for 1995, using data for total international departures and arrivals. Bilateral tourism flows are generated by the model. The simulations are driven by five variables: general attractiveness, distance, population, income, and temperature. General attractiveness is a calibration parameter. It is kept constant. It represents all factors influencing tourist destination choice that are mentioned above, but are not explicitly included in the model. Distance is assumed constant and has no effect on the results. It is relevant to construct the 1995 tourism pattern, however. The effect of population growth is (assumed to be) simple: more people implies more tourists. The effect of per capita income is twofold. Firstly, richer people travel more frequently. Secondly, tourists avoid poor countries. A world that grows ever richer – HTM runs on the SRES scenarios (Nakicenovic and Swart, 2001) – thus sees more tourists, and much more tourists from developing countries. In addition, developing countries become more attractive as tourist destinations.

The annual temperature is the index for climate. There are two quadratic relationships. Firstly, cool destinations become more attractive as they get warmer, and warm destinations become less attractive. Secondly, cool countries generate less international tourists as they get warmer, and warm countries generate more. Put together, these two effects generate an interesting pattern. Climate change shifts international tourists towards the poles and up the mountains. However, climate change also reduces the total number of tourists, because international tourism is dominated by the Germans and the British, who would prefer to take their holidays in their home countries (after climate change has made Germany and the UK more pleasant). See Figure 2. The reduction in international tourism because of climate change is, however, dwarfed by the growth due to population and economic growth.

Hamilton *et al.* (2005b) slightly change the simulation model, initially allowing tourism to grow more rapidly with economic growth but then assuming saturation of demand. This does not drastically change the results, although tourists from hot and poor countries gain in importance; these tourists would increasingly seek to escape to cooler places during their holiday. Recent model developments include the explicit modeling of domestic tourism, and an increased spatial resolution. Next steps are the inclusion of seasons and more climate variables.

Few of the climate change and tourism studies reviewed above extend into economics. Those that do (e.g. Maddison, 2001 and Mendelsohn and Markowski, 1999), offer a straightforward welfare analysis limited to an estimate of the direct costs and benefits. The sole exceptions are the study of Berritella *et al.* (2004) and Bigano et al. (forthcoming). Using the Hamburg Tourism Model of Hamilton *et al.* (2005b) as an input, Berritella *et al.* use the GTAP5 computable general equilibrium model to analyse the economy-wide implications. Climate change impacts on tourism are represented as two additive shocks. Firstly, there is a transfer of income from the countries that receive fewer tourists to those that receive more; this is because the GTAP data is based on the gross *domestic* product. This, of course, partially cancels out in the regional aggregation. Secondly, there is a shift in demand as people consume different things whilst on holidays (e.g., tourists buy less household appliances and more entertainment).

The results show that the global impact is negligible. There is substantial redistribution, however. Countries in Western Europe, the subtropics and the tropics are negatively affected. North America, Eastern Europe and the former Soviet Union, and Australasia are positively affected. The negative impacts may amount to –0.3% of GDP by 2050, the positive impacts of 0.5% of GDP. These numbers are large compared to other monetized impacts of climate change (e.g., Smith *et al.*, 2001).

Bigano et al. (forthcoming) extend this framework to allow for the interactions between sea level rise and tourism, both directly (beach erosion implies less tourists) and indirectly (through prices and incomes). They find that the indirect interactions are larger than the direct ones, primarily because beach nourishment minimizes the negative impact of sea level rise on tourism – note that the study ignores the findings of Hamilton (2007). Bigano et al. also find that the economic impacts of changes in tourism are much larger than those of sea level rise; and that tourism modulates the estimated impact of sea level rise but not vice versa.

4. The impact of climate change on tourism in the Mediterranean

4.1. The Hamburg Tourism Model

The tourism model simulates tourism demand from countries- how many tourists each country produces - and the demand for countries - how many tourists take a holiday in each country. This is carried out through the following steps: First, the total demand for tourist trips is determined. This is estimated using data on the population and on the per capita income of each country. The ratio of domestic to international tourist trips is then estimated, again using per capita income but also data on land area, the length of the coast and temperature. This is carried out for each one of the 207 countries and territories. The next step is to estimate where the international tourists go. For this a matrix of bilateral flows of tourists between all of the countries and territories was constructed and calibrated using data for the year 1995. Similarly, the equations that are used in the previous steps were estimated using data from 1995. The final step is to total up all of the tourists arriving at each country and to estimate expenditure and length of stay.

The data used for the model pose some problems. First, not all countries actually report tourism data. This has meant that missing data had to be estimated. Second, the countries that report do not report on exactly the same thing – some report on the number of visitors (including day visitors), some report on the number of tourists and some report on the number of arrivals at hotels and similar establishments. Finally, there is no distinction made between different types of tourism; leisure, business and visiting family and friends are all lumped together, and there may be a great variation in the responsiveness of these types of tourism to climate. Nevertheless, the database used is the best one available.

Scenarios of population and income growth and climate change are used to produce simulations of tourism flows for the 21st century. The scenarios cause changes on the supply side: that is, the relative attractiveness of holiday destinations changes. On the demand side, the scenarios affect the total number of tourists in each origin country. The data for population and per capita income growth are taken from the Netherlands Environmental Assessment Agency's Integrated Model to Assess the Global Environment (*IMAGE)* version *2.2* implementation[3] (IMAGE Team, 2002) of the scenarios from the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (SRES) (Nakicenovic and Swart, 2001). The original SRES scenarios are specified for 17 world regions; the growth rates of countries in our model are given the growth rate of their specific region. The scenarios of climate change are derived from the FUND model[4], an integrated

[3] For more information see http://www.rivm.nl/image/overview/
[4] For more information see http://www.fnu.zmaw.de/FUND.5679.0.html

assessment model of climate change, (Tol, 1999) and the COSMIC model[5], which is a climate forecasting model (Schlesinger and Williams, 1998).

The model simulates tourism flows in steps of 5 years throughout the century. It can also simulate past years. This is useful for checking the validity of results through the comparison of observed data with the estimates from the simulation. The model simulates for 207 countries and territories. A regional representation would better, particularly for larger countries or countries with diverse climates. The currently available data, however, does not allow for this. Even so a simplified regional extension of the model has been produced for the UK, Germany and Ireland (Hamilton and Tol, 2007).

4.2. Global results

Figure 1 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 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. 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. After 2030, however, the other regions, but particularly Asia, capture a larger share of the market.

The impact of climate change on domestic tourist numbers, both over time and over space, is shown in Figure 2. 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 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 2. 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 3 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 2), 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%

[5] For more information see http://www.crga.atmos.uiuc.edu/COSMIC/announce.html

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 4. 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.

4.3. Mediterranean results

Figure 5 shows the impact of climate change on domestic tourist numbers in 2100. The results are expressed as the difference between the cases with and without climate change, as a percentage of the case without climate change. Climate change will reduce numbers on south side of the Mediterranean and the island nations, whereas more holidays will be spent in the country of residence on the north side. The explanation is that the colder countries to the north will move closer to the optimum temperature for domestic holidays, while the warmer countries to the south will move away from that optimum.

Figure 6 shows the impact of climate change on international tourist arrivals in 2100. The picture is dramatically different than Figure 5. Most Mediterranean countries will see a decline in arrivals, up to 52% for Algeria, but 13 countries will see a drop in visitors of more than 20%. Bosnia & Herzegovina and Slovenia are the two exceptions – these countries are cool compared to the rest of the Mediterranean, and even pick up some of the tourists who would have gone to other countries.

Similarly, Figure 7 shows the impact of climate change on total tourism expenditures. By and large, Figure 7 is the sum of Figures 5 and 6, weighted by the initial distribution of domestic and foreign tourists. Eight countries will gain economically from the impact of climate change on tourism (up to 23% for Slovenia) while the other 14 will lose (up to 31% for Cyprus).

Recall that these numbers are for the impact over a century. When expressed as an annual percentage, the numbers are small relative to the observed and expected growth rates in tourism.

5. Climate change and Mediterranean tourism: a proverbial marriage coming to an end?

The Mediterranean climate is one of the main tourist attractions in the world, and tourism is a major industry in the countries of the Mediterranean. The prospect of climate change is therefore a concern. However, the literature surveyed in this chapter suggests that climate is but one of many factors that shape tourism flows. This is confirmed by the presented model results. Although the model finds large and mostly negative impacts from climate change, the pace of climate change is slow compared to the other trends in the tourism industry.

The research into climate change and tourism is incomplete. We did not consider drought, heat waves, or flash floods. We omitted sea level rise and coastal protection. We ignored shifts in the tourism season, and adaptation by tourist operators. Some of these factors imply that the presented results are too optimistic, and other factors led us to overstate the negative impacts. Future research will need to estimate the size and importance of these issues.

For now, we can conclude that climate change will have an important and sizeable impact on tourism in the Mediterranean. We cannot say, however, the climate change will be the end of tourism. Tourists will continue to come, and tourist numbers will even continue to grow – but tourism growth will be substantially slower because of climate change.

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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.

Agnew, M.D. and Palutikof, J.P. (2001). Climate impacts on the demand for tourism. In *International Society of Biometeorology Proceedings of the First International Workshop on Climate, Tourism and Recreation*. Retrieved from http://www.mif.uni-freiburg.de/isb/ws/report.htm

Amelung, B. and Viner, D. (in press). The vulnerability to climate change of the Mediterranean as a tourist destination. In *Climate Change and Tourism: Assessment and Coping Strategies*, ed. B. Amelung, K. Blazejczyk, A. Matzarakis and D. Viner. Dordrecht: Kluwer Academic Publishers.

Berrittella, M., A. Bigano, R. Roson and R.S.J. Tol (2006), 'A General Equilibrium Analysis of Climate Change Impacts on Tourism', *Tourism Management*, **27** (5), 913-924.

Bigano, A., F. Bosello, R. Roson and R.S.J. Tol (forthcoming), 'Economy-Wide Impacts of Climate Change: A Joint Analysis for Sea Level Rise and Tourism', *Mitigation and Adaptation Strategies for Global Change*.

Bigano, A., J.M. Hamilton and R.S.J. Tol (2006), 'The Impact of Climate on Holiday Destination Choice', *Climatic Change*, **76** (3-4), 389-406.

Bigano, A., J.M. Hamilton and R.S.J. Tol (2007), 'The Impact of Climate Change on Domestic and International Tourism: A Simulation Study', *Integrated Assessment Journal*, **7** (1), 25-49.

Brandenburg, C. and Arnberger, A. (2001). The influence of the weather upon recreation activities. In *International Society of Biometeorology Proceedings of the First International Workshop on Climate, Tourism and Recreation*, ed. A. Matzarakis and C. de Freitas. Retrieved from http://www.mif.uni-freiburg.de/isb/ws/report.htm.

Breiling, M. and Charamza, P. (1999). The impact of global warming on winter tourism and skiing: a regionalised model for Austrian snow conditions. *Regional Environmental Change*, **1** (1)**,** 4-14.

de Freitas, C.R. (1990). Recreation climate assessment. *International Journal of Climatology*, **10**, 89-103.

de Freitas, C.R. (2003). Tourism Climatology: evaluating environmental information for decision making and business planning in the recreation and tourism sector. *International Journal of Biometeorology***, 48**, 45-54.

Dwyer, J.F. (1988). Predicting daily use of urban forest recreation sites. *Landscape and Urban Planning*, **15** (1-2), 127-138.

Elsasser, H. and Messerli, P. (2001). The Vulnerability of the Snow Industry in the Swiss Alps. *Journal of Mountain Research and Development*, **21** (49), 335-339.

Englin, J. and Moeltner, K. (2004). The value of snowfall to skiers and boarders. *Environmental and Resource Economics*, **29** (1), 123-136.

Gable, F. J. (1997). Climate change impacts on Caribbean coastal areas and tourism. *Journal of Coastal Research*, **27**, 49-70.

Hamilton, J.M. (2003). Climate and the destination choice of German tourists. Research Unit Sustainability and Global Change Working Paper **FNU-15** (revised), Centre for Marine and Climate Research, Hamburg University, Hamburg.

Hamilton, J.M. (2007), 'Coastal landscape and the hedonic price of accommodation', *Ecological Economics*, **62** (3-4), 594-602.

Hamilton, J.M. and Lau, M.A. (forthcoming). The Role of Climate Information in Tourist Destination Choice Decision-Making. In *Tourism and Global Environmental Change*, ed. S. Gössling and C.M. Hall. London: Routledge.

Hamilton, J.M., D.J. Maddison and R.S.J. Tol (2005), 'Climate Change and International Tourism: A Simulation Study', *Global Environmental Change*, **15** (3), 253-266.

Hamilton, J.M., D.J. Maddison and R.S.J. Tol (2005), 'The Effects of Climate Change on International Tourism', *Climate Research*, **29**, 255-268.

Hamilton, J.M. and R.S.J. Tol (2007), 'The Impact of Climate Change on Tourism in Germany, the UK, and Ireland: A Simulation Study', *Regional Environmental Change*, **7** (3), 161-172.

Harrison, S.J., Winterbottom, S.J. and Shephard, C. (1999). The potential effects of climate change on the Scottish tourist industry. *Tourism Management*, **20**, 203-211.

Hu, Y. and Ritchie, J.R.B. (1993). Measuring destination attractiveness: a contextual approach. *Journal of Travel Research*, **32** (2), 25-34.

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. National Institute for Public Health and the Environment, Bilthoven, the Netherlands.

Krupp, C. (1997). *Klimaänderungen und die Folgen: eine exemplarische Fallstudie über die Möglichkeiten und Grenzen einer interdisziplinären Klimafolgenforschung*. Berlin: edition Sigma.

Kuoppamaeki, P. (1996). *Impacts of Climate Change from a Small Nordic Open Economy Perspective -- The Potential Impacts of Climate Change on the Finnish Economy*. Helsinki: ETLA.

Lise, W. and Tol, R.S.J. (2002). Impact of climate on tourism demand. *Climatic Change*, **55** (4), 429-449.

Lohmann, M. and Kaim, E. (1999). Weather and holiday destination preferences, image attitude and experience. *The Tourist Review*, **2**, 54-64.

Loomis, J.B. and Crespi, J. (1999). Estimated effects of climate change on selected outdoor recreation activities in the United States. In *The Impact of Climate Change on the United States Economy*, ed. R.O. Mendelsohn and J.E. Neumann. Cambridge: Cambridge University Press, pp 289-314.

Maddison, D.J. (2001). In search of warmer climates? The impact of climate change on flows of British tourists. *Climatic Change*, **49**, 103-208

Mayor, K. and R.S.J. Tol (2007), 'The Impact of the UK Aviation Tax on Carbon Dioxide Emissions and Visitor Numbers', *Transport Policy*, **14** (6), 407-513.

Mendelsohn, R and Markowski, M. (1999). The impact of climate change on outdoor recreation. In *The Impact of Climate Change on the United States Economy*, ed. R.O. Mendelsohn and J.E. Neumann. Cambridge: Cambridge University Press, pp 267-288.

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

Parker, P. (2001). *Physioeconomics: The Basis for Long-Run Economic Growth*. Cambridge: The MIT Press.

Perry, A. (2000). Impacts of climate change on tourism in the Mediterranean: Adaptive responses. Nota di Lavoro **35.2000**, Fondazione Eni Enrico Mattei, Milan.

Pike, S. (2002). Destination image analysis – a review of 142 papers from 1973 to 2000. *Tourism Management*, **23**, 541-549.

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

Scott, D. and McBoyle, G. (2001). Using a "Tourism Climate Index" to examine the implications of climate change for Climate as a Tourism Resource. In *International Society of Biometeorology*

Proceedings of the First International Workshop on Climate, Tourism and Recreation,. ed. A. Matzarakis and C. de Freitas. Retrieved from http://www.mif.uni-freiburg.de/isb/ws/report.htm

Scott, D., McBoyle, G., Mills, B. and Wall, G. (2001). Assessing the vulnerability of the alpine skiing industry in Lakelands Tourism Region of Ontario, Canada to climate variability and change. In *International Society of Biometeorology Proceedings of the First International Workshop on Climate, Tourism and Recreation*, ed. A. Matzarakis and C. de Freitas. Retrieved from http://www.mif.uni-freiburg.de/isb/ws/report.htm

Smith, J.B., Schellnhuber, H.-J. Mirza, M.M.Q., Fankhauser, S., Leemans, R., Lin, E., Ogallo, L., Pittock, B., Richels, R.G., Rosenzweig, C., Tol, R.S.J., Weyant, J.P. and Yohe, G.W. (2001). Vulnerability to climate change and reasons for concern: a synthesis. In *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, ed. J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White. Cambridge: Cambridge University Press, pp 913-967.

Thorsson, S., Lindqvist, M. and Lindqvist, S. (2004). Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden. *International Journal of Biometeorology*, **48**, 149-156.

Tol, R.S.J. (1999), 'Spatial and Temporal Efficiency in Climate Policy: Applications of *FUND*', *Environmental and Resource Economics*, **14** (1), 33-49.

Tol, R.S.J. (2007), 'The Impact of a Carbon Tax on International Tourism', *Transportation Research D: Transport and the Environment*, **12** (2), 129-142.

Viner, D. and Agnew, M. (1999). *Climate Change and its Impacts on Tourism*. Godalming: WWF-UK.

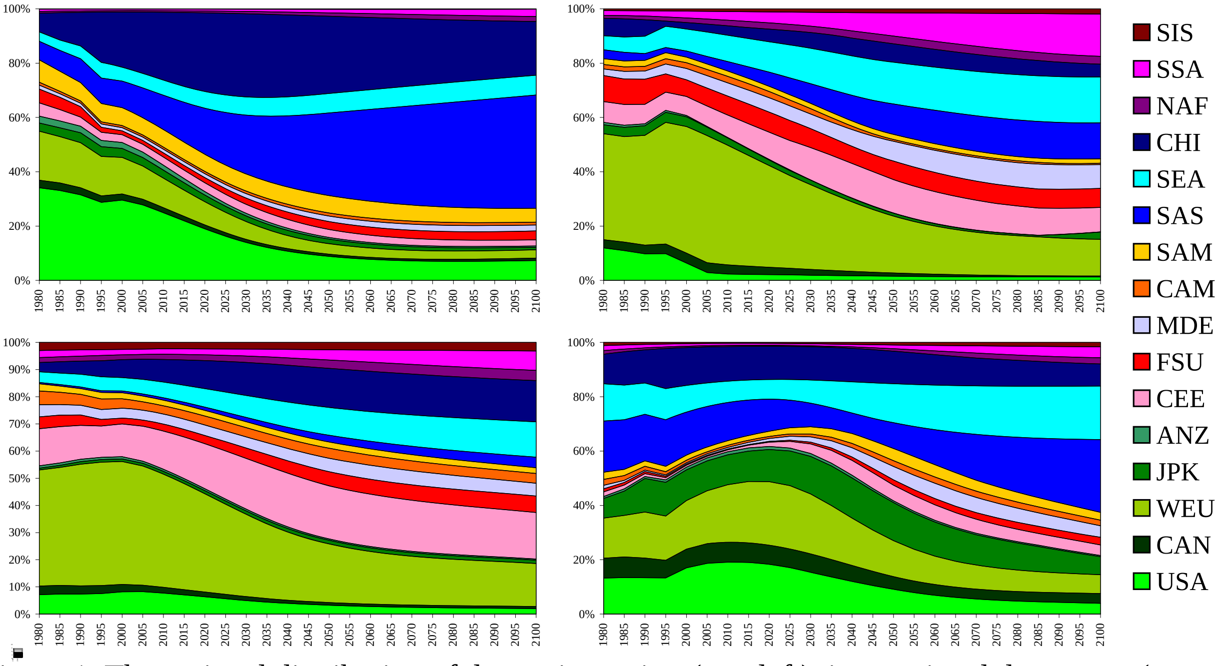


Figure 1. The regional distribution of domestic tourists (top, left), international departures (top, right), international arrivals (bottom, left) and tourism receipts (bottom, right) for the A1B scenarios without climate change. The regions are, from top to bottom: Small Island States; Sub-Saharan Africa; 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.

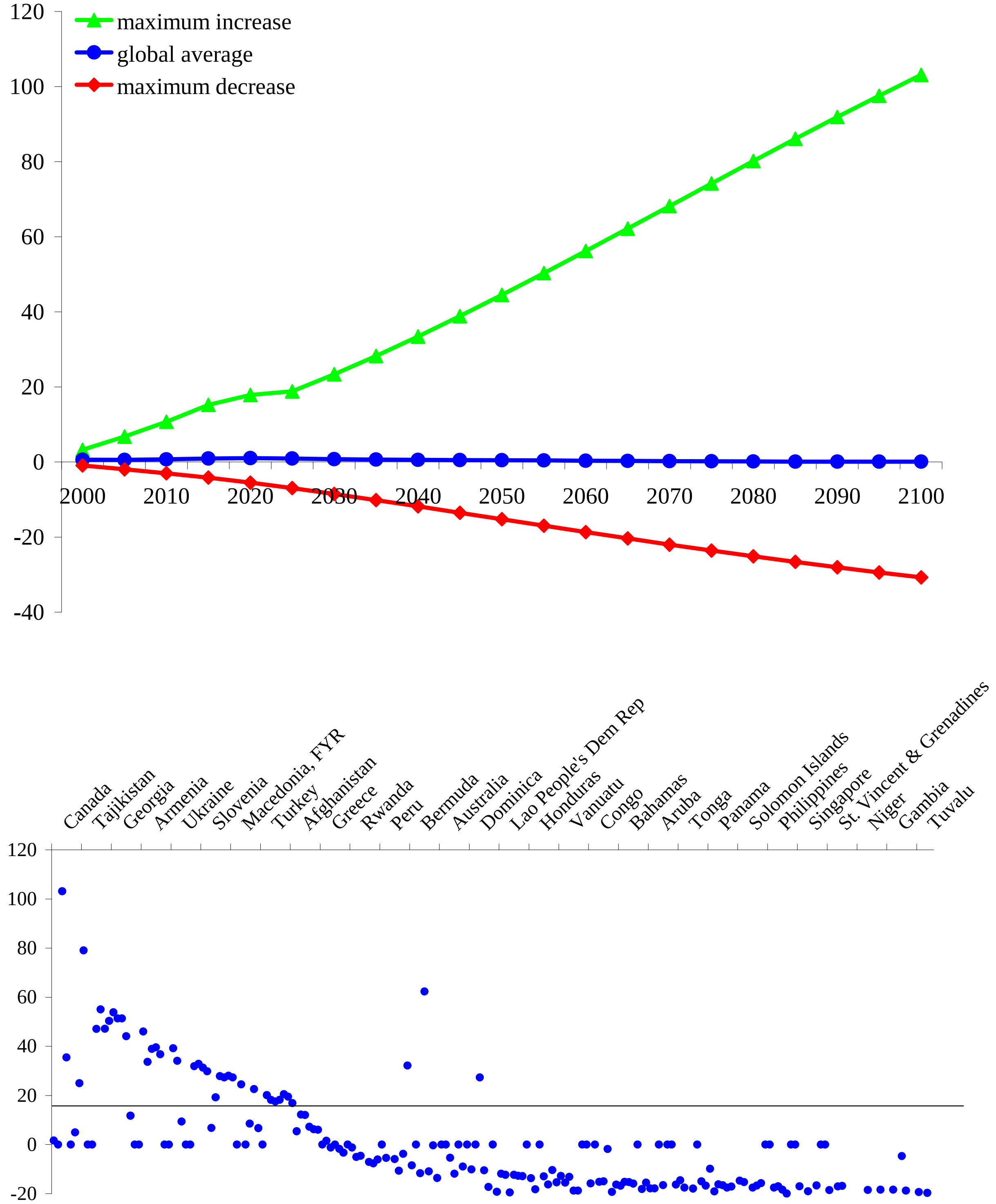
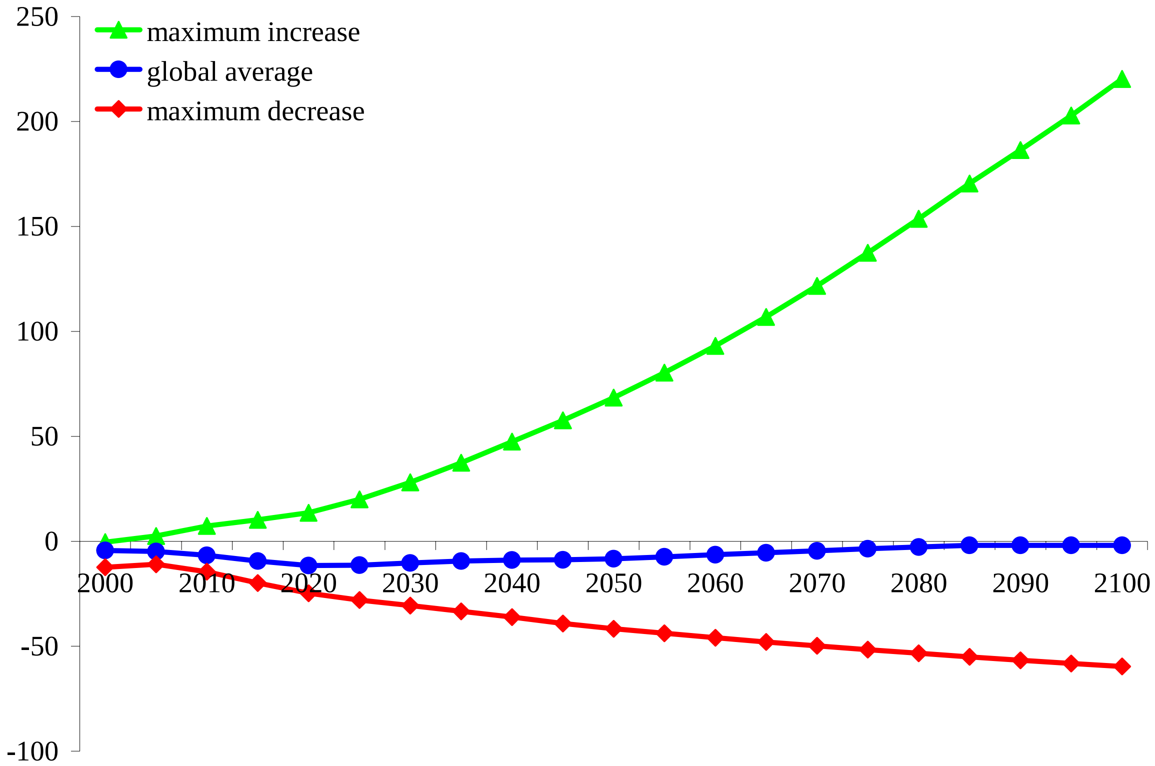


Figure 2. The effect of climate change on domestic tourist numbers, as a percentage of the numbers without climate change; top panel: world average, maximum increase (positive), and maximum decrease (negative); bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.



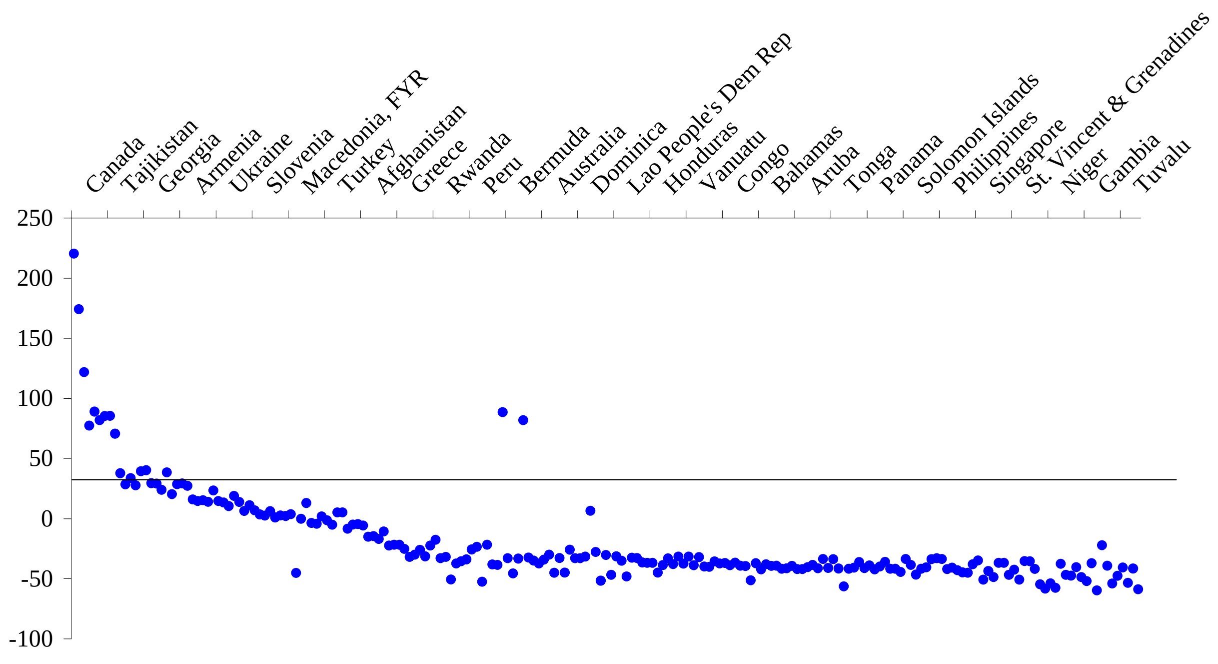


Figure 3. The effect of climate change on international tourist arrivals, as a percentage of the numbers without climate change; top panel: world average, maximum increase, and maximum decrease; bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.

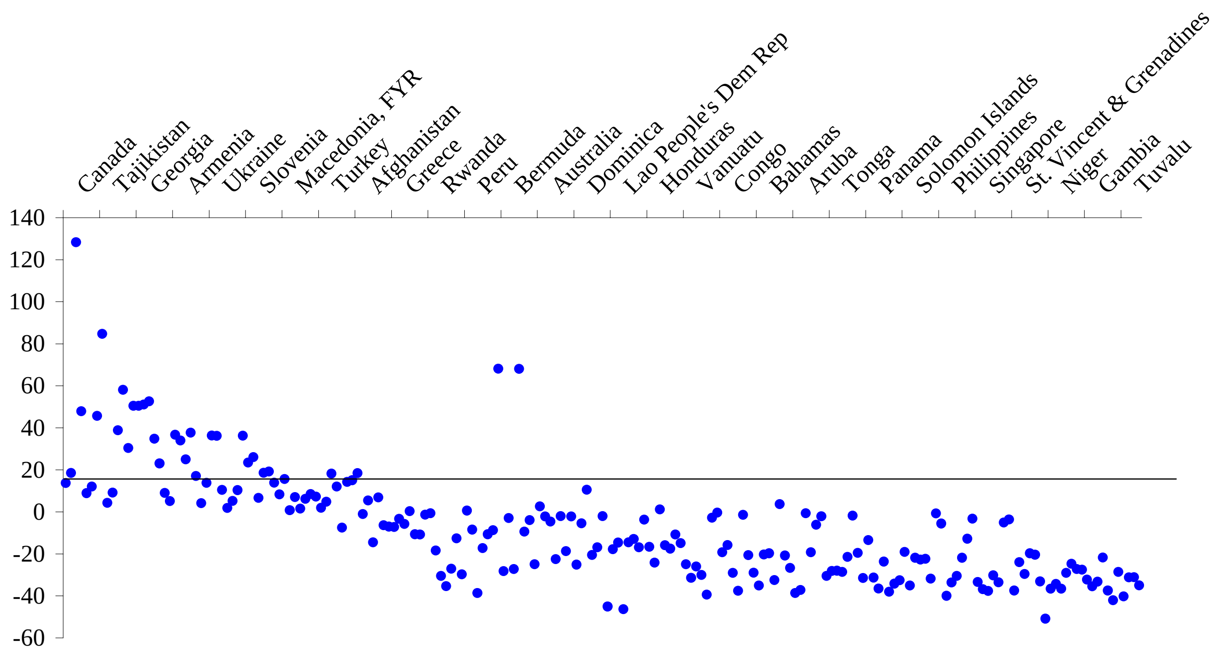


Figure 4. The effect of climate change on total tourism expenditures, as a percentage of expenditure without climate change; top panel: world average, maximum increase, and maximum decrease; bottom panel: impact in 2100, countries ranked to their annual average temperature in 1961-1990.

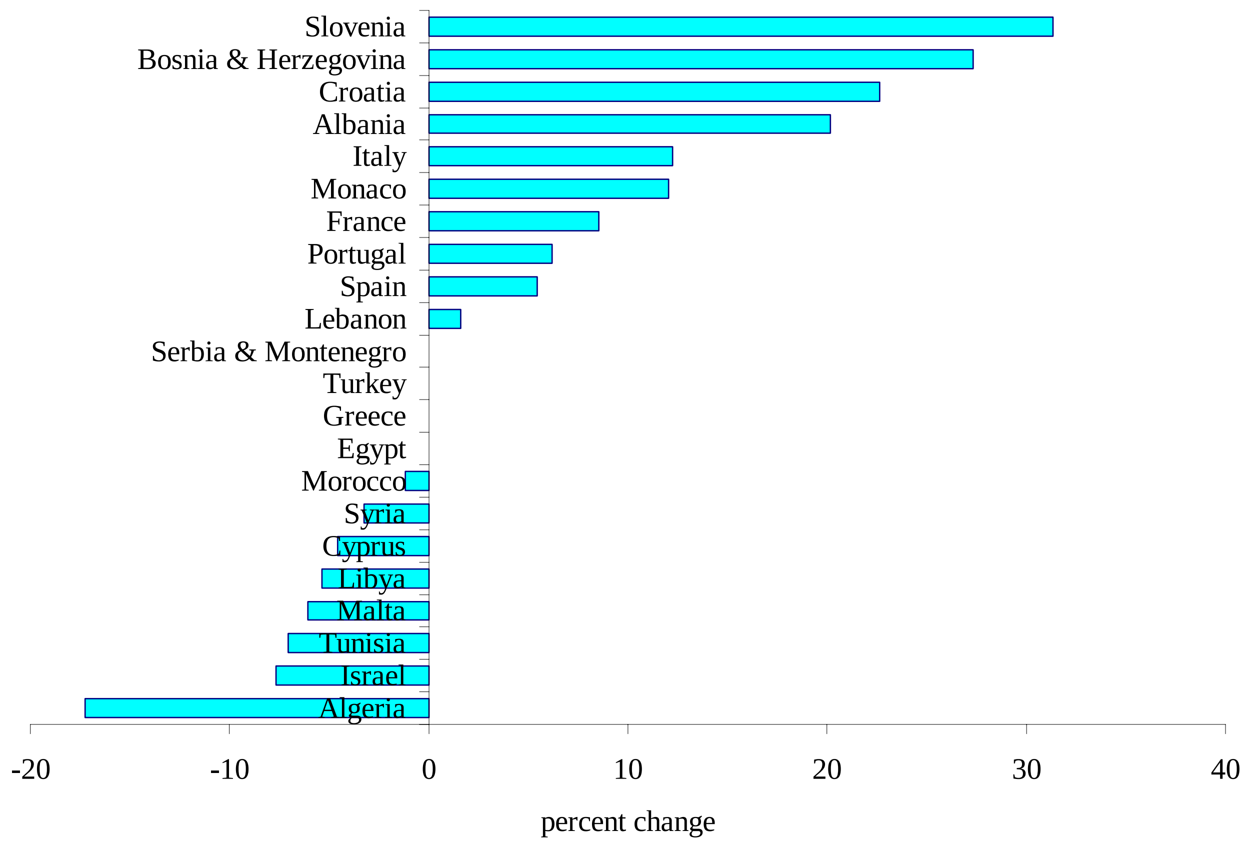


Figure 5. The effect of climate change on domestic holidays in 2100, as a percentage of holiday numbers without climate change, for the countries on the Mediterranean and Portugal.

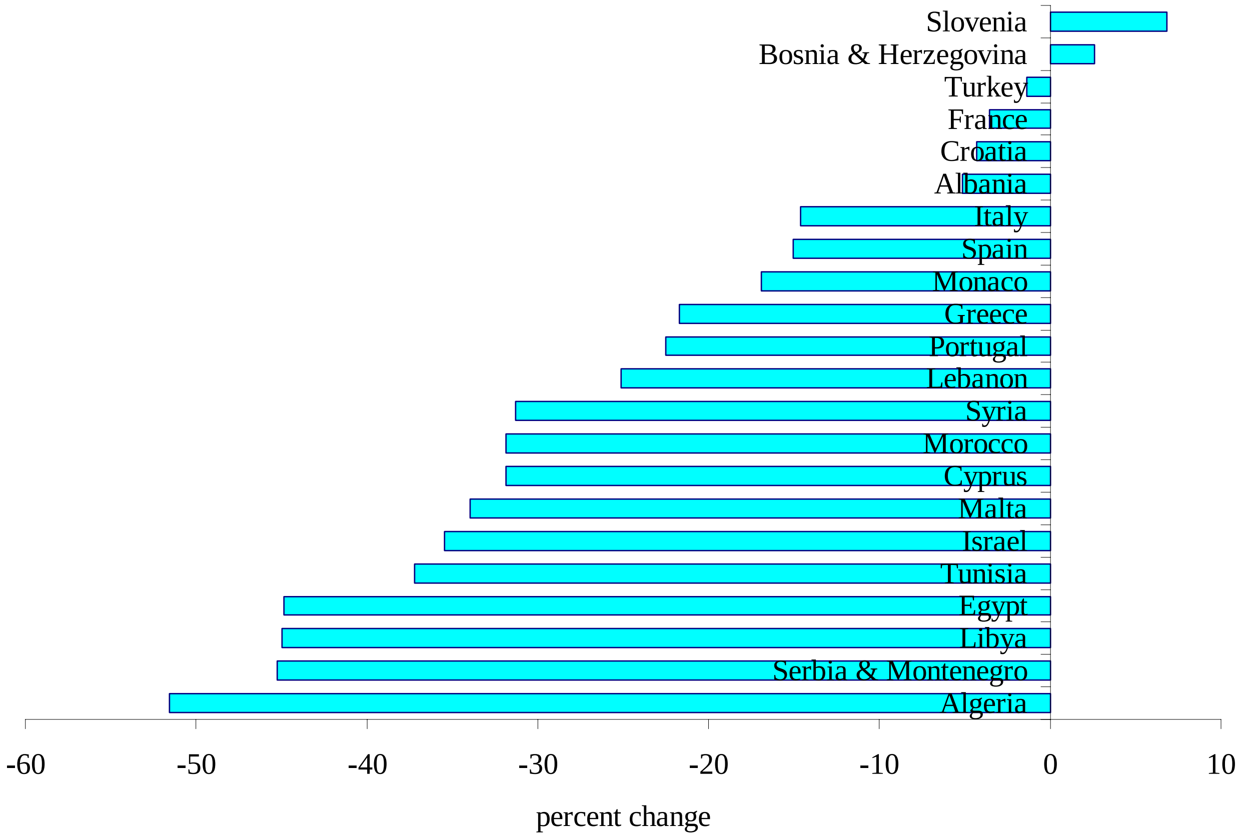


Figure 6. The effect of climate change on international arrivals in 2100, as a percentage of arrival numbers without climate change, for the countries on the Mediterranean and Portugal.

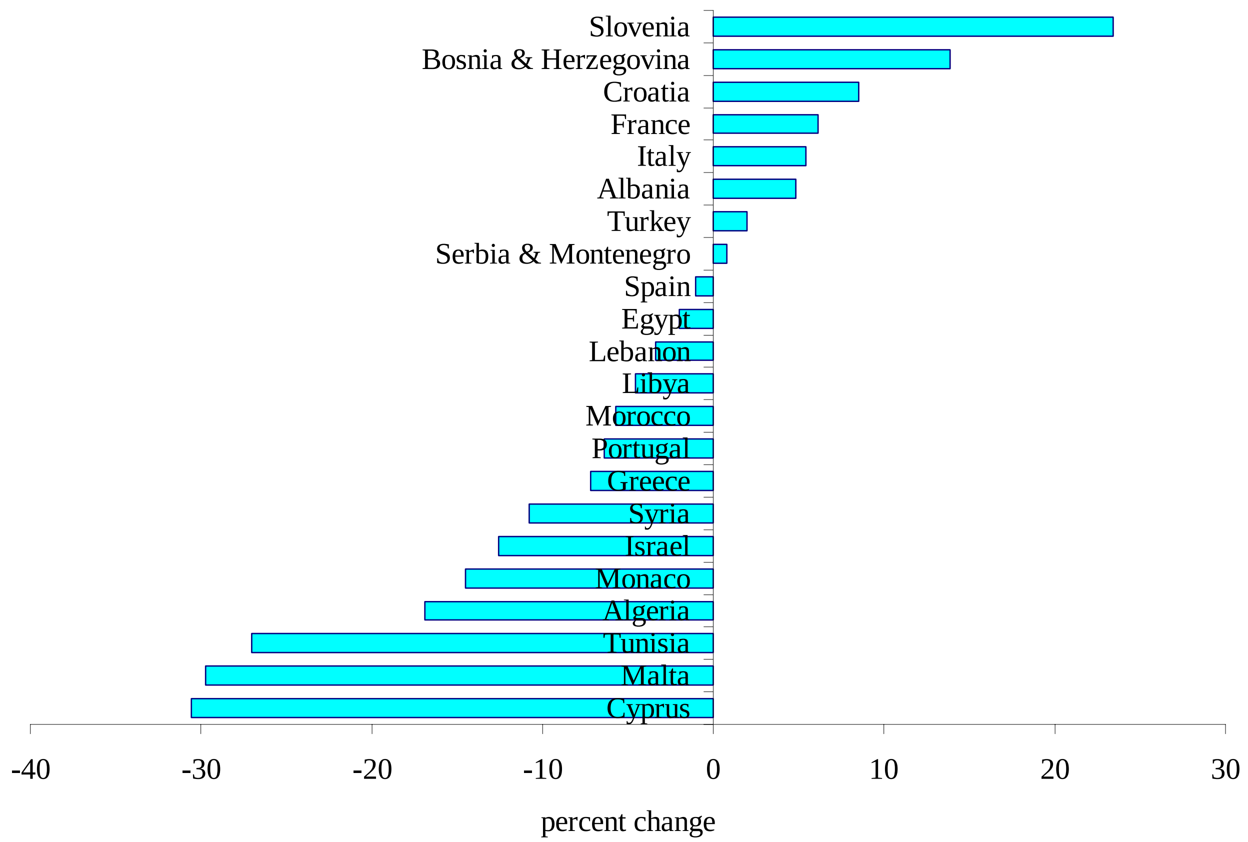


Figure 7. The effect of climate change on total tourism expenditures in 2100, as a percentage of expenditure without climate change, for the countries on the Mediterranean and Portugal.

Working Papers

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Bigano, A., J.M. Hamilton and R.S.J. Tol (2008), *Climate Change and Tourism in the Mediterranean*, **FNU-157** (submitted).

Schneider U.A., J. Balkovic, S. De Cara, O. Franklin, S. Fritz, P. Havlik, I. Huck, K. Jantke, A.M.I. Kallio, F. Kraxner, A. Moiseyev, M. Obersteiner, C.I. Ramos, C. Schleupner, E. Schmid, D. Schwab, R. Skalsky (2008), *The European Forest and Agricultural Sector Optimization Model – EUFASOM*, **FNU-156**.

Schneider, U.A. and P. Kumar (2008), *Greenhouse Gas Emission Mitigation through Agriculture*, **FNU-155**.

Tol, R.S.J. and S. Wagner (2008), *Climate Change and Violent Conflict in Europe over the Last Millennium*. **FNU-154** (submitted).

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Osmani, D. and R.S.J. Tol (2007), *Towards Farsightedly Stable International Environmental Agreements: Part Two*, **FNU-149** (submitted).

Ruane, F.P. and R.S.J. Tol (2007), *Academic Quality, Power and Stability: An Application to Economics in the Republic of Ireland*, **FNU-148** (submitted).

Tol, R.S.J. (2007), *A Rational, Successive g-Index Applied to Economics Departments in Ireland*, **FNU-147** (forthcoming, *Journal of Informetrics*).

Tol, R.S.J. (2007), *Of the h-Index and its Alternatives: An Application to the 100 Most Prolific Economists*, **FNU-146** (forthcoming, *Scientometrics*).

Yohe, G.W. and R.S.J. Tol (2007), *Precaution and a Dismal Theorem: Implications for Climate Policy and Climate Research*, **FNU-145** (submitted).

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Tol, R.S.J. (2007), *The Matthew Effect Defined and Tested for the 100 Most Prolific Economists*, **FNU-143** (submitted, *Journal of the American Society for Information Science and Technology*).

Berrittella, M., K. Rehdanz, R.S.J. Tol and J. Zhang (2007), *The Impact of Trade Liberalisation on Water Use: A Computable General Equilibrium Analysis*, **FNU-142** (submitted, *Journal of Economic Integration*).

Lyons, S., K. Mayor and R.S.J. Tol (2007), *Convergence of Consumption Patterns during Macroeconomic Transition: A Model of Demand in Ireland and the OECD*, **FNU-141** (submitted).

Osmani, D. and R.S.J. Tol (2007), *Towards Farsightedly Stable International Environmental Agreements*, **FNU-140** (submitted).

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Link, P.M. and C. Schleupner (2007), *Agricultural land use changes in Eiderstedt: historic developments and future plans*, **FNU-137** (submitted).

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Mayor, K. and R.S.J. Tol (2007), *The Impact of the EU-US Open Skies Agreement on International Travel and Carbon Dioxide Emissions*, **FNU-134** (*Journal of Air Transport Management*, **14**, 1-7).

Schneider, U.A., M. Obersteiner, and E. Schmid (2007), *Agricultural adaptation to climate policies and technical change*, **FNU-133** (submitted).

Lychnaras, V. and U.A. Schneider (2007), *Dynamic Economic Analysis of Perennial Energy Crops - Effects of the CAP Reform on Biomass Supply in Greece*, **FNU-132** (submitted).

Mayor, K. and R.S.J. Tol (2007), The Impact of the UK Aviation Tax on Carbon Dioxide Emissions and Visitor Numbers, **FNU-131** (*Transport Policy*, **14** (6), 407-513).

Ruane, F. and R.S.J. Tol (2007), *Refined (Successive) h-indices: An Application to Economics in the Republic of Ireland*, **FNU-130** (forthcoming, *Scientometrics*).

Yohe, G.W., R.S.J. Tol and D. Murphy (2007), *On Setting Near-Term Climate Policy as the Dust Begins the Settle: The Legacy of the Stern Review*, **FNU-129** (*Energy & Environment*, **18** (5), 621-633).

Maddison, D.J. and K. Rehdanz (2007), *Happiness over Space and Time*, **FNU-128** (submitted).

Anthoff, D. and R.S.J. Tol (2007), *On International Equity Weights and National Decision Making on Climate Change*, **FNU-127** (submitted).

de Bruin, K.C., R.B. Dellink and R.S.J. Tol (2007), *AD-DICE: An Implementation of Adaptation in the DICE Model*, **FNU-126** (submitted, *Climatic Change*).

Tol, R.S.J. and G.W. Yohe (2007), *The Stern Review: A Deconstruction*, **FNU-125** (submitted).

Keller, K., L.I. Miltich, A. Robinson and R.S.J. Tol (2007), *How Overconfident Are Current Projections of Anthropogenic Carbon Dioxide Emissions?*, **FNU-124** (submitted, *Energy Journal*).

Cowie, A., U.A. Schneider and L. Montanarella (2006), *Potential synergies between existing multilateral environmental agreements in the implementation of Land Use, Land Use Change and Forestry activities*, **FNU-123** (submitted)

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Anthoff, D., C. Hepburn and R.S.J. Tol (2006), *Equity Weighting and the Marginal Damage Costs of Climate Change*, **FNU-121** (submitted, *Ecological Economics*)

Tol, R.S.J. (2006), *The Impact of a Carbon Tax on International Tourism*, **FNU-120** (*Transportation Research D: Transport and the Environment*, **12** (2), 129-142).

Rehdanz, K. and D.J. Maddison (2006), *Local Environmental Quality and Life Satisfaction in Germany*, **FNU-119** (forthcoming, *Ecological Economics*)

Tanaka, K., R.S.J. Tol, D. Rokityanskiy, B.C. O'Neill and M. Obersteiner (2006), *Evaluating Global Warming Potentials as Historical Temperature Proxies: An Application of ACC2 Inverse Calculation*, **FNU-118** (submitted, *Climatic Change*)

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Link, P.M. and Tol, R.S.J. (2006), *The Economic Impact of a Shutdown of the Thermohaline Circulation: An Application of FUND*, **FNU-103** (submitted, *Climatic Change*).
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Tol, R.S.J. (2005), Europe's Long Term Climate Target: A Critical Evaluation, ***FNU-92*** *(*Energy Policy*,* ***35*** *(1), 424-434)*
Hamilton, J.M. (2005), Coastal Landscape and the Hedonic Price of Accommodation, ***FNU-91*** *(Ecological Economics,* ***62*** *(3-4), 594-602)*
Hamilton, J.M., D.J. Maddison and R.S.J. Tol (2005), Climate Preferences and Destination Choice: A Segmentation Approach, ***FNU-90*** *(submitted)*
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Röckmann, C., U.A. Schneider, M.A. St.John, and R.S.J. Tol (2005), *Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints*, **FNU-84** (*Natural Resources Modelling*, **20** (2), 223-262)
Tol, R.S.J. and G.W. Yohe (2005), *Infinite uncertainty, forgotten feedbacks, and cost-benefit analysis of climate policy*, **FNU-83** (*Climatic Change*, **83**, 429-442)
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Lonsdale, K., T.E. Downing, R.J. Nicholls, D. Parker, A.T. Vafeidis, R. Dawson and J.W. Hall (2005), *Plausible responses to the threat of rapid sea-level rise for the Thames Estuary*, **FNU-77** (submitted, *Climatic Change*)
Poumadère, M., C. Mays, G. Pfeifle with A.T. Vafeidis (2005), *Worst Case Scenario and Stakeholder Group Decision: A 5-6 Meter Sea Level Rise in the Rhone Delta, France*, **FNU-76** (submitted, *Climatic Change*)
Olsthoorn, A.A., P.E. van der Werff, L.M. Bouwer and D. Huitema (2005), *Neo-Atlantis: Dutch Responses to Five Meter Sea Level Rise*, **FNU-75** (submitted, *Climatic Change*)
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Schleupner, C. (2005), *Evaluation of coastal squeeze and beach reduction and its consequences for the Caribbean island Martinique*, **FNU-72** (submitted)
Schleupner, C. (2005), *Spatial Analysis As Tool for Sensitivity Assessment of Sea Level Rise Impacts on Martinique*, **FNU-71** (submitted)
Sesabo, J.K. and R.S.J. Tol (2005), *Factors affecting Income Strategies among households in Tanzanian Coastal Villages: Implication for Development-Conservation Initiatives*, **FNU-70** (submitted)

Fisher, B.S., G. Jakeman, H.M. Pant, M. Schwoon. and R.S.J. Tol (2005), *CHIMP: A Simple Population Model for Use in Integrated Assessment of Global Environmental Change*, **FNU-69** (*Integrated Assessment Journal*, **6** (3), 1-33)

Rehdanz, K. and R.S.J. Tol (2005), *A No Cap But Trade Proposal for Greenhouse Gas Emission Reduction Targets for Brazil, China and India*, **FNU-68** (submitted, *Climate Policy*)

Zhou, Y. and R.S.J. Tol (2005), *Water Use in China's Domestic, Industrial and Agricultural Sectors: An Empirical Analysis*, **FNU-67** (*Water Science and Technoloy: Water Supply*, **5** (6), 85-93)

Rehdanz, K. (2005), *Determinants of Residential Space Heating Expenditures in Germany*, **FNU-66** (*Energy Economics **29***)

Ronneberger, K., R.S.J. Tol and U.A. Schneider (2005), *KLUM: A Simple Model of Global Agricultural Land Use as a Coupling Tool of Economy and Vegetation,* **FNU-65** (submitted, *Climatic Change*)

Tol, R.S.J. (2005), *The Benefits of Greenhouse Gas Emission Reduction: An Application of* FUND, **FNU-64** (submitted, *Global Environmental Change*)

Röckmann, C., M.A. St.John, U.A. Schneider, F.W. Köster, F.W. and R.S.J. Tol (2006), *Testing the implications of a permanent or seasonal marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions*, **FNU-63-revised** (*Fisheries Research*, **85**, 1-13)

Letsoalo, A., J. Blignaut, T. de Wet, M. de Wit, S. Hess, R.S.J. Tol and J. van Heerden (2005), *Triple Dividends of Water Consumption Charges in South Africa*, **FNU-62** (*Water Resources Research*, **43**, W05412)

Zandersen, M., Termansen, M., Jensen,F.S. (2005), *Benefit Transfer over Time of Ecosystem Values: the Case of Forest Recreation*, **FNU-61** (submitted)

Rehdanz, K., Jung, M., Tol, R.S.J. and Wetzel, P. (2005), *Ocean Carbon Sinks and International Climate Policy*, **FNU-60** (*Energy Policy*, **34**, 3516-3526)

Schwoon, M. (2005), *Simulating the Adoption of Fuel Cell Vehicles*, **FNU-59** (submitted)

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, *Integrated Assessment Journal*)

Bosello, F., R. Roson and R.S.J. Tol (2004), *Economy-wide estimates of the implications of climate change: Human health*, **FNU-57** (*Ecological Economics*, **58**, 579-591)

Hamilton, J.M. and M.A. Lau (2004) *The role of climate information in tourist destination choice decision-making*, **FNU-56** (forthcoming, Gössling, S. and C.M. Hall (eds.), Tourism and Global Environmental Change. London: Routledge)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2004), *The impact of climate on holiday destination choice*, **FNU-55** (*Climatic Change*, **76** (3-4), 389-406)

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** (*International Journal of Tourism Research*, **9**, 147-174)

Susandi, A. and R.S.J. Tol (2004), *Impact of international emission reduction on energy and forestry sector of Indonesia*, **FNU-53** (submitted)

Hamilton, J.M. and R.S.J. Tol (2004), *The Impact of Climate Change on Tourism and Recreation*, **FNU-52** (forthcoming, Schlesinger et al. (eds.), Cambridge University Press)

Schneider, U.A. (2004), *Land Use Decision Modelling with Soil Status Dependent Emission Rates*, **FNU-51** (submitted)

Link, P.M., U.A. Schneider and R.S.J. Tol (2004), *Economic impacts of changes in fish population dynamics: the role of the fishermen's harvesting strategies*, **FNU-50** (submitted)

Berritella, M., A. Bigano, R. Roson and R.S.J. Tol (2004), *A General Equilibrium Analysis of Climate Change Impacts on Tourism*, **FNU-49** (*Tourism Management*, **27** (5), 913-924)

Tol, R.S.J. (2004), *The Double Trade-Off between Adaptation and Mitigation for Sea Level Rise: An Application of* FUND, **FNU-48** (*Mitigation and Adaptation Strategies for Global Change*, **12** (5), 741-753)

Erdil, E. and Yetkiner, I.H. (2004), *A Panel Data Approach for Income-Health Causality*, **FNU-47**

Tol, R.S.J. (2004), *Multi-Gas Emission Reduction for Climate Change Policy: An Application of* FUND, **FNU-46** (*Energy Journal* (Multi-Greenhouse Gas Mitigation and Climate Policy Special Issue), 235-250)

Tol, R.S.J. (2004), *Exchange Rates and Climate Change: An Application of* FUND, **FNU-45** (*Climatic Change*, **75**, 59-80)

Gaitan, B., Tol, R.S.J, and Yetkiner, I. Hakan (2004), *The Hotelling's Rule Revisited in a Dynamic General Equilibrium Model*, **FNU-44** (submitted)

Rehdanz, K. and Tol, R.S.J (2004), *On Multi-Period Allocation of Tradable Emission Permits*, **FNU-43** (submitted)

Link, P.M. and Tol, R.S.J. (2004), *Possible Economic Impacts of a Shutdown of the Thermohaline Circulation: An Application of* FUND, **FNU-42** (*Portuguese Economic Journal*, **3**, 99-114)

Zhou, Y. and Tol, R.S.J. (2004), *Evaluating the costs of desalination and water transport*, **FNU-41** (*Water Resources Research*, **41** (3), W03003)

Lau, M. (2004), *Küstenzonenmanagement in der Volksrepublik China und Anpassungsstrategien an den Meeresspiegelanstieg*,**FNU-40** (*Coastline Reports* (1), 213-224.)

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

Bosello, F., Lazzarin, M., Roson, R. and Tol, R.S.J. (2004), *Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise*, **FNU-38** (*Environmental and Resource Economics*, **37**, 549-571)

Schwoon, M. and Tol, R.S.J. (2004), *Optimal* CO_2*-abatement with socio-economic inertia and induced technological change*, **FNU-37** (*Energy Journal*, **27** (4), 25-60)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2004), *The Effects of Climate Change on International Tourism*, **FNU-36** (*Climate Research*, **29**, 255-268)

Hansen, O. and R.S.J. Tol (2003), *A Refined Inglehart Index of Materialism and Postmaterialism*, **FNU-35** (submitted)

Heinzow, T. and R.S.J. Tol (2003), *Prediction of Crop Yields across four Climate Zones in Germany: An Artificial Neural Network Approach*, **FNU-34** (submitted, *Climate Research*)

Tol, R.S.J. (2003), *Adaptation and Mitigation: Trade-offs in Substance and Methods*, **FNU-33** (*Environmental Science and Policy*, **8** (6), 572-578)

Tol, R.S.J. and T. Heinzow (2003), *Estimates of the External and Sustainability Costs of Climate Change*, **FNU-32** (submitted)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2003), *Climate change and international tourism: a simulation study*, **FNU-31** (*Global Environmental Change*, **15** (3), 253-266)

Link, P.M. and R.S.J. Tol (2003), *Economic impacts of changes in population dynamics of fish on the fisheries in the Barents Sea*, **FNU-30** (*ICES Journal of Marine Science*, **63** (4), 611-625)

Link, P.M. (2003), *Auswirkungen populationsdynamischer Veränderungen in Fischbeständen auf die Fischereiwirtschaft in der Barentssee*, **FNU-29** (*Essener Geographische Arbeiten*, **35**, 179-202)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China – An Assessment of Structural Impacts on Decision-making Processes*, **FNU-28** (*Ocean & Coastal Management*, No. 48 (2005), pp. 115-159.)

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** (*Integrated Assessment*, **6** (1), 75-82)

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** (*Desalination*, **163** (4), 225-240)
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** (*Ecological Economics*, **52** 111-125)
Tol, R.S.J., (2003), *The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties*, **FNU-19** (*Energy Policy*, **33** (16), 2064-2074).
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** (forthcoming, *Climatic Change*).
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** (*Climate Policy*, **4**, 269-287).
Rehdanz, K (2002), *Hedonic Pricing of Climate Change Impacts to Households in Great Britain*, **FNU-13** (*Climatic Change* **74**).
Tol, R.S.J. (2002), *Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of* FUND, **FNU-12** (*Environment and Development Economics*, **10**, 615-629).
Rehdanz, K. and Tol, R.S.J. (2002), *On National and International Trade in Greenhouse Gas Emission Permits*, **FNU-11** (*Ecological Economics*, **54**, 397-416).
Fankhauser, S. and Tol, R.S.J. (2001), *On Climate Change and Growth*, **FNU-10** (*Resource and Energy Economics*, **27**, 1-17).
Tol, R.S.J.and Verheyen, R. (2001), *Liability and Compensation for Climate Change Damages – A Legal and Economic Assessment*, **FNU-9** (*Energy Policy*, **32** (9), 1109-1130).
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** (*Environmental and Resource Economics*, **28**, 209-232).
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).
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).