THE IMPACT OF A CARBON TAX ON INTERNATIONAL TOURISM

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Abstract

A simulation model of international tourist flows is used to estimate the impact of a carbon tax on aviation fuel. The effect of the tax on travel behaviour is small: A global $1000/tC would change travel behaviour to reduce carbon dioxide emissions from international aviation by 0.8%. This is because the imposed tax is probably small relative to the air fare. A $1000/tC tax would less than double air fares, and have a smaller impact on the total cost of the holiday. In addition, the price elasticity is low. A carbon tax on aviation fuel would particularly affect long-haul flights, because of high emissions, and short-haul flights, because of the emission during take-off and landing. Medium distance flights would be affected least. This implies that tourist destinations that rely heavily on short-haul flights (that is, islands near continents, such as Ireland) or on intercontinental flights (e.g., Africa) will see a decline in international tourism numbers, while other destinations may see international arrivals rise. If the tax is only applied to the European Union, EU tourists would stay closer to home so that EU tourism would grow at the expense of other destinations. Sensitivity analyses reveal that the qualitative insights are robust. A carbon tax on aviation fuel would have little effect on international tourism, and little effect on emissions.

Key words

International tourism, tax, carbon dioxide, aviation

JEL Classification

L83, L93, Q54

1. Introduction

Transport is responsible for a large portion of carbon dioxide emissions, and its emissions are growing faster than those from other sources.[1] Moreover, emission reduction appears to be more difficult and more expensive in transport than it is in other sectors, particularly power

[1] See Greening (2004), http://www.epa.gov/climatechange/emissions/co2_human.html, and http://themes.eea.europa.eu/Environmental_issues/climate/indicators.

generation (Barker *et al.*, 2001; Schaefer and Jacoby, 2005; Van Vuuren *et al.*, 2006). International aviation is the fastest growing part of transport and it is more difficult to regulate than domestic transport, inter alia because it is outside the jurisdiction of a single country. Should abatement be successful for power generation and domestic transport, the increasing emissions from international aviation would stand out (Pridmore *et al.*, 2003) and pressure to reduce emissions would increase. This paper investigates the potential contribution of emission reduction from international aviation.

The paper starts with the heroic assumption that at least a group of countries will be able to agree on a tax on kerosene. I will not analyse the chance of this occurring, or which countries would be likely to take the initiative. It should be noted the European Union, particularly at the initiative of France, used to promote the idea of a kerosene tax,[2] but recently the political attention has shifted to including aviation in the European Trading System for carbon dioxide permits.[3] In this paper, I assume that there is a tax. Tradable permits would raise the price just as a tax would (Tietenberg, 2001).

The paper is limited to *international* aviation *demand* by *tourists*. Domestic air travel is excluded, as is travel for business purposes.[4] The short reason is that the paper is based on an existing model that includes neither domestic travel nor business travel. The reason that the model excludes these aspects is that there is a global database of reasonable quality on international tourist travel – but there is nothing of the sort for domestic tourist travel or for business travel.[5] So, a choice has to be made between comprehensiveness in a geographic sense, and comprehensiveness in a travel sense. The current paper opts for the former, which of course does not make the latter less relevant. Note that business travellers are less likely to respond to price changes than are tourists.

The paper is limited to shifts in demand induced by a kerosene tax. Of course, a kerosene tax would also induce changes in flight behaviour, aircraft technology, and perhaps fuel choice – each of which would reduce carbon dioxide emissions (Wit *et al.*, 2002). However, this would dampen the price signal to the traveller. The results suggest that this is not a major problem. Note that other studies focus on technical measures that would reduce carbon dioxide emissions (Bates *et al.*, 2000; Wit *et al.*, 2002, 2005; Wulff and Hourmouziadis, 1997).

I was able to find only three previous studies that estimate the effect of carbon pricing on international aviation. In a report to CEC DG Energy and Transport, Wit *et al.* (2002) find that a €50/tCO_2 would reduce air travel demand such that emissions fall by 4.9%.[6] This is almost entirely due to a loss in total travel demand – modal shift is minimal. Unfortunately, Wit *et al.* (2002) do not state how they got to this estimate.[7] The results are from "the AERO model", but the report does not detail the model, while the reference list does give any specific information as to where a model description can be found. There is no reference to the AERO model on the website of the alleged model developer, the Netherlands Civil Aviation Authority. It is hard to imagine that many passengers would be deterred by a €50/tCO_2 carbon tax. According to Wit *et al.* (2002), this is equivalent to up to €9 charge per round-trip.

Olsthoorn (2001) also uses a linear model. Regressing jet-fuel bunker (a good proxy for the fuel used in international aviation) on world GDP and the price of oil, he finds that fuel

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[2] See http://www.euractiv.com/en/energy/eu-kerosene-tax-fight-global-poverty/article-135109.
[3] See http://www.euractiv.com/en/sustainability/aviation-climate-change/article-139728.
[4] Note that business travel is combined with tourism travel for some countries.
[5] Although this information can be had for selected countries.
[6] For a €10/tCO_2 tax, emissions drop 1.0%; for €30/tCO_2 tax, 3.1%. Travel demand appears to be linear in price.
[7] Wit *et al.* (2005) revise the estimates of Wit and Dings (2002). However, they only comment on the CO_2 emission reduction due to technological change. The 2002 estimates are 3 times as high as the 2005 estimates.

demand falls by 4 PJ for every $1 added to the oil price. He imposes a draconian tax of $1500/t$CO_2$, and reduces aviation emissions by up to 90%.

Michaelis (1997) uses price elasticities of –0.7 and –2.1 (after Oum *et al.*, 1990) and finds that a $125/tC tax would increase ticket prices by 7% on average, and reduce demand by 4.4% to 13.3%. Like Wit *et al.* (2002), Michaelis (1997) argues that travel demand falls rather than shifts to other modes. Acutt and Dodgson (1996) indeed report very low cross-elasticities for the various modes of travel.

Wohlgemuth (1997) has price elasticities that are notably lower than those used by Michaelis (1997): -0.39 (-0.39) for the USA, -0.09 (-0.04) for Europe and –0.03 (-0.02) for Japan for the long-term (short-term). For developing countries, he assumes a price elasticity of –0.15 with respect to the price of crude oil. In their survey of the tourism demand literature, Witt and Witt (1995) find a range of travel cost elasticities of –0.04 to –4.34, with a median estimate of –0.50. In his meta-analysis of the tourism literature, Crouch (1995) finds a central estimates of the travel cost elasticity of –0.85, with a standard deviation of 1.15; the underlying estimates range from 0.11 to –1.89. Morley (1998) estimates a range of fare elasticities of –0.04 to –2.80 for travellers to Australia. Garin-Munoz (2006) estimates crude oil price elasticities of –0.12 to –0.15 in the short run, and –0.22 to –0.41 in the long run for visitors to the Canary Islands. For German visitors to Spain, Garin-Munoz (2007) estimates short-term elasticities of –0.24 to –0.33, and long-term elasticities of –0.52 to –0.67. This suggests that Michaelis' (1997) lower estimate is more valid. The elasticities used in this paper are in the same range.

The paper continues as follows. Section 2 presents the models. Section 3 discusses the first results. As many parameters are uncertain yet important, Section 4 shows a number of sensitivity analyses. Section 5 concludes.

2. The model

The Hamburg Tourism Model (HTM) describes, at a reasonable level of geographic disaggregation, the reactions of tourists to climate change and climate policy (Hamilton *et al.*, 2005a,b; Bigano *et al.*, 2005). Here, attention is limited to climate policy. The model computations have four steps. First, total holiday demand is determined. Then, the fraction of domestic and foreign holidays is set. Third, the destination of holidays abroad is chosen. Fourth, total tourist numbers per country, average length of stay, and total expenditures are computed. A tax on aviation fuel in international travel would primarily affect the third model stage.

2.1. Data and interpolation

A simulation model is driven by data. Data on international arrivals and departures for 1995 are taken from the World Resources Databases (http://earthtrends.wri.org). There are two major problems with this dataset. Firstly, for some countries, the reported data are arrivals and departures for tourism only. For other countries, the data are arrivals and departures for all purposes. Unfortunately, it is impossible to correct for this. Secondly, there are missing observations, particularly with regard to departures.

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

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

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

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

$$\ln\frac{D_o}{P_o} = \underset{17.05}{1.51} - \underset{0.17}{0.18}T_o + \underset{16.82}{4.83}\cdot 10^{-3}T_o^2 - \underset{4.22}{5.56}\cdot 10^{-2}B_o + \underset{0.09}{0.86}\ln Y_o - \underset{0.13}{0.23}\ln G_o \qquad (2)$$

$$N = 99; R_{adj}^2 = 0.66$$

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

For most countries, the volume of domestic tourist flows is derived using 1997 data contained in the Euromonitor (2002) database. For some other countries, we rely upon alternative sources, such as national statistical offices, other governmental institutions or trade associations; see Bigano *et al.* (2005). Data are mostly in the form of number of trips to destinations beyond a non-negligible distance from the place of residence, and involve at least one overnight stay. For some countries, data in this format were not available, and we resorted to either the number of registered guests in hotels, campsites, hostels etc., or the ratio between the number of overnight stays and the average length of stay. The latter formats underestimate domestic tourism by excluding trips to friends and relatives; nevertheless, we included such data for completeness, relying on the fact that dropping them did not lead to any dramatic change.

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

$$\ln\frac{D_o + H_o}{P_o} = -\underset{0.83}{1.67} + \underset{0.10}{0.93}\ln Y_o \qquad (3)$$

$$N = 63; R_{adj}^2 = 0.60$$

Note that people may take a holiday more than once a year. As we measure population numbers in thousands, the parameters imply that people with an income of $10,000 per person per year take one holiday per year.

The ratio of domestic to total holidays was interpolated using

$$\ln \frac{H_o}{D_o + H_o} = -\underset{1.19}{3.75} + \underset{0.42}{0.83} \cdot 10^{-1} \ln G_o + \underset{0.30}{0.93} \cdot 10^{-1} \ln C_o + \underset{0.32}{0.16} \cdot 10^{-1} T_o - \underset{1.11}{0.29} \cdot 10^{-3} T_o^2$$

$$+ \left(\underset{0.12}{0.16} - \underset{1.24}{4.43} \cdot 10^{-7} Y_o \right) \ln Y_o \tag{4}$$

$$N = 63; R_{adj}^2 = 0.36$$

The individual temperature parameters are not statistically significant from zero at the 5% level, but they are jointly significant. “Observations” for 1995 were derived from 1997 observations by dividing the latter by the population and per capita income growth between 1995 and 1997, correcting the latter for the income elasticity of (3) and (4). The income elasticity of domestic holidays is positive for countries with low incomes but falls as income grows and eventually goes negative. Qualitatively, this pattern is not surprising. In very poor countries, only the upper income class have holidays and they prefer to travel abroad, also because domestic holidays may be expensive too. As a country gets richer, the middle income class have holidays too, and they first prefer cheap, domestic holidays. The share of domestic in total holidays only starts to fall if the lower income class are rich enough to afford a holiday abroad; with the estimates of Equation (4), this happens if average income exceeds $360,000, a high number.

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

For international tourism, we also need the matrix of bilateral flows of tourists from one country to the next. That matrix is largely unobserved. In order to build this matrix, we take Equation (1), multiply it with the distance (in kilometres) between the capital cities raised to the distance elasticity, and allocate the tourists from a particular country to all other countries proportional to the result. This procedure delivers the results for the base year 1995.

For other years, we use a similar approach. The total number of tourists per country follows from Equation (3). This is divided into domestic and international tourists using Equation (4), holding everything constant except for temperature and per capita income. For the simulation years, we allocate international departures in the same way as we build the matrix of bilateral tourist flows, keeping everything as in 1995 except for per capita income and temperature.

2.2. Extrapolation

In previous versions of the model, the equations for interpolation are also used for extrapolation. HTM, version 1.3, deviates from this practice. The reason is that new data and new results have become available. Particularly, the study of Bigano *et al.* (2006) sheds new light on preferences for holiday destinations. See Table A1. Data for the 1970s can be found in Senior (1982) and OECD (1989), sources that were previously overlooked. These data provide the opportunity to improve the calibration of the dynamic features of HTM.

Bigano *et al.* (2006) estimate holiday destination choice models for 45 countries for the year 1999:

$$\ln(A_i^j) = c^j + \alpha_1^j \ln(D_i^j) + \alpha_2^j \ln(y_i) + \alpha_3^j T_i + \alpha_4^j T_i^2 + \alpha_5^j H_i + \alpha_6^j C_i + \alpha_7^j A_i + \alpha_8^j S_i \tag{5}$$

where A_i^i denotes the arrivals in country *i* from country *j*; D_i^j is the great-circle distance between the two countries; y_i is per capita income in the destination country; T_i is the annual average temperature in the destination country; H_i is the number of world heritage sites per million square kilometers in the destination country; C_i is the length of the coast line of the destination country; A_i is the land area of the destination country; and S_i is an index of the political stability of the destination country.

OECD (1989) has data on domestic and foreign holidays, for some countries as far back as 1972. Combined with the data of Bigano *et al.* (2005), this gives a reasonable time series. We regressed the natural logarithm of the ratio of domestic to total holidays on the natural logarithm of per capita income. Table A2 has the results. The mean income elasticity is –0.10 (0.01). This is used in the base case. We use the temperature sensitivity of (2), which implies that the domestic-to-international ratio is at a maximum at 18°C. Note that the ratio of Equation (4) is not necessarily smaller than unity; we restrict the ratio of domestic to total tourists to lie between 0.01 and 0.99.

According to Equation (5), international tourists prefer to stay closer to home, as this reduces travel cost and travel time. Bigano *et al.* (2006) find that the distance elasticity is closer to zero – that is, distance matters less – if people get richer. Re-estimating that relationship including the 1979 data (Senior, 1982), we get:

(6) $$\alpha_1^j = -\underset{(1.34)}{7.56} + \underset{(0.14)}{0.68} \ln y_j$$

For an income of \$23,000 (as in the UK in 2002), for instance, the distance elasticity is –0.73. This is towards the lower end of the range in Oum *et al.* (1990).

2.3. Travel costs

Equation (5) has distance, but tourists are deterred by the cost and duration of travel. However, at an aggregate scale, data on travel cost and travel time are impossible to get. Indeed, it is even difficult to get such data at a micro-level (Maddison, 2001; Hamilton, 2002; Lise and Tol, 2003). As an approximation, we collected travel time and cost for flights from London to the capitals of the world. Only direct flights were included. The cost was the cheapest offer on www.expedia.com, for a flight two months in the future, including a weekend at destination. Travel time correlates very well with distance. One needs 47 minutes for take-off and landing (on paper), and needs 4 seconds per kilometre (875 km/hr). The R^2 is 99.5%. The data on travel cost is noisier. On average, one pays \$30 to get in the plane, and 14 cents per kilometre. The R^2 is only 70.0%. We use these two linear equations to derive travel time and travel cost from the distances that were in the previous versions of the model.

The previous model version had an income-dependent distance elasticity. See (5) and (6). Travel time and travel cost elasticities are derived as follows. The time and price elasticities are arbitrarily assumed to have the same value (-0.45) for UK citizens. The value is chosen such that the travel patterns of the British based on time and cost closely mimics that based on distance, based on least squares. The time elasticity is assumed to be constant, but the price elasticity varies with income. It is calibrated so that the travel behaviour for the time and cost model is close (least squares) to that for the distance model for people with an income one-tenth of the UK average. The cost elasticity then equals –1.50 +0.14ln*y*. This is obviously crude – sensitivity analyses are reported below.

2.4. Emissions

Pearce and Pearce (2000) report carbon dioxide emissions per type of plane and length of trip, and such emissions can also be computed from the data presented in Wit *et al.* (2002). Take-off and landing are energy-intensive compared to cruising, so short trips emit more carbon per kilometre than do long trips. The average plane of Pearce and Pearce (2000) emits about the same as the average plane of Wit *et al.* (2002). We transformed emissions per plane (from Pearce and Pearce, 2000) to emissions per passenger using the higher occupancy rates of Wit *et al.* (2002). This implies 6.5 kg C per passenger for take-off and landing, and 0.02 kg per passenger-kilometre. The resulting carbon dioxide emissions per trip are very similar to those found on www.climatecare.org, the site at which one can buy emission offsets.

Total emissions follow from multiplying emissions per passenger-kilometre by the number of passenger-kilometres. We assume that no holidays at less than 500 km distance (one way) are by air, and that all holidays beyond 5000 km are by air; in between the fraction increases linearly with distance. For island nations, the respective distance are 0 and 500 km. Total emissions in 2000 are 140 million metric tonnes of carbon, which is 2.1% of total emissions from fossil fuels. This is from tourism only. Total international aviation is reckoned to be responsible for some 3% of global emissions. There are no published numbers on the share of tourism in total international travel. The modelled emissions are not completely off, but may be a bit high.

2.5. Validation

HTM is a static model. There are no differential equations in the model. This implies that the model can be run backwards in time, as well as forwards. In the next section, we consider the future. For validation purposes, the model was run for the period 1980-1995. Figure A1 shows modelled and observed international arrivals for 1980, 1985, 1990 and 1995. The model reproduces the data very well; the R^2 is at least 90%. Figure A2 shows modelled and observed international arrivals. The model fit is less impressive, but does not fall below 73%. Figure A3 shows the ratio of domestic to total holidays for 1980 and 1995; there are no comprehensive data available for intermediate years. The model fit is impressive for the calibration year (it'd better), but for 1980, the R^2 is only 64%. A glance at Table A2 shows the reason. Different countries have had different trends in the structure of their holidays, while the model uses a common trend for all. Nonetheless, Figures A1-3 offer some level of confidence in the model results.

3. Results

In the base case, the effect of a kerosene tax on international tourist travel is investigated for the year 2010 for three alternative taxes: \$10/tC, \$100/tC and \$1000/tC,[8] using the parameters as described above. The tax is applied at global level, for the Annex 1 countries, for the countries of the European Union and its affiliates, and for the European Union only.

Figure 1 shows the change in the world total of passenger kilometres, and the change in total carbon emissions if the tax is applied globally. For a \$1000/tC kerosene tax, international tourism travel falls by about 0.8% and the associated carbon dioxide emissions fall by 0.9%. There are a number of reasons for the result on emissions. Firstly, the number of travellers stays the same. Secondly, although shorter trips are generally favoured over longer ones, if there is little alternative to flying, medium distance trips actually become more attractive relative to short trips. Thirdly, the price elasticity is assumed to be low. Fourthly, the price change is low: \$73 for a 1,000 km roundtrip, for example. This is less than a doubling of the air fare, even for a very high tax.

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[8] In the European Trading System, carbon permits trade at some \$40/tC. The marginal damage cost of carbon dioxide is probably less than \$50/tC (Tol, 2005). See Schipper *et al.* (2001) for an estimate of the total environmental costs of aviation.

The difference between the change in travel distance and the change in carbon dioxide emissions is due to a shift from air travel to others modes on the one hand, and to the large emissions of take-off and landing on the other hand.

The relative importance of these factors can only be investigated with a sensitivity analysis, reported below.

Figure 2 shows the change in the number of international arrivals for the countries that are most affected in an absolute sense (Hong Kong, United Kingdom) and in a relative sense (Cyprus, South Korea). Results are also shown for Ireland. Hong Kong and South Korea benefit from the shift in demand from tourists from Japan and China, to which they are close, as well as from a shift general East and Southeast Asian shift away from destinations in Europe and North America. Cyprus, Ireland and the United Kingdom suffer from being on the fringe of Europe as well as being island nations.

Figure 3 shows a world map with winners and losers. The Americas and Africa generally lose, because of the large share of intercontinental visitors in the case without a kerosene tax. Western Europe loses too. Central and Eastern Europe gain – from each other's custom but also from redirect Scandinavian and British travel. Interestingly, the countries that neighbour China and India all gain – a sign of the growing importance of these two countries in international tourism.

Above, the kerosene tax is global. This is unlikely. As an alternative, the tax is applied to the Annex I countries, the European Union plus its affiliates, and the European Union only. The tax is implemented as a departure fee, covering the entire one-way flight.[9] As all trips are assumed to be roundtrips, it does not matter whether it is a departure fee or a landing fee.[10] The landing fee is paid twice on flights from an Annex 1 country to another Annex 1 country, once on flights from or to an Annex 1 country, and not on flights from and to an non-Annex I country.

The \$1000/tC global kerosene tax reduces carbon dioxide emissions in 2010 by 0.81% of the projected 2010 emissions without a tax. If applied to Annex 1 countries only, this falls to 0.40%; for the EU plus, this is 0.21%; for the EU, 0.19%. As Europe has such a large share of international tourist travel, this is as expected.

Figure 4 shows the effect on travel patterns. An EU tax would divert European travellers from the USA, Africa, and the Middle East to Europe. The Americas would benefit from a US citizens not travelling to Europe. South Asia, East Asia, and Australasia would benefit from tourists diverted from Europe. Iceland, Ireland and the UK lose market share because they are heavily dependent on airborne tourists. Norway, and Switzerland, even though exempt from the tax, lose market share, Norway because it is relatively remote, Switzerland because it is central and therefore sees a relatively high price increase. Figure 4 also displays the difference between the global tax and the EU. The EU would obviously lose a share of the market in international tourism, but so would countries that disproportionally rely on European visitors, such as Pakistan, South Korea and Japan. The rest of the world, including Norway and Switzerland, would gain.

4. Sensitivity analyses

[9] One may question the legality of taxing emissions in another country's airspace, as this may violate the Chicago Convention. On the other hand, the atmosphere is the common property of mankind.

[10] A departure (landing) fee would be an export (import) tax based on the carbon-content of the flight service. Export taxes are easier to defend under WTO rules than are import taxes.

There are a large number of parameters in HTM. All of them are uncertain and affect the impact of kerosene taxation on carbon dioxide emissions; yet, some are more uncertain than others, and some have a greater effect. I here limit myself to the most important parameters.

The parameters that govern the modal choice for international tourist travel are my guess, based on some travel experience and casual observations. If aviation has a larger (smaller) share of international tourism travel, then total emissions rise (fall). The most important parameter is the distance above which 100% of travel is by aeroplane. If this were twice the base value, emissions would be 14% lower. Emission reduction responds with the opposite sign: If aviation has a larger (smaller) share of international tourism travel, then emission reduction are smaller (larger) for the same carbon tax. This is because modal shift is more (less) effective. However, if the distance below which no travel is by air is raised, this pattern is broken. This is because many more destinations are within a 1000 km reach than with a 500 km reach. The carbon tax would then have a greater impact on destination choice. If modal choice were endogenous rather than driven by a set of fixed parameters, then the effect of a carbon tax would be larger as tourists would switch travel mode as well as destination to reduce their travel costs.

If all international tourist travel were by plane, carbon dioxide emissions were more than twice as high (Table 1). In this case, a $1000/tC would *increase* emissions. This is because tourists are assumed to make their destination choice based on the *relative* attractiveness of destinations. Because of the high emissions of take-off and landing, nearby destinations face a greater relative price increase than destinations that are further afield – so that tourists travel farther and emit more. This implies that, in the base case, emission reductions are achieved by combination of shorter travel and model shift.

Table 1 also shows the case in which the carbon tax is proportional to the distance travelled. Technically, carbon emissions from take-off and landing are set to zero; and per-kilometre emissions are re-calibrated so that global emissions are as in the base case. Under this assumption, short trips are not disadvantaged relative to medium-distance trips. Indeed, emissions fall further than in the base case, by 0.95% for a $1000/tC tax.

The price elasticity is obviously important. It is also very uncertain. The survey of Oum *et al.* (1980) reveals a wide range of estimates. The price elasticity used here is a result of calibration rather than estimation. In the calibration, it is assumed that, for the UK, the travel cost elasticity and the travel time elasticity have the same value. This is arbitrary. The model was recalibrated so that the price elasticity equals two times and four times the time elasticity. The price elasticity then increases from 0.45 (base case) to 0.58 (twice) and 0.68 (four times) for a country with the average income of the UK.[11] For a country with an average income one-tenth of the UK, the price elasticities are 0.88, 0.95, and 1.01.

Table 1 shows the results. Recalibration has little impact on total carbon dioxide emissions in the case without a kerosene tax. There is also little effect on travel patterns (results not shown). Figure 1 shows that, as expected, the higher the price elasticity, the stronger the emission reduction for any given kerosene tax. Table 1 shows that emission reduction more than doubles for the very high price elasticity compared to the base case. Still, a $1000/tC would cut emissions by 1.7% only.

Recall that the price elasticity only covers substitution between international destinations – all of which face a price increase. Total demand for international travel is not affected by the kerosene tax, at least in the base case. In order to test the sensitivity of this assumption, the

[11] Note that the studies in Oum *et al.* (1980) typically do not include travel time. This implies an upward bias in the price elasticity. Note also that tourists are likely to judge a holiday on its total cost, another reason why the price elasticity of a single holiday component is limited.

average travel cost of international tourism with and without tax is computed and, with the price elasticity of the base case, used to reduce the demand for international holidays; domestic holidays are the substitute. This is probably an overestimate, as a tourist may well compare the *total* costs of foreign and domestic holidays, and a foreign holiday may be considered as a status good. At the same time, the base case allows for no substitution at all, a sure underestimate. Figure 1 and Table 1 show the results. The effect is large: a €1000/tC tax would cut emissions by 7.6%, eight times larger than in the base case. However, this is a very large tax, while emission reduction is still small. For a €10/tC tax, emissions fall by 0.1%; for a €100/tC tax, emissions fall by 0.9%.

Besides carbon dioxide, planes also emit nitrogen oxides and water vapour. Both contribute to warming, but the effect is regional and situation-specific. An equivalence to CO_2 has therefore not been established (Ramaswamy *et al.*, 2001). A uniform, global tax would be an inappropriate instrument. Therefore, no formal sensitivity analysis was performed. However, the consequences can be gleaned from the above. Compared to CO_2, emissions of NO_x are even more concentrated during start and landing. An NO_x tax would imply that short-haul flights are hit extra hard. For water vapour, the opposite is true. Cruising is more important than take-off and landing. Williams and Noland (2006) suggest that water vapour emissions may be ten times as important as carbon dioxide emissions. If that is true, a $1000/tC tax is conceivable.

The model omits behavioural and technical measures for reducing carbon dioxide emissions, such as changes in taxiing, take-off and landing; changing in aircraft occupancy; upgraded engines; and the use of light-weight materials. As traveller behaviour is not very responsive to the limited price signals that carbon taxation would bring about, behavioural and technical change may contribute more to emission reduction. If such measures would be implemented rationally, air fares would rise less. This would further limit the response of travellers.

5. Discussion and conclusion

This paper presents estimates of the impact of a kerosene tax on international tourism. A kerosene tax disproportionally increases the price of short flights, because take-off and landing are very energy-intensive. A kerosene tax would induce a shift from long flights to medium distance one, a shift from medium distance flights to short distance car and train holidays, and a shift from short flights to medium distance ones. Island nations would be disproportionally hurt by a kerosene tax. If the tax is applied regionally rather than globally, then the taxed region looses market share to the non-taxed region. Emissions would fall only by a small amount, even if the kerosene tax is very high. This is because a kerosene tax would raise the cost of flying by only a limited amount. To put this differently, very high kerosene taxes would be need to substantially reduce carbon dioxide emissions from international aviation. Emission reduction can be had elsewhere for much less money.

There are a number of caveats to these results. The model does not allow for technical measures to reduce emissions. This implies that emission reductions are underestimated. It also implies that the estimate travel response is overestimated. The model does not allow for substitution between domestic and international holidays, or indeed between holidays and no holidays. As the estimated effect on international travel is only small, this is probably not a major shortcoming. Similarly, the model does not allow for explicit modal shifts – although modal shift is implicit. The sign of the introduced bias is unknown. Furthermore, the results depend to a large extent on the assumed travel price elasticity of tourism demand – and on the assumed travel costs. Both are uncertain. The model does not differentiate between regular and discount airlines, again for want of data. Discount airlines would face the same kerosene taxes, and therefore experience a higher relative price increase. Finally, the model ignores emissions of water vapour.

The implications of the results, notwithstanding the above caveats, are as follows. The shifts in tourist flows are small if kerosene is taxed at the levels currently being discussed for the appropriate price of carbon (up to $100/tC). Even though an island nation such as Cyprus or Ireland would be disproportionally hurt, the effect is too small to warrant strong opposition. Similarly, the airline industry has little ground for opposition. Although the revenue of the kerosene tax would be high, most of the cost would be passed on to the travellers, who would hardly change behaviour. If the kerosene is not taxed, but subject to emissions trading; and the permits are grandfathered but the costs is passed on to customers nonetheless; then the airlines would actually benefit. However, a kerosene tax is unlikely to substantially reduce emissions – because the tax is low compared to the air fare, and because the price elasticity is small. These two reasons are model independent.

A kerosene tax may of course induce technological and behavioural change. If so, that would be good. If not, the impact is limited. It is not clear, however, whether a tax is the best way to bring about such change. Some aspects of emission reduction are under control of the airlines, such as the type and size of the aircraft and its engines. Airlines can influence the number of passengers on board. Airlines already work hard to keep the costs per passenger to its minimum. Flight routes, landing and take-off, and taxiing are the remit of air control and the airport, however. A tax would not affect them. This suggests that a mix of instruments would be needed, or perhaps that flight emissions should be partly attributed to flight control and airports.

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Andrea Bigano, Jackie Hamilton and David Maddison were very instrumental in developing earlier versions of the Hamburg Tourism Model. Alan Barrett, John FitzGerald and Laura Malaguzzi Valeri had helpful comments on earlier versions of the paper. Funding by the ESRI Energy Policy Research Centre and the Princeton Environmental Institute is greatly acknowledged.

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Table 1. Carbon dioxide emissions from international tourism aviation and emission reduction for alternative parameterisation of travel mode choice.

	Emissions	Difference	Reduction	Difference
	10^6 tC	%	%	%
Base case	140		0.81	
Max = 2500	148	5.6	0.31	-61.6
Max = 10000	121	-13.5	1.36	67.5
Min = 250	139	-0.5	0.85	4.6
Min = 1000	141	0.6	0.82	1.2
Island = 250	140	0.1	0.81	-1.0
Island = 1000	140	-0.2	0.83	2.0
No modal shift	308	119.7	-0.06	-107.7
Proportional to distance	140	-0.1	0.95	17.2
High price elasticity	140	0.2	1.30	59.8
Very high price elasticity	140	0.3	1.67	105.5
Domestic substitution	140	0.0	7.59	833.3

Note: In the base case, all trips longer than 5000 km (max) are by aeroplane and no trips shorter than 500 km (min). For island nations, min = 0 and max = 500. For “no modal shift”, all distance parameters equal nought.

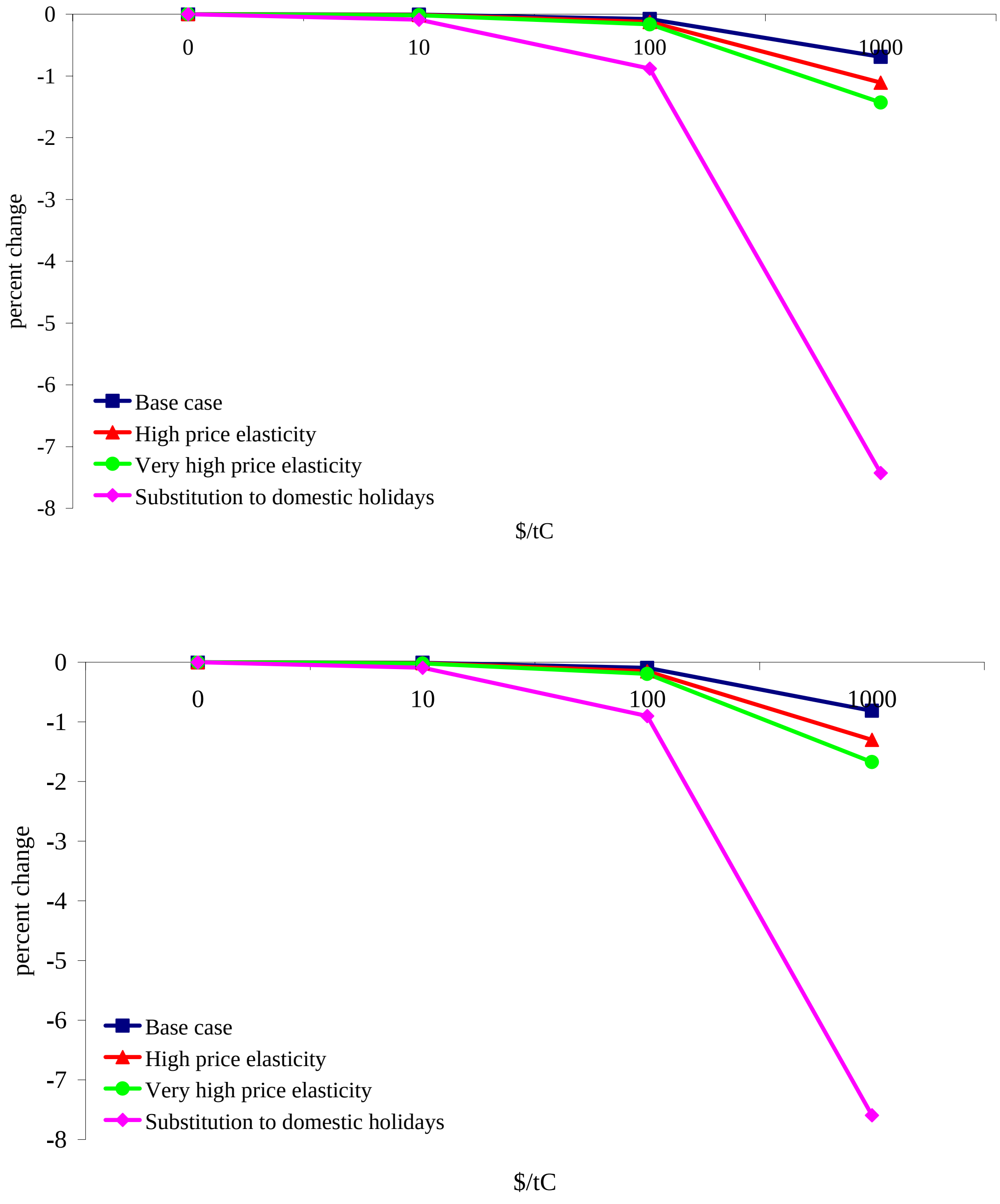

Figure 1. The effect of a kerosene tax on the world total passenger-kilometres (top panel) and the world total carbon dioxide emissions (bottom panel) for international tourism.

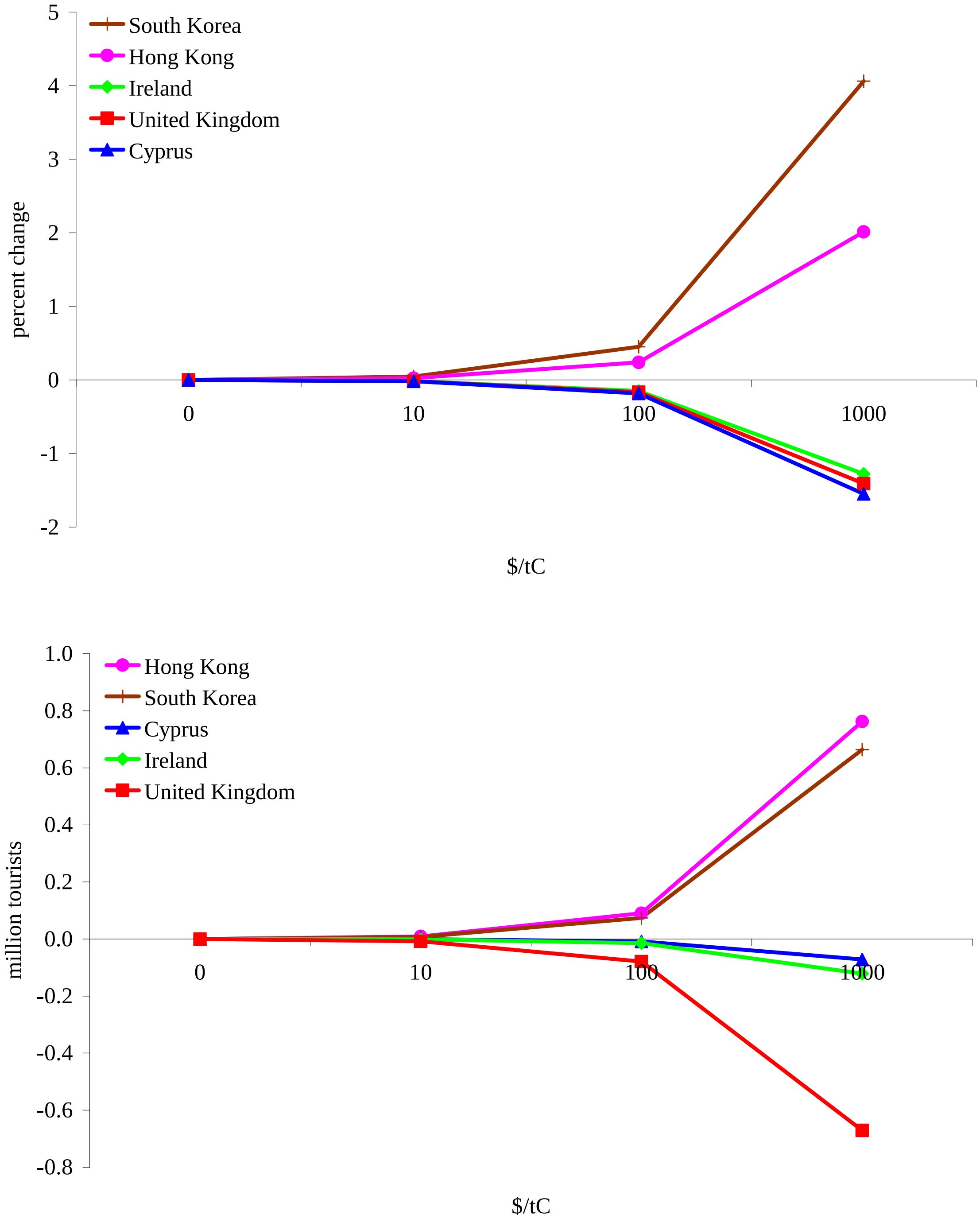

Figure 2. The effect of a kerosene tax on international arrivals in selected countries; changes relative to baseline (top panel) and in absolute numbers (bottom panel).

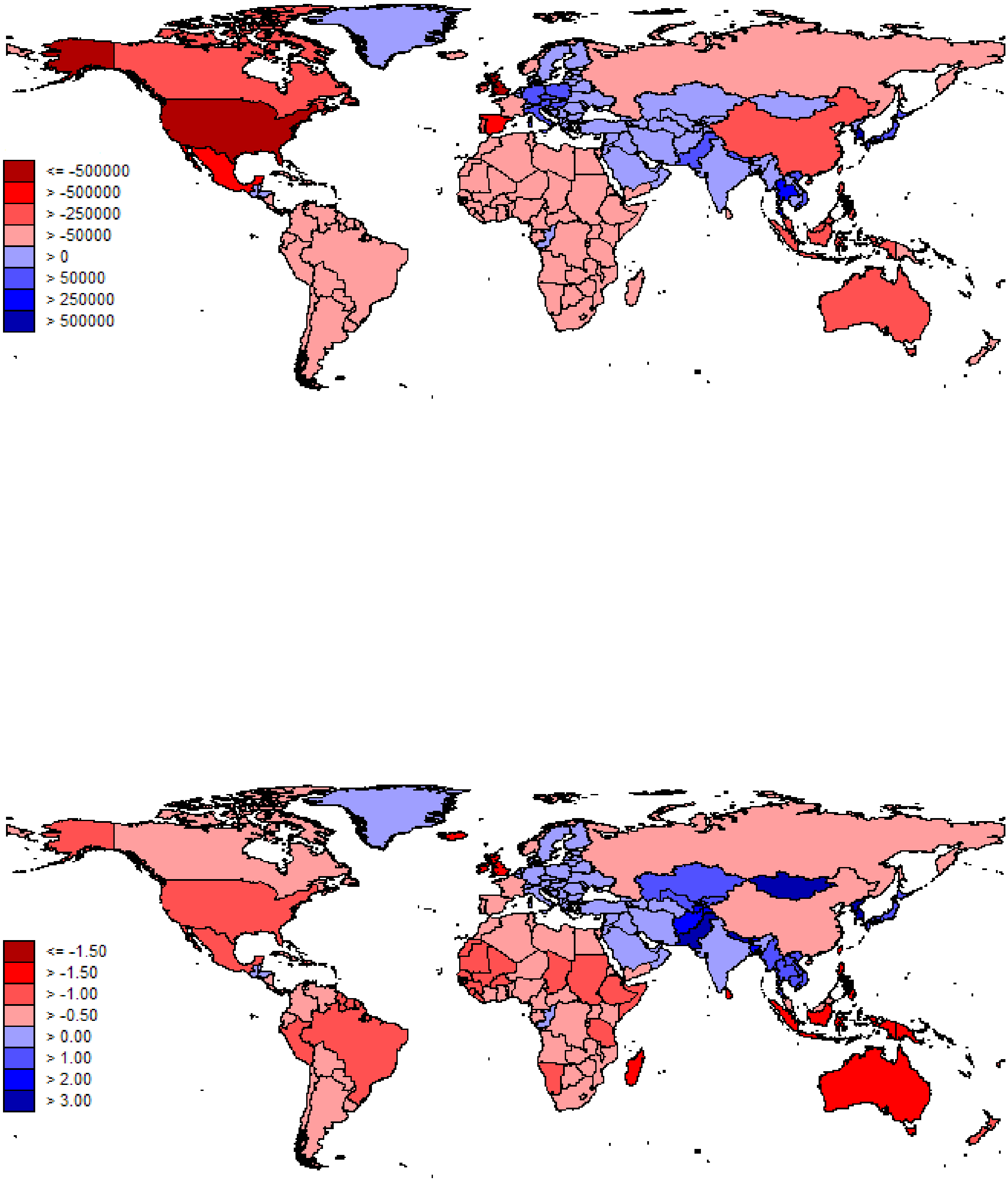

Figure 3. The effect of a global, $1000/tC kerosene tax on international tourist arrivals in 2010 in absolute numbers (top panel) and in percent of the case without a tax (bottom panel).

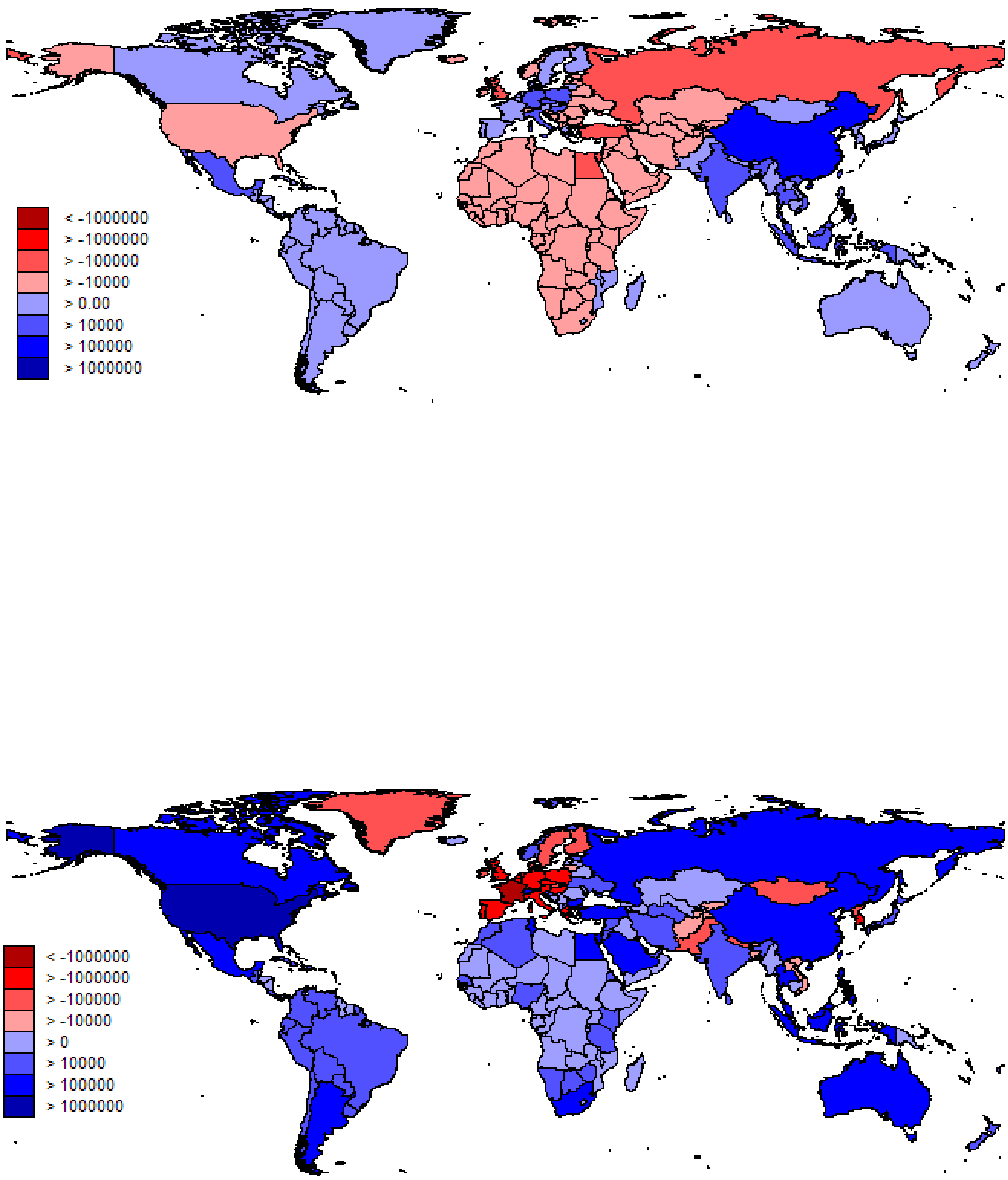

Figure 4. The difference in international tourism numbers in 2010 between the case without a tax and a $1000/tC kerosene in the EU (top panel) and between a global and an EU tax

(bottom panel).

Table A1. Optimal holiday temperature for tourists from selected countries in 1979 and 1999; standard deviations are in brackets.

	1979		1999		Difference	
Australia	15.28	(2.12)	14.64	(0.93)	-0.64	(2.31)
Belgium	14.91	(2.99)				
Canada	*14.41*	*(1.30)*	*18.71*	*(1.65)*	*4.30*	*(2.10)*
France	15.95	(2.53)	18.66	(2.82)	2.71	(3.79)
Germany	13.25	(1.73)	18.84	(5.63)	5.59	(5.89)
Italy	16.08	(1.99)	18.45	(2.55)	2.37	(3.23)
Japan	16.64	(3.52)	17.37	(1.26)	0.74	(3.74)
Netherlands	13.65	(1.94)	15.62	(1.82)	1.97	(2.66)
New Zealand	16.96	(3.04)	14.26	(1.12)	-2.70	(3.24)
Spain	15.94	(1.97)	16.65	(1.63)	0.72	(2.55)
Switzerland	17.08	(3.73)	15.09	(1.16)	-1.99	(3.90)
UK	14.13	(1.50)	18.08	(1.82)	3.95	(2.35)
USA	13.21	(1.62)	17.60	(2.18)	4.39	(2.71)

Table A2. Income elasticity of domestic to total holidays.

Country	Elasticity	
Australia	-0.0670	(0.0091)
Austria	-0.6799	(0.1623)
Belgium	-0.2235	(0.3888)
Canada	0.8128	(0.3932)
Denmark	-0.7022	(0.2394)
Finland	-0.1429	(0.2799)
France	-0.3257	(0.0542)
Germany	0.7153	(0.3121)
Iceland	-0.2784	(0.1301)
Ireland	-0.3285	(0.0642)
Japan	-0.1756	(0.0398)
Netherlands	0.4200	(0.2534)
Norway	-0.4945	(0.1467)
Portugal	-0.6019	(0.0767)
Spain	-0.7181	(0.0623)
Sweden	1.7842	(0.8042)
Switzerland	-2.1831	(0.9930)
UK	-0.1404	(0.1487)
USA	0.0395	(0.0428)
average	-0.0996	(0.0083)

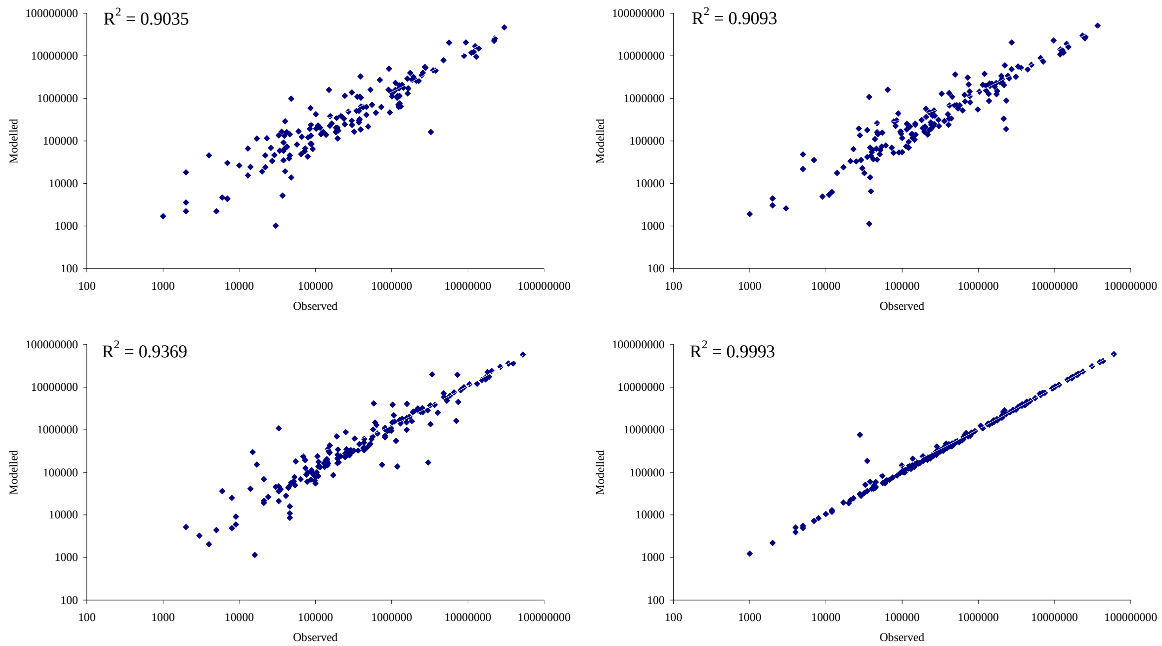

Figure A1. International tourist arrivals as observed and as modelled in 1980, 1985, 1990 and 1995 (from left to right and from top to bottom).

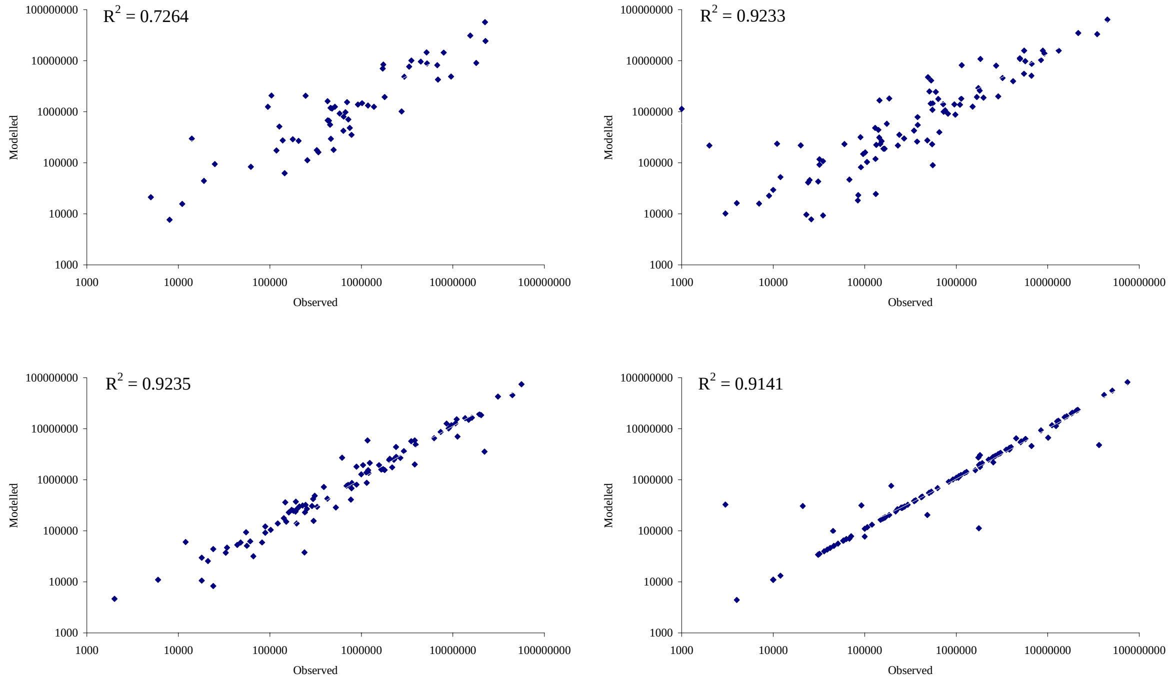

Figure A2. International tourist departures as observed and as modelled in 1980, 1985, 1990 and 1995 (from left to right and from top to bottom).

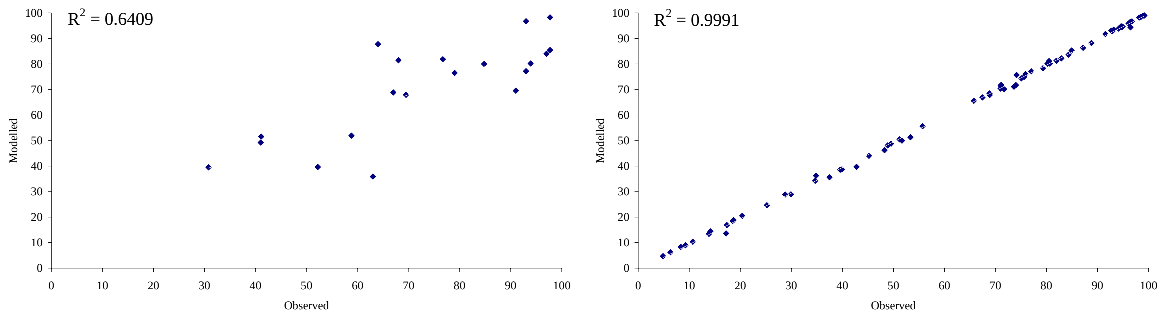

Figure A3. The percentage of domestic in all holidays as observed and as modelled in 1980 (left panel) and 1995 (right).