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Internalisation of emissions costs from Swedish aviation

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Abstract

This thesis examines the emissions costs of Swedish aviation and their degree of internalisation under current economic instruments. The results show that the degree of internalisation spans from practically zero for a long-haul flight to 6 per cent for a typical domestic flight, where the climate cost, including high-altitude impact, makes up the main part of the cost. To inform evaluation of the consequences of this under-internalisation, or attempts to correct for it using price instruments, the price and income elasticities of international leisure air travel from Sweden are estimated using household expenditure data and two different price measures. The resulting elasticities are very high – 2.03 or 2.04 for the income elasticity and -2.53 or -1.88 for the price elasticity – and should be interpreted cautiously due to data limitations, especially for the price elasticities. However, even a cautious interpretation seems to support other authors' findings that demand for leisure air travel is price and income elastic. This means that pricing the uninternalised costs would have a clear effect on demand and hence on emissions, without undesired distributional effects. The thesis concludes with a discussion of how such price instruments could be designed.

Sammanfattning

I denna uppsats studeras internaliseringsgraden för flygets utsläppskostnader, dvs. i vilken utsträckning miljökostnaderna från flygets utsläpp betalas av flygbolagen i stället för att bäras av samhället i stort. Redan tidigare studier har pekat på att flyget bara betalar en mindre del, men dessa studier har i allmänhet antingen använt gamla kostnadsskattningar för olika utsläpp eller bortsett från stora delar av flygets miljöpåverkan. För att bättre kunna bedöma konsekvenserna av om flyget i stället skulle betala sina fulla utsläppskostnader har pris- och inkomstelasticiteten, dvs. hur mycket flygresandet påverkas av förändringar i biljettpriser eller hushållens inkomster, skattats med hjälp av data om hushållens utgifter i olika inkomstgrupper och två olika prismått.

Flygets totala klimatpåverkan, inklusive höghöjdseffekter, är i snitt runt dubbelt så stor som endast koldioxidens klimatpåverkan. För andra luftföroreningar står utsläppen på marschhöjd för ungefär 80 procent av flygets totala bidrag till förtida dödsfall. Dagens ekonomiska styrmedel – EU:s utsläppshandel som bara omfattar koldioxid och Swedavias avgasavgift som bara omfattar kväveoxider under start och landning – är därför otillräckliga för att prissätta flygets utsläpp. Överskottet på EU:s utsläppsmarknad och det därmed mycket låga utsläppspriset förvärrar problemet ytterligare.

När samhällskostnaderna för flygets utsläpp jämförs med flygbolagens kostnader för utsläppen för tre olika typflygningar framkommer att klimatkostnaden är internaliserad till 4–5 procent för flygningar inom EU och inte alls till destinationer utanför EU där utsläppshandeln inte gäller. För luftkvalitet ligger internaliseringsgraden mellan 4 procent för en typisk långresa och 13 procent för en typisk inrikesresa. Sammantaget ger detta en internaliseringsgrad på närmare noll för en långflygning och 6 procent inrikes.

Om flyget skulle beskattas för att täcka de miljökostnader som inte är internaliserade så skulle det utslaget per enkelbiljett motsvara 156 kr för en resa Arlanda–Göteborg, 493 kr Arlanda–Madrid och 2 914 kr Arlanda–Bangkok. En sådan prisökning skulle ha en dramatisk effekt på efterfrågan åtminstone på längre flygningar, och därmed också på utsläppen. Även om brister i dataunderlaget gör att resultatet ska tolkas mycket försiktigt så ger elasticitetsskattningen stöd för tidigare studier som visar att hushållens efterfrågan på flyg är pris- och inkomstelastisk, dvs. att förändrade biljettpriser eller inkomster påverkar flygresandet mer än proportionellt (minskar vid högre biljettpriser och ökar vid högre inkomster).

Rika hushåll lägger en betydligt större andel av sina totala hushållsutgifter på flygresor, och har i tidigare studier dessutom visats vara mer priskänsliga än låginkomsttagare. Argumentet att en flygskatt bara skulle slå mot långinkomsttagare medan höginkomsttagare skulle flyga lika mycket som förut kan därför avfärdas.

Hur en flygskatt skulle utformas kräver noggranna juridiska överväganden, eftersom beskattning av flygbränsle är förbjuden i EU:s energiskattedirektiv och de flesta bilaterala flygavtal, vilket i praxis även kommit att innefatta skattebaser med hög korrelation till bränsleanvändning. De flesta europeiska länder som idag beskattar flyg gör därför detta genom en avståndsrelaterad passageraskatt. Det framstår i dagsläget som den mest framkomliga vägen även för Sverige i väntan på större framgång i det internationella arbetet för att flyget ska betala sina miljökostnader – och inte minst som ett sätt att driva på detta.

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1 Introduction

A guiding principle of Swedish transport policy is that taxes and charges motivated by transport policy considerations should reflect the marginal social costs of transport (Trafikutskottet, 2006). For aviation, a relatively polluting and rapidly growing transport mode, there are reasons to believe that this is not the case. For this reason, the Swedish government is considering a tax on aviation (Regeringen, 2014). If such a tax were to be implemented, it would be relevant to determine what costs, if any, that are already internalised by existing instruments and what costs, if any, that are to be internalised by the aviation tax. Also, the demand elasticities for air travel would be relevant when evaluating the environmental effectiveness of such a tax. A high price elasticity would imply that taxation would be effective, but if the increase in air travel is instead mainly driven by a high income elasticity, taxation would be less effective in curbing the emissions from aviation. The aim of this thesis is therefore two-fold: (1) to determine the external costs of emissions from Swedish aviation and their degree of internalisation and (2) to estimate the price and income elasticities of Swedes' demand for air travel, more specifically international leisure journeys, to inform evaluation of the consequences of this probable under-internalisation and possible corrective taxation.

Studies on the degree of internalisation of the external costs of aviation are by necessity country-specific just like the economic instruments that are part of the evaluation. Most Swedish studies report a very low degree of internalisation, e.g. Hansen & Nerhagen (2008). Despite using comparably low unit cost valuations from a small 2003 study, they estimate the air quality cost for a typical flight Arlanda–Gothenburg to SEK 487,3–1188,9, which they compare to the emission charge at the time of SEK 356. SIKA (2009) build on the results of Hansen & Nerhagen, but add a cost estimation for the CO_2 emissions of SEK 8,509 for Arlanda–Gothenburg. At that time, however, aviation was not yet covered by the European Emissions Trading Scheme (ETS), so there was no pricing instrument to which to compare the climate cost.

Ahlberg (2014) focuses primarily on reviewing cost estimations rather than on matching instruments, claiming that the climate cost is internalised by the EU ETS. He concludes that the air quality cost estimations currently used in Swedish policy appraisal are probably too low, but that more research is needed. According to Ahlberg, the most updated cost estimations are provided in the EU Handbook on the external costs of transport by Korzhenevych et al. (2014). The handbook presents recommended methodologies and updated cost estimations for different pollutants, while its output values in terms of e.g. €/passenger kilometre are highly aggregated and in the case of aviation ignores the high-altitude climate impact and cruise emissions of air pollutants.

The most recent Swedish internalisation study by Trafikanalys (2015b) mainly bases its calculation of the degree of internalisation of emissions costs on a preliminary version of this thesis, although the calculations are slightly changed to harmonise better with the methodology used for other transport modes. Their results are thus very close to those of this thesis for the emissions costs, and as for the other social costs of aviation, like noise, accidents and infrastructure, these are in aggregate internalised to more or less 100 per cent.

With the exception of Trafikanalys (2015b), previous studies either use dated cost valuations for the relevant pollutants (Hansen & Nerhagen, 2008; SIKA, 2009) or fail to reflect the full environmental impact of aviation (Ahlberg, 2014; Korzhenevych *et al.*, 2014). Also, Ahlberg without much discussion assumes that the climate impact of EU aviation is internalised by the EU ETS, which could be questioned considering the present functioning of the market. On the other hand, whereas Trafikanalys (2015b) do not consider the climate impact internalised by the emissions trading, they do not discuss the potential complications of using complementary internalising instruments for emissions that are already capped by the ETS. This thesis, as described below, attempts to fill these gaps by combining updated cost valuations from Korzhenevych *et al.* with a modern scientific understanding of the full environmental impact of aircraft emissions, for domestic as well as international flights. Also, both the relevance of the EU ETS in internalising the emissions costs and the consequences of complementary measures are discussed.

Regarding the literature on the elasticities of air travel, there is remarkably little research of recent years. Older studies are not necessarily valid today, since elasticities can change over the years. Graham (2000) concludes that the income elasticity for UK leisure air travel has decreased since the 1970s, arguing that the market is becoming more mature. Based on consumer spending on holiday trips, she finds an income elasticity of 1.30 and 1.28, respectively, for 1970-1998 and 1984-1998, or 2.23 and 1.89, respectively, when only considering international air travel.

Although most empirical research has used cross-sectional data, most notably a sample of city-pair data (e.g. Grosche *et al.*, 2007), panel data estimations have recently become more common, typically for studies of inbound tourism such as air travel to the Canary Islands (Garín-Muñoz, 2006), the Balearic Islands (Garín-Muñoz & Montero-Martín, 2007) or Hawaii (Nelson *et al.*, 2011). Still, recent estimations of domestic and outbound air travel typically rely on time series data on aggregate quantity of air travel, average airfares and aggregate income (e.g. Njegovan, 2006; Chi & Baek, 2012; Kopsch, 2012a). Njegovan reports a price elasticity of outbound UK leisure air travel of -0.7 and an income elasticity of 1.5 using a demand system including expenditure on non-fare components of travel abroad and expenditure on domestic leisure. Chi & Baek find price and income elasticities for US domestic and international air travel of -1.56 and 3.74, respectively, whereas Kopsch for domestic air travel in Sweden finds a price elasticity of -0.82 in the short run and -1.13 in the long run, and an income elasticity of 0.44.

To see how elasticity estimates differ between studies with different approaches, Brons *et al.* (2002) and Gallet & Doucouliagos (2014) use meta-regression analysis to survey the literature on the price and income elasticities, respectively. Brons *et al.*, reporting a mean price elasticity of -1.146, find significant differences in that business class travellers are less price sensitive than economy class travellers and that the price elasticity is higher in the long run. However, they find no significant effect of distance, arguing that "the theoretically predicted decreasing effect on price sensitivity due to a relative lack of substitute modes on long-distance flights may prove insufficient to dominate the theoretically predicted increasing effect on price sensitivity because long-distance flights demand a larger share of the disposable income than short-distance flights" (p 172).

Gallet & Doucouliagos report an income elasticity 1.186 in their preferred baseline estimate, corresponding to static panel data studies of domestic air travel, which increases to 1.546 on international routes. Moreover, they get significant differences for some aspects of the specification or estimation, such as using dynamic models (lower) or times series data (higher), but no significant difference between studies of air travel in North America, Asia, Australia and New Zealand, and Europe.

The small number of recent elasticity studies is in itself a motivation for more studies in the field. Moreover, the dominance of time series and cross-section specification is troublesome. Brons *et al.* point out disadvantages with both time series and cross-section estimations: cross-section data generally exhibit relatively little variation in airfares per unit of distance within a given fare class, which renders accurate estimation difficult, and the close correlation between fares and distance implies multicollinearity problems. Time series estimates generally suffer even worse multicollinearity, because price and income tend to be tightly correlated with a time trend. Moreover, service variables such as schedule frequencies, speed of aircraft and density of seating may change even more frequently than prices.

Although Brons *et al.* do not explicitly mention them, there are certainly other factors besides service variables that could change over time, such as prices of all substitutes and complements that cannot possibly be fully accounted for in a regression. Failing to account for them implies that the resulting estimates will be distorted.

Panel data offer greater possibilities for accurate estimation, but unfortunately the cited studies of inbound tourism using panel data are not directly comparable to the problem at hand when evaluating the effectiveness of price instruments on aviation in a certain country. In the latter case the interest is in the effect on total demand for air travel in terms of passenger kilometres and not so much in whether tourists fly to the Canary Islands, the Balearic Islands or another close substitute. Theoretically, cheap destinations could experience the peculiar situation that higher income and lower airfares lead to less tourism, if the tourists instead choose more expensive destinations. Clearly, it would be erroneous to hence conclude that the demand for outbound tourism from a country would also decrease in response to higher income or lower airfares.

One type of panel data estimation that is rarely, if ever, encountered in the air travel demand literature is household expenditure data for different income groups. By comparing the share of air travel expenditure of total household expenditure, the income (or rather expenditure) elasticity can more reliably be estimated, because the variation between income groups can be isolated when factors that vary between years or countries do not interfere. The price elasticity is then a residual, which may still reflect other changes in the economy and will so suffer from the same problems as other time series estimation. Also, using household expenditure data implies that only leisure travel can be studied, but since this makes up 74 per cent of Swedish air travel with overnight stay – 47 per cent of domestic passengers and 81 per cent of Swedes flying abroad (Tillväxtverket, 2013, own calculations) – this will still capture the majority of Swedish air travel. Therefore, in order to overcome some of the weaknesses of previous studies, this is the approach to be used in this thesis, as described further below.

The methodology of the first part of the thesis, determining the degree of internalisation of emissions costs, has three components: (1) determining the emissions costs, which in turn requires evaluating the environmental impact of the emissions and then valuing those impacts in economic terms, (2) determining what economic instruments are to be considered internalising and (3) comparing the costs to the internalising instruments. The first part consists of a review of the literature on the climate and air quality impact of aviation combined with estimations of climate and air quality costs provided in the handbook by Korzhenevych *et al.* (2014). The second part describes taxes, charges and the EU ETS, including a discussion of why the ETS cannot be said to fully internalise the carbon dioxide cost of EU aviation. In the third part, the aircraft emissions reported in the guidebook of EMEP/EEA (2013) are valued at the costs, adjusted for high-altitude effects, found in the first part, and compared to the economic instruments from the second part. Since the degree of internalisation calculated this way will vary between different aircraft, distances etc., three typical flights – one domestic, one intra-EU and one extra-EU – are used as illustrative examples.

The estimation of the price and income elasticities is based on household expenditure data from Statistics Sweden (SCB). Data on the total household expenditure (a proxy for lifetime income) and the expenditure on international air travel (proxied by the category “travel abroad, part paid in Sweden”) are presented for different income deciles for the years 2003-2008 and 2012. Two different airfare measures are used: a price index from SCB and a measure based on passenger revenue per passenger kilometre for the largest Swedish airline SAS. The expenditure on air travel is then divided by the two price measures, yielding two measures of the quantity of air travel. Finally a regression is run of how the quantity of international air travel in different deciles is determined by airfares and total household expenditure.

The results show that aviation indeed pays a very low fraction of its emissions costs. The climate cost is internalised to 4–5 per cent for typical flights within the EU and 0 per cent for flights to destinations outside of the EU, where the ETS does not apply. For air quality, the degree of internalisation spans from 4 per cent for a typical long-haul flight to 13 per cent for a typical domestic flight. In total then, the degree of internalisation of emissions costs spans from practically zero for a long-haul flight to 6 per cent for a domestic flight. If the emissions costs currently not paid for by the airlines would be internalised by means of taxation or other price instruments, the effective tax per passenger for the three typical flights studied would be SEK 156 for Arlanda–Gothenburg, SEK 493 for Arlanda–Madrid and SEK 2,914 for Arlanda–Bangkok. The price and income elasticities are, depending on which price measure is used, estimated to -1.88 or -2.53 and 2.03 or 2.04, respectively. However, they should be interpreted cautiously due to data limitations, especially for the price elasticity.

The rest of the thesis is organised as follows: Section 2 combines evaluations of the environmental impacts of aviation emissions with economic valuations of those impacts to determine the environmental costs of aviation emissions. Those costs are then compared to the costs paid by the airlines under the economic instruments in use today for three typical flights of different distances. In section 3, the price and income elasticities of the demand for international leisure air travel from Sweden are estimated. Section 4 discusses the implications of the results from the previous sections for the design of economic instruments for aviation and the consequences of those, and section 5 concludes.

2 The degree of internalisation of the emissions costs of Swedish aviation

Determining the degree of internalisation of emissions costs has three parts: (1) determining the emissions costs, which in turn requires evaluating the environmental impact of the emissions and then valuing those impacts in economic terms, (2) determining what economic instruments are to be considered internalising and (3) comparing the costs to the internalising instruments. The first two parts mainly consist of a literature review, but some judgements must be made regarding how to value a certain impact and whether a certain instrument can be considered internalising before proceeding to the final part. In that part, the degree of internalisation is calculated for three typical flights in order to give some sense of the orders of magnitude.

2.1 The external costs of aircraft emissions

Since existing studies tend to ignore high-altitude climate impact and air pollutants emitted during cruise, a review of the science of the impacts of aircraft emissions is offered in this sub-section before returning to a more familiar economic problem, namely the valuation of these impacts.

2.1.1 The environmental impact of aircraft emissions

The environmental impacts of aircraft emissions are either global in nature – climate change – or more local or regional, causing adverse health effects or contributing to eutrophication, acidification, ozone-induced crop losses or other effects on crops or ecosystems. In the following, these will be referred to as climate and air quality, respectively.

Emissions from aircraft jet engines include carbon dioxide (CO_2), water vapour (H_2O), nitrogen oxides (NO_X), carbon monoxide (CO), sulphur oxides (SO_X), unburned hydrocarbons (HC) or volatile organic compounds (VOCs), particulate matter (PM), and other trace compounds. CO_2 and H_2O have no adverse health effects, except through climate change, whereas many of the other compounds have been linked to adverse health impacts.

Turning first to these health impacts and other aspects of air quality, one of the main problems is NO_X. NO_X includes both NO and NO_2 and are involved in the formation of surface ozone and secondary particulate matter (PM), which both have negative health effects, especially PM. Aircraft exhaust SO_X mainly consists of sulphur dioxide (SO_2), with trace concentrations of sulphur trioxide (SO_3) and gas-phase sulphuric acid (H_2SO_4). Like NO_X, SO_X is involved in the formation of secondary PM.

Particles from aircraft combustion are small, less than 2.5 μm in diameter, and are therefore often called $PM_{2.5}$. Although exhaust contains some primary PM, the main PM contribution from aviation is from secondary PM in the form of ammonium sulphates, ammonium nitrates and other constituents, originating from the emissions of NO_X, SO_2 and hydrocarbons. This secondary PM will develop over the course of hours and days, so it will be well removed from the place where it was emitted by the time it contributes to increased ambient levels of atmospheric PM concentrations. PM precursors from aviation are not different from those emitted from other combustion sources, so they too will contribute to premature mortality and morbidity, including cardiovascular and respiratory ailments. For more information and further references on the health effects of aircraft emissions, see e.g. Mahashabde *et al.* (2011).

In addition to health effects, aircraft emissions can also affect crops and natural ecosystem (see e.g. Langner *et al.*, 2005). Surface ozone formed by NO_X emissions can reduce crop yields and acidifying and eutrophying deposition of oxidised nitrogen can affect agricultural soils and natural ecosystems. Acidification and ozone formation are also affected by other emissions, e.g. SO_X and VOCs.

Traditionally, only emissions during the landing and take-off (LTO) cycle have been considered relevant from an air quality perspective. This can be seen in valuations of the external costs of these emissions (e.g. Korzhenevych *et al.*, 2014). Also, the Swedavia emission charge (see sub-section 2.2.1) only considers emissions during LTO. For some pollutants, this could perhaps be a reasonable simplification, but Barrett *et al.* (2010) show that this severely underestimates the health effects of other pollutants. Using a recent aircraft emissions inventory, a global chemistry-transport model, population density and disease statistics, and concentration-response functions derived from epidemiological studies to assess the impact of aircraft emissions globally on premature mortality, they estimate that ∼8,000 premature mortalities per year are attributable to aircraft cruise emissions globally, representing ∼80 per cent of the total impact of aviation. The mortality impacts are to 99 per cent dominated by secondary sulphate-ammonium-nitrate aerosols formed though reaction with aircraft-attributable HNO_3 and H_2SO_4, from NO_X and SO_X, respectively, and background NH_3. This means that cruise emissions, at least NO_X and SO_X, should be accounted for when estimating damage costs of aircraft emissions. Furthermore, they show that impacts can be displaced from flight paths by several thousand kilometres due to meridional and zonal circulation patterns at cruise altitudes. The distance and direction of the displacement depends on both latitude and altitude, but typically there is a strong eastward displacement and a weaker southward displacement (the majority of the flights taking place in the northern hemisphere).

Langner *et al.* (2005) model the fate and chemical interactions of the NO_X emissions in Swedish airspace. Although they only consider the part of the flight taking place in Swedish airspace, they show that the impacts in terms NO_X deposition and increased levels of surface ozone and $PM_{2.5}$ reach far down through Eastern Europe, with Russia, Sweden, Poland and Ukraine being most severely affected. In figure 1, the results for $PM_{2.5}$ are shown; NO_X deposition and surface ozone show similar patterns.

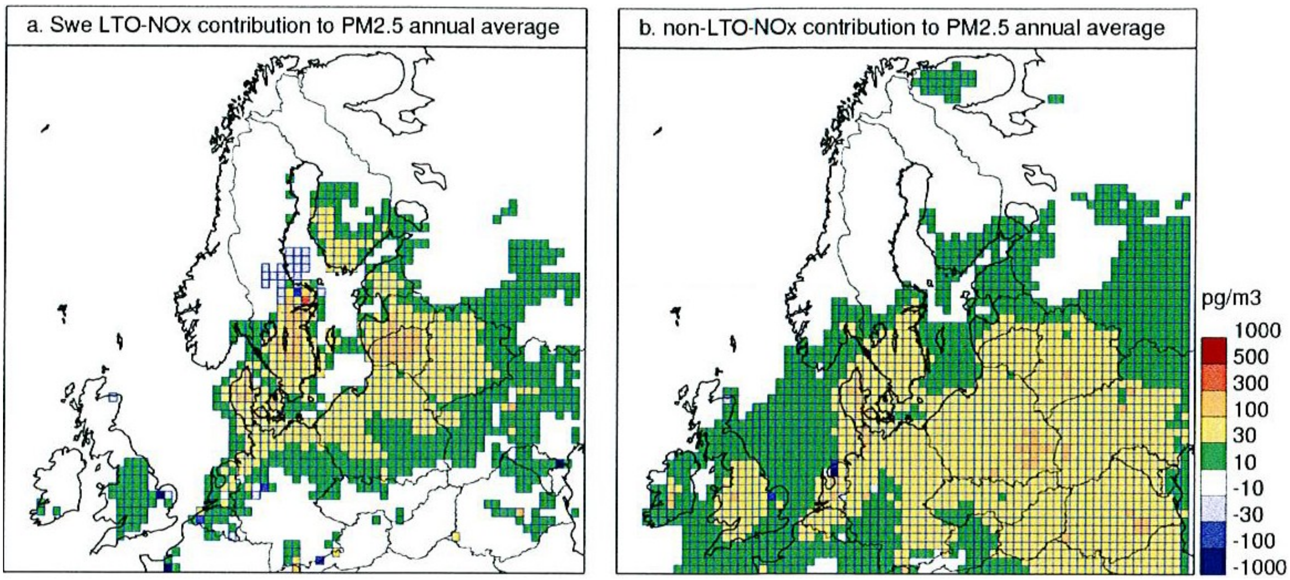

Figure 1. Changes in surface $PM_{2.5}$ concentrations from NO_X emissions of aviation in Swedish airspace (Langner et al., 2005, p 10).

Turning then to the climate impact of aviation, one important factor that determines the impact is flight altitude. Commercial aircraft normally fly at an altitude of approximately 9–13 km (Ahlberg, 2014). To a great extent, this coincides with the tropopause, i.e. the boundary between the troposphere (the lowest layer of the atmosphere) and the stratosphere (the next layer). Its altitude varies between approximately 15 km at the equator and 10 km at the poles; in Sweden it averages 12 km. In and around this region, aviation has additional high-altitude climate impacts besides the CO_2 impact (Karyd, 2015).

Lee *et al.* (2010) present a thorough review of the non-CO_2 climate impact of aviation. This impact is driven by long-term impacts from CO_2 emissions and shorter-term impacts from non-CO_2 emissions and effects, which include the emissions of water vapour, particles and nitrogen oxides. Emissions of NO_X result in production of ozone, which gives a warming effect, and the reduction of ambient methane, which gives a cooling effect. Based upon current understanding the overall balance is warming.

In ice-supersaturated air masses in the upper troposphere, aircraft produce persistent contrails which reflect solar radiation and trap outgoing terrestrial radiation. These are routinely observed to shear and spread, producing additional cloudiness termed contrail-cirrus. The scientific understanding of the formation of aviation induced cirrus is lower than for the other climate forcers, but the overall effect of contrails and enhanced cloudiness is considered to be a positive forcing and could be substantial, compared to other effects. These other effects include, apart from CO_2 and NO_X described above, the warming effect of water vapour and soot aerosols and the cooling effect of sulphate aerosols, but these effects are comparably small.

When comparing different climate forcers, care must be taken to account for the different time scales of different climate forcers. The effects of CO_2 on global mean surface temperature last for many hundreds of years, while the non-CO_2 effects of aviation last for decades. Several metrics have been proposed in order to compare the impact of different climate forcers. The one preferred by the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) is GWP_{100}, i.e. global warming potential with a 100-year time horizon. Using that metric, the total climate impact of aviation (including aviation induced cirrus) amounts to 1.9–2.0 times that of CO_2 only.

Azar & Johansson (2012) present another set of estimations of the emissions weighting factors for non-CO_2 climate impact. Three are based on physical metrics similar to those used by Lee *et al.* (2010) and two are based on economic metrics, using the climate economy model MiMiC. The economic metrics are Relative Damage Cost (RDC), which is the ratio of the climate damage in economic terms from emission of 1 kg of greenhouse gas X compared to the climate damage in economic terms of the emission of 1 kg of CO_2, and Cost-Effective Trade-Off (CETO), which is the ratio of the shadow prices of the emission of 1 kg of greenhouse gas X to the shadow price of 1 kg of CO_2, under the assumption that a specific climate target should be met at the lowest possible cost.

RDC is based on a cost-benefit approach, estimating the net present value of all costs caused by emitting one unit of gas X, whereas CETO estimates the cost-effective tax on the emission of gas X required to reach the temperature target at the lowest possible cost. If the damages from climate change were considered infinite for temperature changes above 2° C and zero for temperature changes below that, Azar & Johansson explain that RDC and CETO would be equivalent. Since that is not how the global warming damage function is normally modelled, and certainly not in their article, the results differ so that the CETO value is lower initially but then rises sharply at the time the temperature is to stabilise. The RDC value is close to the GWP_{100} value – 1.8 compared to 1.7 as a best estimate, with a total range for both metrics of 1.3–2.9.

These estimates are useful for evaluating the aggregate impact of aviation. However, the authors stress that applying the factor to individual flights in a policy situation would result in too blunt a policy instrument, since when and where the flights occur have a significant impact on the resulting climate impact. For example, a flight may lead to very strong contrail formations and induce cirrus if it flies in a region supersaturated with ice whereas another flight flying somewhere else does not, and night and winter flights have a stronger warming effect than daytime and summer flights (when there is more incoming radiation to reflect, partly balancing the warming effect of trapping outgoing radiation). Moreover, a measure to reduce one type of climate impact may increase another: if a plane flies at lower altitudes, it may cause less contrails at the expense of higher CO_2 emissions (due to higher air resistance at lower altitudes).

According to Karyd (2015), a flight altitude of at least 8,000 m is normally required for the formation of contrails and contrail-cirrus, and also NO_X has a stronger effect at high altitudes. Hardly any Swedish domestic flight reaches that altitude, and besides many aircraft for domestic flights are of the turboprop type, with a maximum altitude of 7,500 m. For these turboprop aircraft, Karyd recommends that high-altitude impact is considered to be zero, but for domestic jet aircraft, he recommends an uplift factor of 1.5 in line with the precautionary principle. For international flights, he recommends an uplift factor based on the formula 1,5+0,00012d, where d is the flight distance in km. This formula reflects the fact that the longer the flight distance, the greater is the portion flown at high altitude, and is calculated so that the total value for a very long flight – 10,000 km – corresponds to the upper end of the interval for GPW_{100} estimated by Azar & Johansson (2012).

2.1.2 Valuation of emissions costs

There are numerous studies aimed at valuing the cost of different pollutants, especially CO_2. In search for a recommended set of methods and default values for the external costs of transport to use when conceiving and implementing transport pricing policy and schemes, the European Commission commissioned a study in order to summarise the existing scientific and practitioner's knowledge. This study resulted in a handbook in 2008, which was subsequently updated by Korzhenevych *et al.* (2014). The update of the handbook on external costs of transport, hereafter "the EU handbook" or simply "the handbook", is based on a comprehensive literature review, aiming to present the state of the art and best practice for external cost estimations. This approach makes this EU handbook a suitable source for cost estimations for the following.

Starting again with air quality, cost estimations typically follow the Impact Pathway Approach (IPA), as does the EU handbook. The IPA includes the following steps:

- Quantifying the burden of pollutant emission, e.g. using vehicle emission factors.
- Modelling the dispersion of pollution around its source and its chemical transformation in the environment.
- Assessing the exposure, i.e. the population and the ecosystem being exposed to the air pollutant emissions.
- Determining the impacts by applying so-called exposure response functions that relate changes in human health and other environmental damages to unit changes in ambient concentrations of pollutants.
- Valuing the damages in monetary terms, often based on valuation studies assessing e.g. the willingness to pay for reduced health risks.

For quantifying the burden, the EU handbook uses emission factors from the official EMEP/EEA guidebook (EMEP/EEA, 2013). Combining information from EMEP/EEA with the unit costs found in the following steps, the air quality costs can be found for a particular aircraft of interest.

For the other steps of the IPA, the EU handbook uses damage costs from the NEEDS project (Preiss & Klotz, 2007). The NEEDS project does not only cover health effects, but also quantifies the side effects of emitted NO_X and SO_2 on materials (e.g. buildings), biodiversity and crops. Estimations of health effects are based on willingness-to-pay surveys. Although “it seems natural to let the values for different countries reflect the differences in the attitude to risk, income levels etc.”, the handbook argues, “one can also argue that such differentiation must be avoided for ethical reasons” (Korzhenevych *et al.*, 2014, p 34). In the end, the recommendation is not to differentiate between different countries with respect to willingness to pay. On the other hand, differences in average population exposure numbers are accounted for by producing country specific estimations of unit costs for the pollutants deemed to be most relevant in the transport sector. These pollutants are NO_X, SO_X/SO_2, NMVOC and $PM_{2.5}$, with unit costs for Sweden of 5.247, 5.389, 0.974 and 14.578 €/kg, respectively, in 2010 prices.

In principle, climate cost estimation follows the same IPA method as for air quality, only that the dispersion and exposure steps are irrelevant. Just as for air quality, emission factors are found in the EMEP/EEA guidebook. Unlike air quality, however, where the damage cost approach is used, the EU handbook recommends using the avoidance cost approach, i.e. the cost of achieving a given amount of emissions reduction, when estimating climate costs. Their argumentation builds on van Essen *et al.* (2011), who view the damage cost approach as the first-best estimation generally to be preferred, but point out two complications in the case of climate change:

- Lack of knowledge about the physical impacts caused by global warming. While some effects are quite certain and proven by detailed modelling, other possible effects, like more dramatic non-linear effects, are often not taken into account due to lack of information on the relationship between global warming and these effects. It is even more difficult to assess indirect effects such as socially contingent damages (e.g. regional conflicts). Even if the probabilities are low or unknown, the potential damage could be very high. Since most people are risk-averse, the precautionary principle means that these possible impacts should be taken into account. Yet, there are currently no methodologies for taking risk-aversion into account under the damage cost approach.
- Equity considerations, especially in connection with irreversibility and uncertainty. Climate change involves issues of intra- as well as inter-generational equity. The cost estimations vary considerably when changing the discount rate or when using regional weighting in order to reflect differences in marginal utility of consumption due to differences in income.

For these reasons, van Essen *et al.* prefer the avoidance cost approach for estimating CO_2 costs. They argue that if there are clear reduction targets that represent people’s preferences appropriately, then the marginal avoidance cost related to the target could be seen as a correct willingness-to-pay value. And even if the targets were not optimal, measures will have to be applied until the target is met.

The EU handbook recommends choosing avoidance costs corresponding to stabilising global warming at 2°C, a target embraced by the UNFCCC and the EU. There is a variety of cost estimations which differ substantially depending on the choice of inter-temporal discount rate and fossil fuel price forecast, so the handbook bases its cost estimation on a meta-study by Kuik *et al.* (2009). This is based on a wide range (26 models) of available estimates of abatement costs and originated from a joint effort of different modellers calculating mutually comparable scenarios. Due to the nature of this meta-study, the handbook considers their paper a reliable source for average estimates.

In their paper, Kuik *et al.* (2009) estimate marginal abatement costs corresponding to different target levels for the years 2025 and 2050. These marginal abatement costs can be interpreted as carbon permit prices in an idealised global emissions trading system where prices are equalised across all sources. For 2°C they find €129/t CO_2-eq in 2025 (with a range €69–€241) and €225/t CO_2-eq in 2050 (€128–€396), measured in 2005 prices. In the handbook, the 2025 values are discounted back to 2008 using a discount rate of 3 per cent per year and converted from 2005 prices to 2010 prices using the Eurozone inflation rate (GDP deflator), resulting in a range €48–€168, with a central value €90.

According to the handbook, their cost estimate matches well enough with some other reviews used as guidelines for policy appraisal in UK and Germany, respectively, both reporting a central value of €80. It can also be compared to the official Swedish "ASEK value" of SEK 1.08/kg (in 2010 prices) which is used in project appraisals and based on the Swedish CO_2 tax (Trafikverket, 2015).

As a comparison, the handbook refers to a study by Tol (2012), who reports CO_2 damage cost for a statistical distribution based on 232 published estimates. His mean value is markedly lower – €49 – and varies greatly depending on the pure rate of time preference. Tol himself, however, does not seem to favour indiscriminately using the damage cost approach. In another article, Tol (2010) cautions that the uncertainty of the economic effects of climate change is vast and right-skewed. Intuitively he argues that "it seems that negative surprises should be more likely than positive surprises. While it is relatively easy to imagine a disaster scenario for climate change – for example, involving massive sea level rise or monsoon failure that could even lead to mass migration and violent conflict – it is not at all easy to argue that climate change will be a huge boost to economic growth" (Tol, 2010, p 20). "Missing impacts" that are not sufficiently understood to be included in damage cost estimations are a reason and for concern and, Tol argues, justify greenhouse gas emission reduction beyond that recommended by a cost-benefit analysis under quantified risk. The size of the "uncertainty premium", he further argues, is a political decision.

If one agrees with Tol above, it is natural to view avoidance cost estimations as a combination of an implicit damage cost valuation and a politically decided uncertainty premium. Moreover, using the avoidance cost approach instead of the damage cost approach leaves the value judgements relating not only to uncertainty but also to intra- and inter-generational equity to politicians, who unlike economists are elected for making such judgements. Hence, the following calculations are based on the avoidance cost approach for valuing climate impact, using adjusted values from Korzhenevych *et al.* (2014).

2.2 Current economic instruments for aviation

This sub-section presents the economic instruments for aviation emissions currently in use. As noted earlier, existing studies focus mainly on instruments aimed at local pollutants, assuming that the climate impact is entirely internalised by the EU ETS. For this reason, this sub-section also includes a discussion of why this assumption might not be valid.

2.2.1 The Swedavia emission charge

The major airports in Sweden are run by state-owned Swedavia. At Swedavia's airports, all aircraft are charged an emission charge based on certified emission values of nitrogen oxides (NO_X) in the landing and take-off (LTO) cycle. The emission values depend on type of aircraft, engine and typical taxi times at each airport, where Arlanda is the most expensive and smaller airports are cheaper. Other pollutants and NO_X emissions during cruise are excluded, as are small aircraft and all aircraft operating at private and municipal airports. The level of this charge – SEK 50 per kg of NO_X in the LTO cycle – is set so as to cover costs for control and measurement of emissions at the airport and mitigating activities (Swedavia, 2014).

2.2.2 The EU Emissions Trading System

The European emissions trading system is regulated in the EU ETS directive (European Parliament and Council, 2003). For the aviation sector, 82 per cent of the allowances are given for free and 15 per cent of the allowances are allocated by auctioning. The remaining 3 per cent are allocated to a special reserve for later distribution to fast growing airlines and new entrants into the market. The free allowances are allocated by a benchmarking process which measures the previous activity of each operator in terms of the number of passengers and freight that they carry and the total distance travelled. Only aviation's emissions of CO_2 are covered, but no non-CO_2 climate impact.

Initially, the scope of the system was restricted to heavy energy-using installations in power generation and manufacturing industry, but aviation was included in 2012. However, trade between aviation and stationary sources is only allowed in one direction: airlines may use permits issued to stationary sources but not vice versa. According to Kopsch (2012b), the Commission wanted to give aviation the opportunity to continue to grow by purchasing additional permits, but since aviation is not included in the Kyoto Protocol, the Commission did not want to jeopardise their goals by introducing additional permits for stationary sources. In practice, this barrier makes no difference. According to Vespermann & Wald (2011), aviation is considered a strong net buyer of permits, so the flow of permits goes from stationary sources to aviation anyway.

The inclusion of aviation led to fierce protests from some non-European countries, which disapproved of the idea that European and non-European airlines alike would have to buy permits when flying to and from the EU. Fearing that the conflict might complicate the ongoing negotiations in the International Civil Aviation Organisation (ICAO) concerning a possible future global market-based measure for emissions from international aviation (or possibly a trade war), it was decided that only flights within the European Economic Area (EEA; EU, Iceland, Liechtenstein and Norway) were to be included in the scheme (European Parliament and Council, 2014).

The 2013 assembly of the ICAO (ICAO, 2013) agreed to report back in 2016 with a proposal for a global market-based measure scheme capable of being implemented by 2020. If and when such a scheme will indeed be implemented remain to be seen, but the exemption for extra-EEA flights will remain in place until the end of 2016.

High-altitude impact and extra-EEA flights are clearly not internalised by the EU ETS, but the present state of the ETS makes it complicated to judge whether CO_2 emissions from intra-EEA flights are internalised or not. Some (e.g. Ahlberg, 2014) argue that the CO_2 costs of intra-EEA flights are internalised because of the ETS, implying that the ambition of the ETS would reflect the true socially desirable emission level. Others (e.g. Trafikanalys, 2015b) assume that the socially desirable emission level is set by the quantitative reduction targets and argue that since the ETS cannot be expected to deliver the emission reductions needed to reach those targets, the allowance price cannot be said to represent the marginal climate cost of aviation.

If the damage cost approach is used, the question reduces to whether the damage cost happens to coincide with the current allowance price of about €7/tonne. Although there are many damage cost estimations and one of them may actually end up with a value of €7/tonne, this is clearly lower than the average of €49/tonne found by Tol (2012) above. Thus, using the damage cost approach, there is no reason to believe that CO_2 emissions are internalised.

If instead using the abatement cost approach, things would be easy if there was one single target, or several internally consistent targets. Unfortunately, there is a hierarchy of climate targets of varying ambition. The ultimate objective of the UNFCCC is the ‘‘stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system’’ (UNFCCC, 1992). In the Cancun agreements of 2010, parties to the convention committed to keep global warming below 2 degrees Celsius above pre-industrial levels (UNFCCC, 2010). The EU long-term target is an 80–95 per cent reduction of greenhouse gas emissions by 2050 compared to 1990. This is not consistent with the current design of the ETS, where the linear factor at which the cap is to annually decrease only leads to a just over 70 per cent reduction of the ETS cap by 2050 (European Commission, 2012).

Not only is the ETS insufficient to reach the EU long-term climate targets if functioning as intended: it is not functioning as intended today. The current price of an ETS allowance of around €7/tonne is much lower than what was expected when ETS was introduced and has led to considerable debate about the functioning of the scheme. In 2012 the European Commission presented a report of the state of the carbon market, stating that a number of factors including the economic crisis have created a surplus of around 2 billion allowances, accounting for the very low allowance price. It concludes:

> “The EU ETS has created a functioning market infrastructure and a liquid market producing an EU wide carbon price signal. This has contributed to delivering real GHG emissions reductions in line with the EU targets for 2020. However, the effects of the crisis compounded by a number of regulatory provisions related to the transition to Phase 3 have caused serious imbalances to emerge between supply and demand in the short term with potentially negative long-term repercussions. If not addressed, these imbalances will profoundly affect the ability of the EU ETS to meet the ETS target in future phases in a cost-effective manner, when significantly more demanding domestic emission objectives than today would have to be reached.” (European Commission, 2012, p 11)

In a later proposal for a market stability reserve the European Commission (2014b) expects the surplus to grow over the coming years to more than 2.6 billion allowances by 2020. That economic actors now take investment decisions against the background of an oversupply of allowances in the market and the corresponding price signal makes the Commission fear that overall costs relevant for the climate change challenge are bound to increase when considered over the mid- and long-term. That is why the Commission proposed a market stability reserve which, while not addressing the structural imbalances of the carbon market, is supposed smoothen some of the current volatility. The reserve will start operating in 2019 (European Parliament, 2015). Although the European Commission (2012) has put forward a number of other suggestions in order to improve the functioning of the carbon market, the only measure that has been implemented so far is the “back-loading”, or postponement, of 900 million allowances from the years 2014–2016 to the years 2019–2020 (European Commission, 2014a).

In the light of the review just presented, CO_2 emissions are not considered fully internalised by ETS for the following calculations. If they were – despite the present imbalances in the market and despite the fact that the scheme, even if functioning as originally intended, is insufficient to reach the long-term EU climate target – that would imply that any emissions covered by any sort of price instrument, no matter how insufficient to reach any targets set, would be fully internalised. Asking whether the instruments are at an appropriate level would then be meaningless, because by assumption they would be appropriate at any level. Instead, the allowance price is here considered as a partial contribution but by no means a full internalisation.

2.2.3 Taxation

Apart from the EU ETS, there are no other climate-motivated taxes or charges for Swedish aviation. Jet kerosene is exempt from the Swedish carbon and energy tax (SFS 1994:1776). Besides, there is no VAT on international flights and only 6 per cent on domestic travel, including air travel, compared to the standard rate of 25 per cent (SFS 1994:200).

2.3 Internalisation of emissions costs

Having determined the costs and internalising instruments of aviation, these can now be compared to yield the degree of internalisation. Since this will differ for different flights depending on distance and, in the case of air pollutants, type of aircraft, engine and airport, previous studies often use a typical flight as illustration. Here the same domestic flight as in Hansen & Nerhagen (2008) is used, but two additional flights are included so that any differences between domestic, intra-EU and extra-EU flights can be discovered.

2.3.1 Method

First the emissions costs were calculated for the three typical flights. The emissions were taken from the guidebook of EMEP/EEA (2013), which includes emissions for a large number of commercial aircraft for different distances. Three airports at distances from Stockholm-Arlanda close to those available in the database were chosen – Gothenburg, Madrid and Bangkok – but since they do not match perfectly, the following calculations apply to the EMEP/EEA distances and the chosen airports should be seen as illustrative but not exact examples. The actual flight distances were calculated using great circle distance with an additional correction factor proposed by ICAO (2014).

Then, aircraft that typically operate the chosen routes were selected and information about types of engine and number of seats was collected from the airlines. Unfortunately, the EMEP/EEA guidebook does not report which engines are used in their calculations, but at least the calculations of the emission charge are based on the engines actually used. Typical load factors for short, medium and long hauls respectively were taken from the EU handbook (Korzhenevych *et al.*, 2014). The estimated unit costs for the air pollutants were also taken from that handbook, but converted from 2010 to 2015 prices using the Eurozone GDP deflator. Only the emission values for those pollutants that were evaluated in the handbook – apparently those that were deemed most relevant – were taken from the EMEP/EEA guidebook. However, the EMEP/EEA shows values for total hydrocarbons, i.e. including methane, instead of the non-methane volatile organic compounds (NMVOC) valued in the EU handbook. NMVOC values were instead found in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

For CO_2, the 2025 unit costs from sub-section 2.1.2 were instead discounted back to 2015, using the same 3 per cent discount rate, and converted to 2015 prices using the same Eurozone GDP deflator. The central value was then €109, with a range of €58–€203. The wide range highlights the sensitivity of the following calculations to the assumed unit cost of carbon. Therefore, the calculations were repeated using the lower and upper end of the cost range as a sensitivity analysis.

The EMEP/EEA emission values are divided into different flight phases, which were grouped into LTO (taxi out, take off, climb out, approach landing and taxi in) and cruise (climb, cruise and descent above 3,000 ft, i.e. 914 m). In this way, different unit costs could be applied for different flight phases. For CO_2, the unit value of € 109/tonne was applied for LTO emissions, whereas the uplift factor of 1.5 for domestic and 1.5+0,00012*distance for international flights from sub-section 2.1.1 was applied for cruise emissions (although strictly speaking the uplift factor does not represent carbon dioxide but other climate impact). For the other pollutants, all were valued at the unit costs for Sweden in the LTO phase. In the cruise phase, NO_X and SO_X were valued at the same costs as in the LTO phase, whereas the costs of the other pollutants were assumed to be zero during cruise.

Using the unit costs for Sweden could definitely be questioned for the international flights. Even if one for ethical reasons follows the recommendation from Korzhenevych *et al.* (2014) not to differentiate between different countries with respect to willingness to pay, at least differences in average population exposure numbers should preferably be taken into account. The reason this is not done is purely practical: determining the typical flight route between the chosen destinations, calculating the exposed population along that route and weighting the emission cost based on that population exposure (and possibly their willingness to pay) go well beyond the scope of this thesis. Since Sweden is a relatively sparsely populated country, this means the results are likely to be on the conservative side.

After calculating the theoretical emissions costs, the level of charges and ETS allowances applied for the flights were calculated. For climate impact, this is simply the price of ETS allowances, i.e. approximately € 7/tonne, times the CO_2 emissions. Although the majority of the allowances are granted to the airlines for free, the price clearly represents an opportunity cost. For the other pollutants, the emission charge for the chosen aircraft and engine types departing from Stockholm-Arlanda – the most expensive airport – was calculated (Swedavia, 2015).

2.3.2 Results

Table 1 External costs, charges/allowance costs, internalisation and uninternalised cost/passenger for three typical flights

Arlanda–Gothenburg (SEK/flight)			
	Cost	Charge	Internalisation
Climate	11,226	534	5 %
Air quality	2,088	275	13 %
Total	13,313	809	6 %
Uninternalised cost/pkm			0.34
Uninternalised cost/passenger			156

Arlanda–Madrid (SEK/flight)			
	Cost	Charge	Internalisation
Climate	53,324	1,956	4 %
Air quality	7,088	499	7 %
Total	60,413	2,455	4 %
Uninternalised cost/pkm			0.18
Uninternalised cost/passenger			493

Arlanda–Bangkok (SEK/flight)			
	Cost	Charge	Internalisation
Climate	608,828	0	0 %
Air quality	91,529	3,360	4 %
Total	700,357	3,360	0,5 %
Uninternalised cost/pkm			0.35
Uninternalised cost/passenger			2,914

Table 1 shows the costs, charges and degrees of internalisation for the three flights. More detailed results, including figures and assumptions about the flights in questions, are found in appendix A. As was suspected, the degree of internalisation is indeed very low, especially for the climate cost. Even with a lower assumed climate cost, the degree of internalisation does not exceed 10 per cent in any of the studied cases. Although not shown in the appendix, the same can be said about using a lower or even no uplift factor for the high-altitude climate impact.

The Arlanda–Gothenburg flight is basically the same as the one studied by Hansen & Nerhagen (2008), except that they use another engine for the same aircraft for their calculations. Yet, the results here are at the same time higher for the air quality costs and a lower for the emission charge. The higher air quality costs are primarily explained by a generally higher valuation of the unit emissions costs used here compared to the older study from Västerås airport on which Hansen & Nerhagen base their calculation, but also by cruise emissions of SO_X being included in this thesis. The lower emission charge is explained both by a more modern engine and by the fact that the previous hydrocarbon part of the emission charge has been removed.

The climate cost found here is higher than SIKA's (2009). Despite a higher CO_2 valuation of SEK 1.50, high-altitude climate impact is not considered by SIKA, resulting in a lower climate cost.

Not surprisingly, the results are very similar to the ones found in Trafikanalys (2015b) for the three flights. Although they have changed the input values slightly to harmonise better with the methodology used for other transport modes, it makes little difference for the resulting costs. The (opportunity) cost of ETS allowances is not considered in their main calculation, but an alternative calculation including the ETS price results in almost the same uninternalised cost per passenger kilometre as their main result, explained by the very low allowance price.

Comparing the results to the generalised cost/pkm output values of Korzhenevych *et al.* (2014), the costs found here are higher both for climate and air quality. This is not very surprising since their output values only consider CO_2 and LTO emissions, respectively. Apparently, this effect outweighs the fact that they use the EU average as input values for air quality, which are considerably higher than the input values for Sweden.

Both climate and air quality are more internalised at shorter distances, but the reason for this is not quite the same. For climate, the allowance cost is paid in proportion to the CO_2 emissions, but since non-CO_2 effects make up a larger share of the total climate impact at longer distances, where a larger portion of the flight takes place at high altitude, the allowance cost will cover a smaller share of the total climate cost at long flights. Obviously, the degree of internalisation is lower – actually zero – outside of the EES where the ETS does not apply. For air quality, the emission charge is only paid for LTO emissions, which make up a smaller share of the total emissions at longer flights. If instead looking at the total and the uninternalised cost per pkm, the cost is actually higher for both short flights (with proportionally high LTO emissions) and very long flights (with proportionally large high-altitude climate impact), compared to the medium-haul flight.

It is also worth noting that these results apply to one-way trips. For the climate cost, this makes no difference – either allowances are bought for both directions (within the EEA) or not at all (outside of the EEA) – but the emission charge is only paid for flights departing from Swedavia's airports. If there is no corresponding emission charge at the destination airport, or if the charge is lower or higher than Swedavia's, this will affect the results.

The results have also been expressed as the uninternalised cost per passenger. In relation to the Swedish government's plans for a possible tax on aviation, these results give an indication of what order of magnitude such a tax would have for different distances if it is to internalise the costs that are presently not internalised.

3 The elasticity of demand for air travel

Having established that aviation only pays a fraction of its emissions costs, it is natural to ask how large the consequences of this under-internalisation are. If the demand for air travel is price elastic, the consequences for the volume of air travel and hence emissions will obviously be larger than if demand is price inelastic. If, on the other hand, the observed increase in air travel is mainly driven by an income effect, attempts to price this under-internalisation will be less effective. The task of this section is thus to estimate the price and income elasticities of air travel, or more specifically, due to the data at hand, of international leisure air travel from Sweden.

3.1 Swedish air travel

Figure 2 shows the number of one-way air journeys per capita the last decades, or more precisely the number of arriving and departing passengers in international traffic and departing passengers in domestic traffic at Swedish airports divided by the population of Sweden. Domestic travel has been relatively constant or even declining since the 90s, whereas international travel has increased sharply despite dips in response to the 9/11 attacks and the financial crises: 3.7 per cent/year the last decade. This measure does not reflect changes in the average distance travelled; if it did, international air travel would have increased even more in recent years (see sub-section 3.2.1). The fact that international travel is both the largest part of total air travel and the part that is growing fast makes it especially relevant to focus on this part of Swedish air travel.

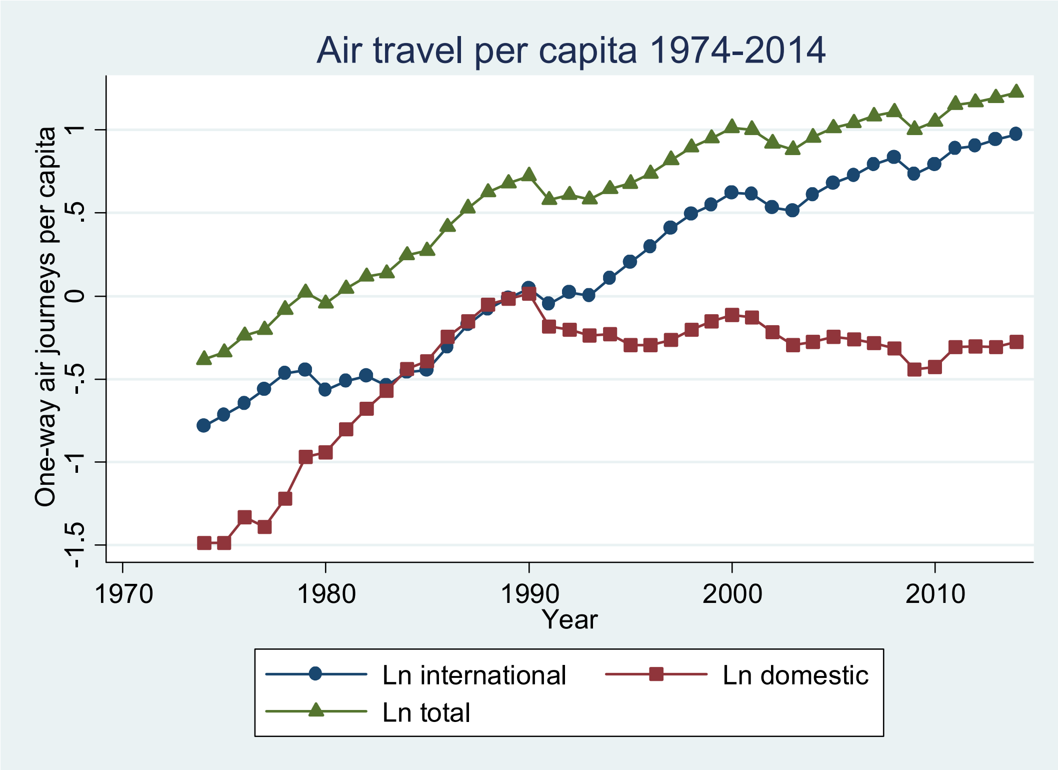

Figure 2. Number of arriving and departing passengers in international traffic and number of departing passengers in domestic traffic at Swedish airports 1974–2013 (Trafikanalys, 2015a) divided by population (source: SCB).

3.2 Data

3.2.1 Household expenditure data

Statistics Sweden (SCB) has collected data on household income and expenditure through interviews and collection of receipts among over 2,000 Swedish households. Their data cover the periods 2003–2008 and 2012 and can be grouped into deciles depending on household income per "consumption unit", a per capita measure differentiating between adults and children in the household (see figure 3, and appendix B for more details).

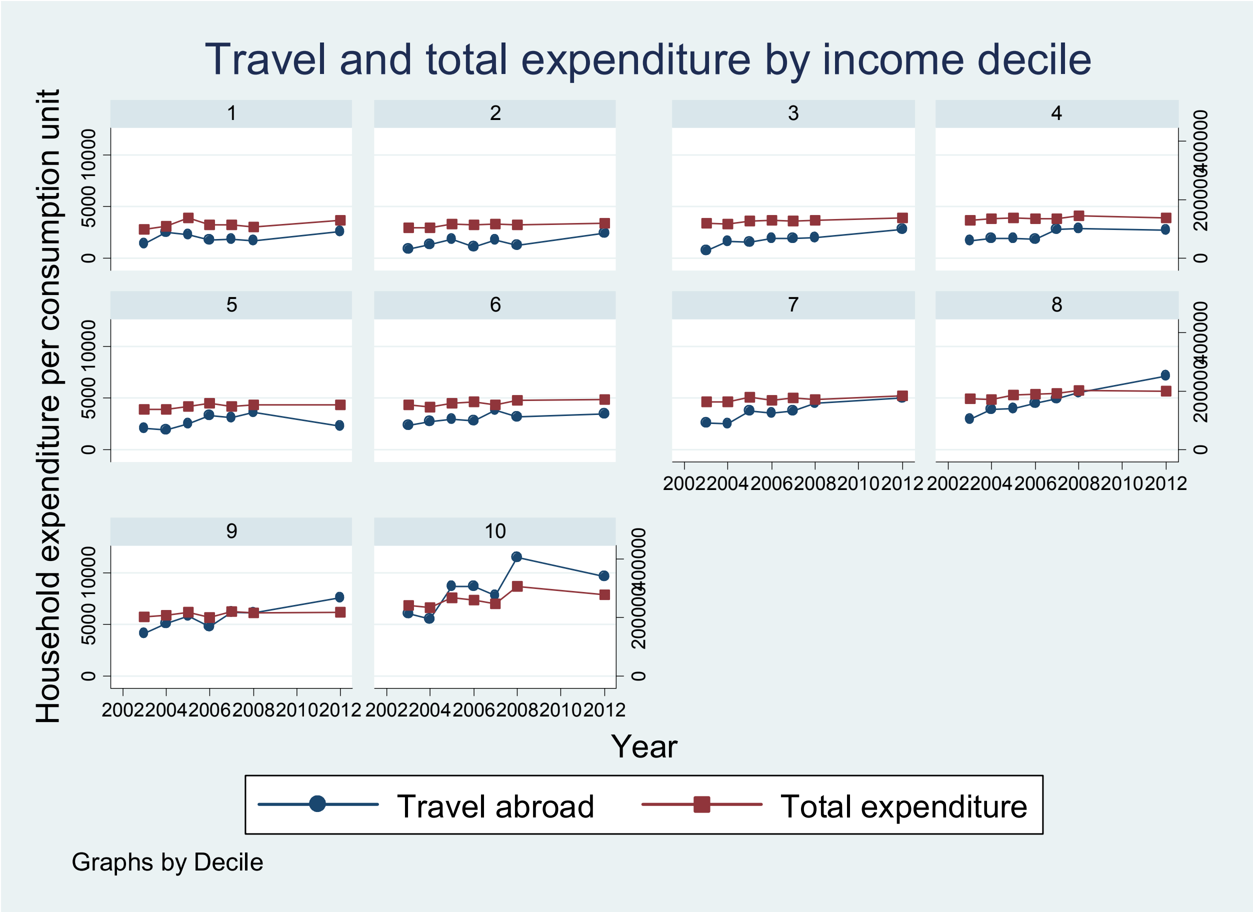

Figure 3. Household expenditure on travel abroad (part paid in Sweden) and total household expenditures per consumption unit, real prices (source: SCB).

Using household data means that only travel paid by the households, hereafter leisure travel as opposed to business travel, can be studied. The data do not distinguish between air travel and other transport modes, but there is a category labelled "travel abroad, part paid in Sweden". Since air travel is the dominant mode for travel abroad, representing 67 per cent of leisure travel with overnight stay (Tillväxtverket, 2013), it could be assumed that this category will correspond well enough to leisure air travel abroad.

The household expenditures on "travel abroad, part paid in Sweden" was then used to construct a measure of the quantity of international air travel for each decile, by dividing the household expenditure per consumption unit on this travel, expressed in real terms, with airfares (see sub-section 3.2.2), also in real terms. Since the SCB data on airfares are only available up to May 2011, and there is no obvious trend that can be used to extrapolate the price, the quantity of travel in 2012 was therefore calculated using the price of 2011 instead.

An interesting observation when studying figure 4, which compares the travel measures constructed above (averaged across deciles) to the measure previously referred to based on the number of per-capita air journeys, is that these new measures increase more steeply than does the number of air journeys alone. Apparently the same factors that lead to more journeys demanded also lead to longer journeys demanded. This means that if instead using a traditional time series approach relating the number of journeys to average airfares and aggregate income/expenditure, although permitting a longer period to be studied, the resulting estimates would be biased.

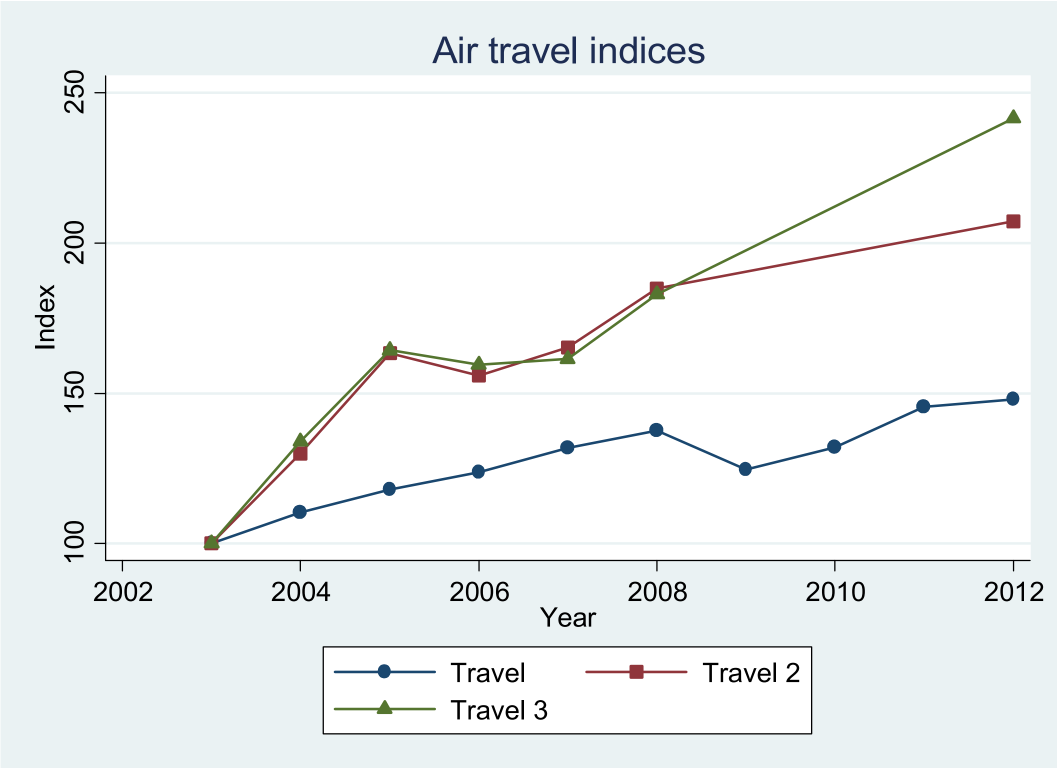

Figure 4. The index "travel" shows the number of per-capita one-way international air journeys (sources: Trafikanalys and SCB), whereas the indices "travel 2" and "travel 3" show the quantity of international air travel constructed from household expenditure data described in sub-section 3.2.1 and the price measures described in sub-section 3.2.2.

3.2.2 Price data

International (and domestic) airfares, excluding business fares, are part of SCB's consumer price index, available from 1996 to 2011. They are separated into airfares for scheduled and charter traffic, respectively, but the distribution of passengers between these types of flights, provided by Transportstyrelsen, can be used to construct an aggregate price index. Still, Transportstyrelsen no longer uses the SCB price index because of its small sample size and lack of transparency, according to Karyd (2014). Karyd claims that the quality of the index has deteriorated with the emergence of low cost airlines with creative charging schemes, which have made the collection of reliable price data much more difficult. He concludes that since no functioning price measure can be constructed, no price elasticity can be estimated either, and elasticity estimations by others should be looked at sceptically. Instead, he suggests that the yield measure in terms of passenger revenue per passenger kilometre that most major airlines report could be used as a proxy for price. Since there have been no changes in VAT or direct taxation that would drive a wedge between the price paid by the consumer and the passenger revenue of the airlines during the studied period, this seems like a plausible suggestion.

The largest airline in Sweden is SAS, with 23 per cent of the Swedish market for international air travel (Transportstyrelsen, 2015). Although yield measures reported in its annual reports correspond to the whole SAS group, i.e. domestic as well as international, business as well as economy class in Sweden, Norway and Denmark, and although 77 per cent of the market – including all low cost carriers (LCC) – are not represented, it turns out that the SAS yield measure and the SCB price index follow each other closely at least up to 2009 (see figure 5, and appendix C for more details).

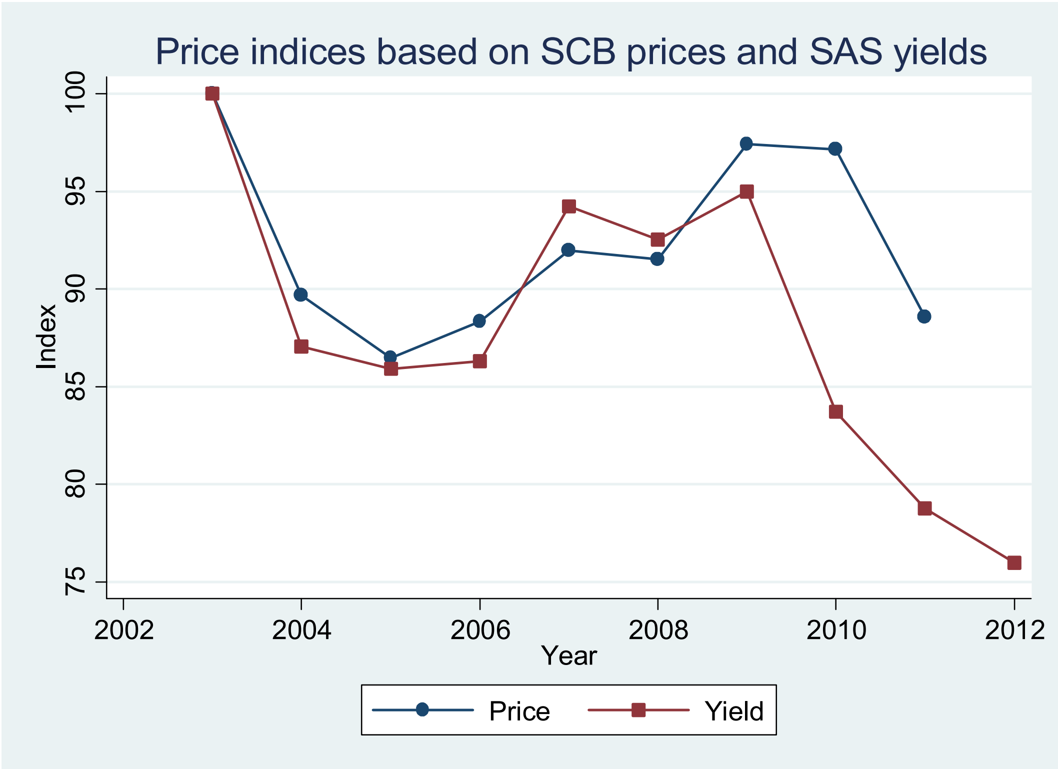

Figure 5. The index "price" shows airfares for international flights from Sweden, scheduled and non-scheduled, real prices (sources: SCB and Transportstyrelsen). The index "yield" shows the yield in terms of passenger revenue per passenger kilometre for SAS, real prices (source: SAS).

Either their biases are correlated, which could be the case if also the SCB index fails to reflect the airfares of LCC, or it seems that both price measures despite their weaknesses still perform fairly well up to 2009. If it is the SCB index deteriorating after 2009 or the SAS yield becoming less representative for international flights from Sweden after 2009 is hard to tell. The almost constant market share of LCC in the Scandinavian market from 2010 and onwards (SAS, 2015) gives no reason to suspect the latter, whereas Karyd's (2014) argument about increasingly complex charging schemes could possibly explain the former. In that case, the yield based measure would be more reliable. Still, instead of entirely discarding the SCB index based on more or less qualified guesses, both measures were used for separate estimations for comparison.

Bringing it together, figure 6 shows the price data together with the averaged household data. Although the variation in average household expenditures and prices is small, the data seem to behave as could be expected: increases in the quantity of air travel are generally associated with increases in total expenditure and/or decreases in price.

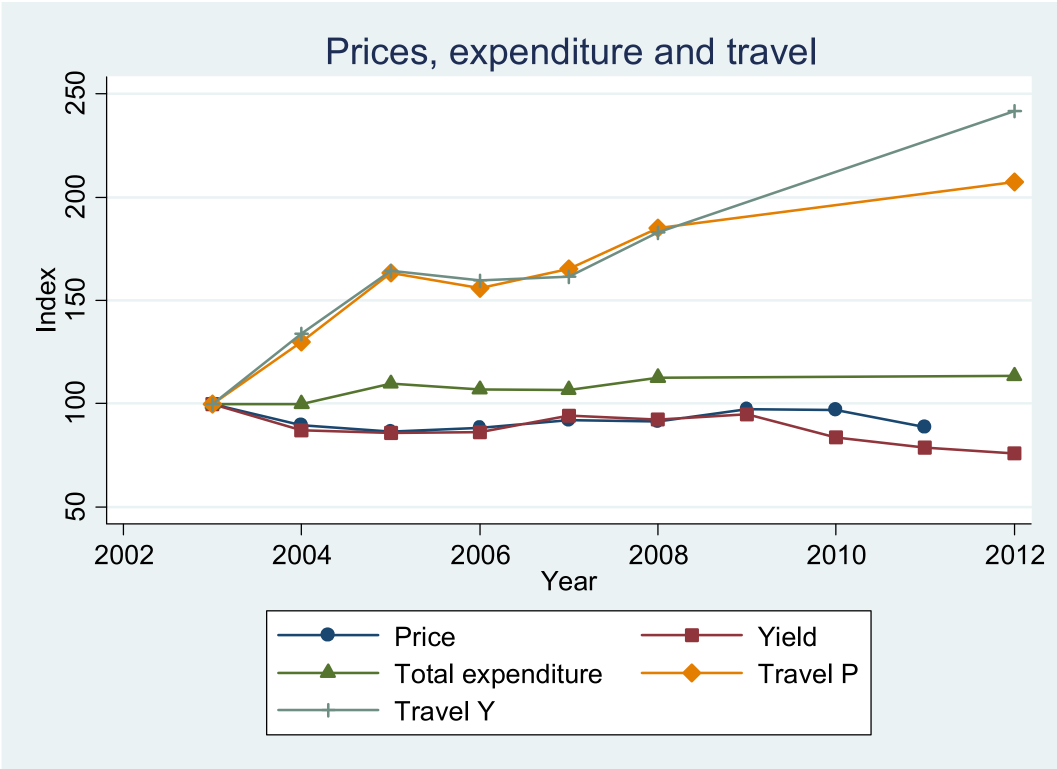

Figure 6. "Price" shows the SCB price index, "yield" shows the SAS yield measure, "total expenditure" shows the average total household expenditure per consumption unit, "travel P" and "travel Y" show the quantity of international air travel constructed by dividing the average household expenditure on travel abroad per consumption unit by "price" and "yield", respectively, all prices in real terms (sources: SCB and SAS).

3.3 Model

The following model was used for the estimation of the price and income elasticities of Swedes' demand for international leisure air travel:

$\ln Q_{it}=\eta_E \ln E_{it}+\eta_P \ln P_t+\beta+\varepsilon_{it}$,

where Q is the quantity of air travel measured as the annual household expenditure per consumption unit on air travel abroad divided by the price of air travel, E is the total annual household expenditure per consumption unit, P is the price of international airfares, either measured by the SCB price index or proxied by the SAS yield. Hence, η_E is the expenditure elasticity and η_P is the price elasticity of international leisure air travel. Furthermore, β is a constant and ε_{it} is an error term.

If the aim is to estimate the income elasticity, it would be logical to study the air travel demanded as a function of disposable household income per consumption unit. However, household data like these do not distinguish between individuals who have above-average incomes over their entire lifetime and individuals who are just in a part of their life in which they have above-average incomes. If one is interested in the effect of a permanent rise in incomes, comparing groups with different current incomes would underestimate the long-run income elasticity. Also, even if distributional effects are the main concern, a group that for one reason or another can afford larger expenditures than another group – possibly because they have accumulated wealth or just temporarily have a lower income – should arguably not be considered poorer just because their current incomes are lower.

Instead, total household expenditure is sometimes used as a proxy for lifetime income (e.g. Poterba, 1991), since households can avoid large fluctuations in their expenditure by saving and borrowing when their current incomes shift up and down. Thus, total household expenditure normally shows a stronger correlation to lifetime income than does current income. The resulting elasticity is then strictly speaking an expenditure elasticity and not an income elasticity. In their meta-analysis of income elasticities, Gallet & Doucouliagos (2014) find no significant difference for studies that use consumer expenditure as a proxy for income.

Therefore, the elasticity estimated here will be referred to as an income elasticity.

It is in important to note, however, that since household expenditure varies considerably less between deciles than does income, an elasticity based on current income would have been lower than this one, based on expenditure. If one were specifically interested in how individual households respond to changes in current incomes, an income-based elasticity estimation would have been more appropriate. If, however, one is more interested in how aggregate demand will respond to rising incomes, or how air travel expenditure differs between households with different lifetime incomes, an expenditure-based elasticity is more appropriate. Since other income elasticity estimations are not usually, if ever, based on household data of different income groups like these (Gallet & Doucouliagos, 2014), an expenditure-based estimation is more comparable to other estimations studying the population in aggregate.

3.4 Results

Table 2. Regression results for the estimations using the SCB price index and SAS yield measure, respectively. P-values within parentheses.

	SCB	SAS
η_E	2.04 (0.000)	2.03 (0.000)
η_P	-2.53 (0.000)	-1.88 (0.000)
β	-9.34 (0.001)	-16.23 (0.000)
R^2	0.8973	0.9029

Table 2 shows the results of the two estimations based on the SCB price index and the SAS yield, respectively, using a pooled OLS regression with robust standard errors. The results are highly significant for both estimations, while the R^2-value is somewhat higher for the estimation based on SAS compared to the one based on SCB. It is tempting to conclude that this means that the SAS estimation is therefore better than the SCB estimation, because the estimated price elasticity seems more reasonable for SAS than for SCB. However, which set of data is most reliable cannot be determined just by looking at which results seem most reasonable or have the better fit. Yet, considering the case made in 3.2.2 for the SAS index, there may be reasons to trust the SAS results slightly more.

Using OLS in a panel data estimation may seem unorthodox, because fixed or random-effects models are often used to control for unobserved heterogeneity between subjects (e.g. Gujarati & Porter, 2009). Unobserved subject-specific effects are typical when the subjects, or panel units, are e.g. individuals, firms or countries, which may all have their own particular time-invariant characteristics which are not accounted for by the explanatory variables. If these subject-specific effects are such that error terms and regressors are correlated, then OLS estimates will not only be biased but also inconsistent.

For the data at hand, it is less obvious that subject-specific effects should be present. Each decile is composed of individuals who vary over years and whose only common characteristic is that they have similar household incomes per consumption unit relative to others'. These household incomes are closely related to total household expenditure per consumption unit, which is in itself an explanatory variable. In fact, differences in household income are not an unobserved heterogeneity; on the contrary there are data on this. If one believes that demand for air travel is better modelled as determined by both household expenditure and household income than by either of them alone, this could easily be done. Yet, this would be even more unorthodox in relation to other studies and imply multicollinearity issues.

While the model used here only includes household expenditure per consumption unit (and price) as explanatory variable, the fact that the grouping is not based on this but on income per consumption unit could imply decile-specific effects. In general, higher deciles have both higher incomes and higher expenditure, but the first decile is an exception. For most years its members actually have higher expenditures than the second decile despite lower incomes. If this complication gives rise to significant decile-specific effects, this would call for either a fixed or a random-effects model, depending on the nature of these effects.

To test for fixed effects, the original OLS regression was repeated using decile-specific dummies. An F-test was then performed for the null hypothesis that the coefficients of these dummies were all zero. The null hypothesis could not be rejected (p-values were 0.2872 and 0.2530 for SCB and SAS, respectively), so a fixed-effects model was not deemed appropriate.

To instead test for random effects, a random-effects GLS regression was run and a Breusch and Pagan Lagrangian multiplier test for random effects performed. This could not reject the null hypothesis of no such effects (p-values were 0.1982 and 0.1851 for SCB and SAS, respectively), so a random-effects model was not deemed appropriate either.

Even without decile-specific effects, there is still a possibility that there are time-variant, decile-invariant effects. This possibility could easily be explained by demand shocks, changing preferences etc. that would affect all deciles in a given year equally. Unfortunately, prices also affect all deciles in a given year equally, implying multicollinearity. Discarding this model, too, it appears that using pooled OLS would be justified after all, as long the heteroscedasticity suggested by figures 7a and 7b and confirmed by a Breusch-Pagan heteroscedasticity test is dealt with. The latter was done by using robust standard errors.

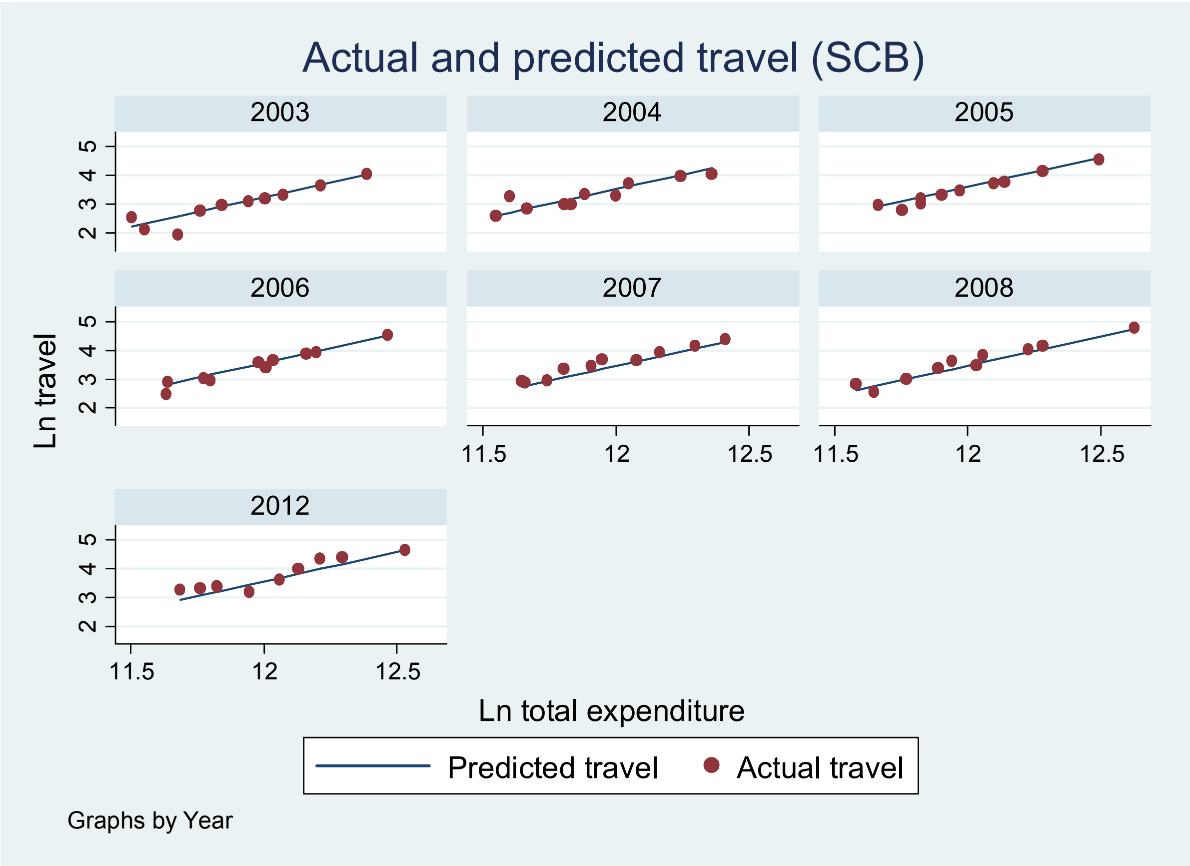

Figure 7a. Actual and predicted travel from the estimation based on the SCB price index.

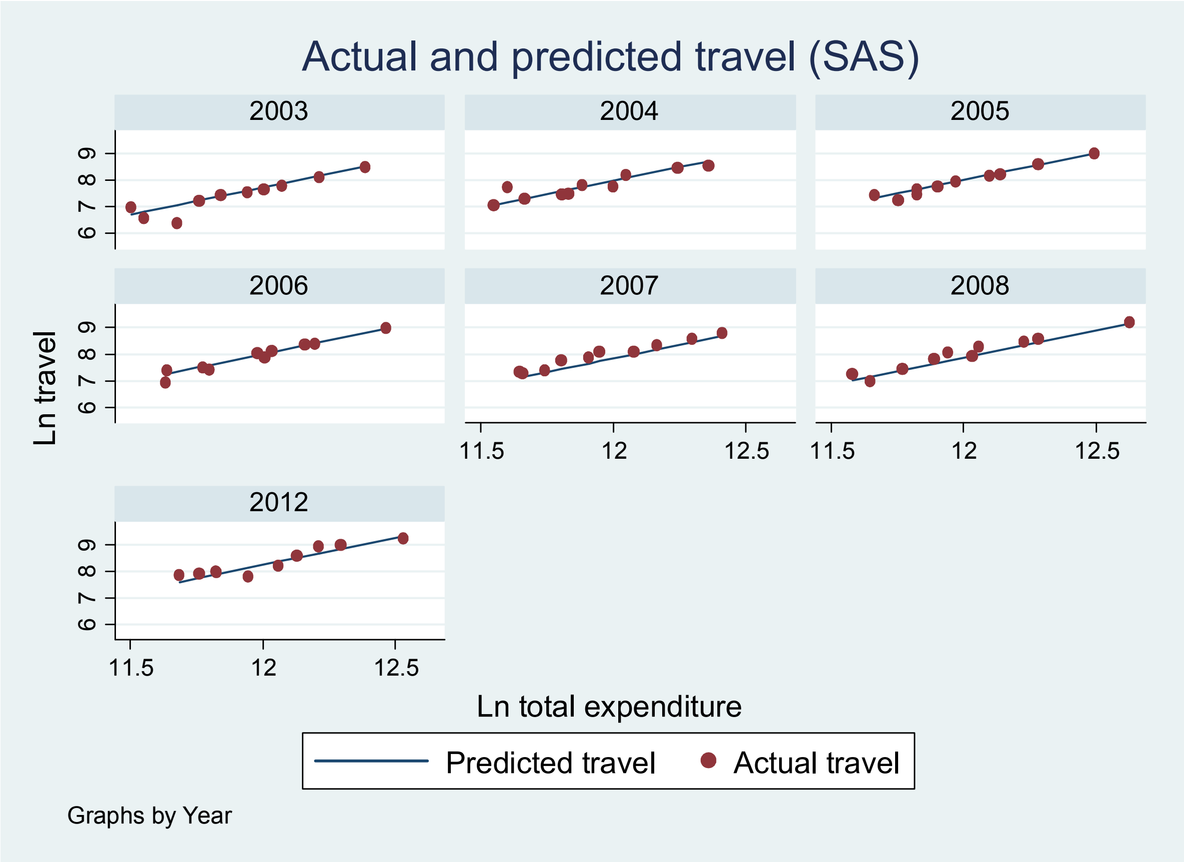

Figure 7b. Actual and predicted travel from the estimation based on the SAS yield.

The decent fit of the model seems to justify the chosen approach to model the quantity of air travel as determined by airfares and household expenditures alone. This is not to say that there could not be other determinants as well. The prices of close substitutes are perhaps the most obvious suspects, but in the case of international air travel, it is not obvious what these close substitutes would be. While feasible for shorter flights, substitutes are scarce for longer flights, so the traveller would not realistically be expected to change mode in response to price changes. Also, the relevant consumption choice for leisure travel is not limited to choosing among different transport modes to a chosen destination. Rather, consumers may choose among different destinations, or decide to trade holiday trips for other consumption which gives them more utility given their budget constraint. Since these alternatives could be basically anything, not including any cross-price elasticities in the model could be justified. Whereas including the price and expenditure of non-fare components of the journey, as suggested by Njegovan (2006), would have been relevant because of their considerable share of the total expenditure on the journey, lack of data on the prices of these components rendered that approach impossible.

There could of course be other forces at work, too, like changes in preferences, globalisation etc., but they are notoriously hard to capture. What could be seen from figure 2, however, is that the studied period, 2003–2008 and 2012, seems to be free of major shocks like the ones following the 9/11 attacks and the recent financial crisis. Also, a Ramsey RESET test for omitted variables was performed, which did not indicate omitted variables. Still, considering the difficulty to control for time-variant effects, it cannot be ruled out that there are other factors contributing to the increase in air travel not captured in the model. If there is in fact omitted variable bias involved, that could be one explanation why the estimated elasticities are so high.

Another explanation could be that the data are flawed. Unfortunately, there are weaknesses in both the household expenditure and the price data. If the household expenditure category “travel abroad, part paid in Sweden”, or more specifically changes in that category between years and deciles, corresponds well enough to international leisure air travel, then the data will provide a sound basis for estimation. However, there are at least two reasons why this might not be the case.

The first reason is that the share of air travel might not be evenly distributed between income deciles. For example, car travel (the second largest mode at 17 per cent) is perhaps not only over-represented at shorter distances but possibly also in lower income groups, in comparison to air travel. This would then tend to underestimate the income effect.

The second reason is that since charter flights make up one third of the outbound leisure air journeys, the "part paid in Sweden"[1] expenditure will in many cases include not only airfare but also accommodation etc., which would otherwise be a part of the category "travel abroad, part paid abroad". If there are systematic differences between deciles or years, e.g. if charter flights make up a larger share of the total travel share in some income groups, this will be a problem.

There are no data showing the distribution of charter flights between different income groups, but it could be suspected that they are over-represented in lower income groups. Yet, there are data from Transportstyrelsen[2] on the distribution of passengers in scheduled and charter flights between different years, showing that charter traffic has remained more or less constant for the relevant period (i.e. 2003–2012), whereas scheduled traffic has almost doubled. This means that the non-fare share of "travel abroad, part paid in Sweden" should have declined over the years, which would partly mask the real increase in air travel. Both these tendencies described would tend to underestimate the responsiveness of air travel expenditure.

As for the price data, they only comprise seven years, which is a very small basis for estimation, and their weaknesses have already been described in sub-section 3.2.2. Specifically, if the price indices do not reliably represent the effect of an increasing LCC market share on prices, and so understate the decrease in average prices during the studied period, then the estimated price elasticity will be exaggerated. In addition, as noted already in the introduction, using household expenditure panel data enables reliable estimates of the income elasticity, whereas the price elasticity will still be subject to possible distortions from failing to include relative price changes and other aspects that change in the economy over the years, and will so be more of a residual.

Considering these weaknesses in the data, it may not come as a surprise that the results presented here depart from the results of previous studies. A price elasticity of -2.53 or -1.88 is much higher (in absolute values) than the previously cited estimates (Brons *et al.*, 2002; Njegovan, 2006; Chi & Baek, 2012; Kopsch, 2012a). Since this thesis focuses on leisure travel, which according to Brons *et al.* is the market segment with the highest elasticity, a higher estimate than their aggregate mean of -1.146 should be expected. On the other hand, the price elasticities found in this thesis would most likely be considered short-run following the categorisation of Brons *et al.* They find that these will generally be lower than long-run elasticities, as the ones used by Chi & Baek (-1.56 for aggregate air travel) and Kopsch for his long-run estimation (-1.20 for domestic leisure air travel, while his short-run estimate is only -0.79).

The fact that Kopsch studies Swedish air travel makes his study especially interesting from a Swedish perspective, but also means that some of the problems pertaining to the Swedish data will be present in his study as well. Although he also depends on price data from SCB, his time series is much longer, spanning from 1980 to 2007, which means the current problems related to LCC charging schemes might not be very prominent. A more serious objection is that Kopsch uses the number of passengers as his measure of the quantity of air travel. As seen in figure 4, this is likely to underestimate changes in the quantity of air travel since changes in the distance travelled are not accounted for, and so the resulting price elasticity will be too low.

Njegovan's study has a similar focus to this thesis, namely outbound leisure travel – in his case from the UK – which means the results should be comparable. However, in addition to the prices of the actual travel, his model includes the prices of on non-fare components of the journey, which are clearly relevant for the consumers' travel choices, and so he ends up with a much lower price elasticity of only -0.7. This approach is attractive from a theoretical point of view, but is not commonly used, most likely because of the challenging data requirements. Therefore, his results are not directly comparable to the ones found here or previously cited.

In conclusion, the above reasoning suggests that Swedes' demand for international leisure air travel should in fact be price elastic, but values of -1.88 and especially -2.53 are still very surprising. Given the serious data

1 Technically the questionnaire asks for the portion of the total expenditure on travel abroad that is paid to *recipients in Sweden*, i.e. paying accommodation etc. over the internet while at home in Sweden is instead part of the category "travel abroad, part paid abroad".
2 Unpublished material.

limitations – a very small sample using two unreliable price indices which possibly overestimate the price elasticity – and a model that is actually more accurate in estimating the income elasticity, it is not recommended to draw any far-reaching conclusions from these results. However, they do support the results of other studies that show that the demand for international air travel is price elastic.

Turning to the income elasticity, the results seem more reasonable. An income elasticity of 2.03 or 2.04 is higher than the income elasticity from Gallet's & Doucouliagos' (2014) meta-analysis of 1.546 for international air travel, but the difference is not unreasonably large. Kopsch's (2012a) GDP coefficient for Swedish domestic flights is only 0.44, but using household expenditure panel data is arguably a more reliable way to estimate income elasticities than using a GDP coefficient in an estimation of price elasticity. In addition, the income elasticity should be higher for international than for domestic travel according to Gallet & Doucouliagos, so the large distance to Kopsch's estimation should not be too discouraging.

If instead looking at Graham's (2000) estimate for international leisure travel of 1.89 for the period 1984-1998, the results are actually relatively well in line. However, her declining trend suggests that the income elasticity should be lower today, especially since Sweden has among the highest travel propensities in Europe in terms of international trips (Graham, 2006), which would imply a larger market maturity.

Gallet & Doucouliagos predict that estimates from time series data will generally by higher than those from panel data, but the panel data they refer to are not of the household expenditure by income group type used here, and so the prediction is not necessarily valid in this case. Finally, the very high income elasticity of 3.74 found by Chi & Baek (2012) shows that the results found here are not extreme.

Although the data have several limitations, if anything it appears they would tend to underestimate the income elasticity. Also, while the short time span studied applies equally to price and household expenditure, at least the latter have ten observations each year. Therefore, despite data weaknesses, it may well be the case that the income elasticity of Swedes' demand for international air travel is indeed very high.

4 Pricing uninternalised emissions costs

This section ties together the results from sections 2 and 3. First, different ways of pricing the currently uninternalised emissions cost by changing existing or introducing new economic instruments for aviation are discussed. Then, the consequences of such instruments on the demand for air travel are sketched.

4.1 Designing economic instruments for aviation

Standard economic theory (e.g. Perman *et al.*, 2009) suggests that the most cost-effective way to internalise external emissions costs is to price the emissions directly. Since the amount of CO_2 emitted is perfectly related to fuel use, a fuel tax would work just as fine theoretically and be easier to handle practically. Unfortunately, there is no prospect of a global CO_2 tax in the foreseeable future, and countries cannot unilaterally impose taxes on jet fuel.

This prohibition is often blamed on the Chicago Convention on International Civil Aviation from 1944, but as Åkerman (2013) explains, the wording of the convention only prohibits taxation of fuel already on board an aircraft on arrival in another state. However, most bilateral air service agreements that regulate international air traffic, including the EU/US Open skies agreement, prohibit fuel taxation, as does the EU energy taxation directive 2003/96/EC. Therefore, countries taxing aviation – at least a few in Europe – do so by some sort of passenger tax levied on airfares. Most of them are differentiated based on distance, and in the British case a distinction is also made between different fare classes. According to Åkerman, the UK planned to change its per passenger tax to a weight-based per plane tax in order to increase the correlation between tax and emissions, but abandoned the plans because it was feared a weight-based tax would be illegal under international law.

The commitment of the ICAO to work out a proposal for a global market-based measure scheme capable of being implemented by 2020 gives some hope, but given the fierce protests from several ICAO member states to the EU ETS, it would be surprising if the ICAO would implement a radical scheme.

Strengthening the price signal of the EU ETS, e.g. by reducing the number of allowances or introducing some sort of price floor, is another option under debate. The European Commission has put forward a number of suggestions, but the only measure that has been implemented so far is the “back-loading”, or postponement, of a number of allowances. Given the difficulties to pass even that proposal, a radical reform of the ETS seems unlikely at the moment.

If Swedish politicians do not want to wait for international consensus but want to lead by example – hoping this will pave the way for more ambitious international measures – the option left is basically some sort of passenger tax like the ones already in use in some European countries, and possibly raising the VAT rate to the standard rate. Although such a tax gives no incentive for technological abatement measures, it does give an incentive to fly less, both in terms of frequency and distance (as long as it varies with flight distance).

Incentives to fly less may actually prove more important than technological and operational measures. Several authors (e.g. Lee *et al.*, 2010; Karyd, 2013; Larsson *et al.*, 2015) are sceptical to the potential for biofuels in aircraft in the foreseeable future. The special demands on jet fuel make it cheaper, both in economic and energy terms, to use the limited available biomass in other applications. Moreover, in the scenarios of future climate impact from aviation produced by Larsson *et al.* (2015), even the most optimistic scenario only exhibits an annual decrease of emissions per passenger kilometre of 1.7 per cent. Of all their scenarios, only those in which the volume of air travel is frozen at current levels are compatible with the target of stabilising global warming below 2ºC. Thus, there seems to be a case for passenger taxes even if they do not lead to any technological improvements but only reduce demand compared to business as usual. Technological improvements could then be promoted by other instruments like emission standards, best available technology requirements, R&D investments etc.

An interesting question is whether a tax on the non-CO_2 climate impact of aviation, differentiated for time, flight route and other aspects that affect ozone production, contrail formation etc., would meet any legal obstacles. Since these effects are only vaguely correlated to fuel use, a layman might conclude that they are not fuel taxes and should thus be legal. On the other hand, the UK had to stop its planned weight-based per-plane tax because of its close correlation to fuel taxes, so the legal aspects need further consideration. If deemed legal, a tax based on the actual or, for practical reasons, estimated non-CO_2 climate impact would give better incentives for technological and operational measures like changing flight altitude than including the non-CO_2 climate impacts in a passenger tax or through a simple uplift factor for aviation in the ETS (i.e. requiring more than one permit per tonne CO_2 for aviation specifically).

A similar point can be made for air quality. Apparently the existing emission charge is not considered a fuel tax, so expanding the charge to cover all air quality relevant pollutants during take-off and landing should not pose any legal constraints. If including cruise emissions, which show some correlation to fuel use, the legality must first be examined. If it is possible to charge actual emissions in all flight phases, the charge would give airlines an incentive to introduce cleaner technologies, while the low air quality cost compared to the climate cost means that the effect on demand would not be quite as dramatic.

Also, part of the charge could be differentiated according to the number of people in the vicinity of the airport, so that measures for reducing emissions with mainly local impact are prioritised at airports where these pollutants cause the largest damage. The current differentiation based on whether the airport is state-owned or not is not an ideal proxy for population exposure. On the other hand, if the charge is to be applied at private and municipal airports, it might be considered a tax. In that case, its compliance with international law must first be examined.

While the low allowance price in the EU ETS means the scheme is insufficient to internalise the climate cost of aviation, the fact that emissions are capped under this scheme means that complementary price instruments, although theoretically contributing to internalising externalities, might not contribute to any real emission cuts. In a well-functioning emissions trading system, the total amount of emissions is set by the total allowance cap, so increasing emission reductions in one sector or country means that emissions can increase correspondingly somewhere else. In that case, complementary measures for sectors covered by the scheme are meaningless, and the only way forward is the long way to get all member states to agree on lowering the cap.

Given the large current surplus of allowances in the ETS, it seems unlikely that any additional reductions would be completely offset by increased emissions elsewhere in the system. More likely, at least part of the reductions would end up increasing the allowance surplus rather than increasing current emissions. Although increasing the allowance surplus means that more can be emitted later, thus postponing rather than decreasing emissions, the future cap of the scheme is not likely to be independent of the way the surplus evolves. Rather, a larger surplus and a lower allowance price would make measures to tighten the cap more politically feasible. Therefore, in a dynamic perspective, there is a case for complementary measures to decrease or at least halt the increase of aviation emissions.

This argument is further strengthened by the fact that the ETS only covers CO_2, while the total climate impact of aviation includes non-CO_2 effects as well. This means that for every allowance transferred from stationary sources to aviation, the cap effectively expands when the climate impact from one tonne of CO_2 is traded for a climate impact that could be twice as large. Thus, measures that reduce aviation's net purchase of allowances from other industries effectively reduce total climate impact.

4.2 Effects of internalising the emissions costs of aviation

If the demand for air travel is indeed price elastic, this means that the under-internalisation of the emissions costs of aviation is not only of matter of who pays for the environmental damage, but also leads to emissions levels that are too high compared to what would be socially desirable. Correspondingly, correcting for the low degree of internalisation through a tax on aviation or some other price instrument would clearly reduce the demand for air travel.

To quantify the effect on air travel demand from internalising the full emissions costs, one would need the average percentage price increase from internalisation, which requires both information on the uninternalised costs to all possible destinations along with the corresponding prices. Clearly, this is an overwhelming task, and considering the limitations of the estimated price elasticities, the results would in any case be very inexact. Also, some of the cost increase could fall on the owners of the airline rather than on its customers, adding further inexactness to the calculations. Probably a less exact approximation would serve well enough to give some sense of the orders of magnitude.

Unfortunately the SCB price index is not expressed in actual prices comparable to the calculated emissions costs, but the SAS yield is expressed as passenger revenue/passenger kilometre (pkm). This measure, which is SEK 0.94 for 2014, can then be compared to the uninternalised costs/pkm, yielding the percentage price increase if the SAS yield were representative for the airfares of the studied flights and if the price were to increase by exactly the uninternalised cost. Certainly, the yield is not the same for all studied flights, but on the other hand, airlines are not likely to distribute the increased costs evenly. Rather, there would be a greater margin to raise airfares for routes with high yields than for routes with lower yields, signalling tougher competition. More generally, airlines would distribute the price increase unevenly among customers with different price elasticities, e.g. raising business class fares more than economy class fares. This means that although business travellers according to other studies are less price sensitive, the actual airfare increase could in practice be such that business travel decreases as much as leisure travel.

The price increase for the typical flights calculated above spans from 19 per cent to 37 per cent, with the medium haul in the lower and the domestic and long haul in the upper end of the range. While the SAS yield may be adequate enough to reflect *price changes*, as used in the estimation of price elasticity, it is probably less adequate in reflecting *absolute price levels*, as used here to determine the price increase from internalising the uninternalised emissions costs. As a comparison, the yield of Norwegian, the main LCC in the Swedish market with a market share of 14.9 per cent (Transportstyrelsen, 2015), can be used. Norwegian's yield in 2014 was NOK 0.43/km (Norwegian, 2015) or SEK 0.50/km, which would imply a price increase in the range of 36–70 per cent if the uninternalised costs were the same. To be exact, LCC could use other aircraft and fly from airports with no emission charge, but since the air quality cost is low compared to the climate cost, this would not make a great difference. Also, although LCC do not normally offer intercontinental flights, holiday trips to distant destinations are frequently offered as charters, where airfares can be lower than those of full-price scheduled flights.

Although the exact way that airlines would distribute the price increases between its customers cannot be known beforehand, it seems that the proportional rise in airfares would in any case differ between airlines in different price segments. With a LCC share of 35 per cent in the Scandinavian market (SAS, 2015) and a charter share of one third of the outbound leisure air journeys (Tillväxtverket, 2013), the average price increase would be somewhere between the extremes above. For illustrational purposes, let us assume an average increase in international airfares of 50 per cent. If the price elasticity were indeed as high as -2, and not only in the price range used in the estimation, then taxing the full emissions costs of aviation would decrease travel by 56 per cent.

Using elasticities calculated for marginal changes (based on possibly flawed data) to predict the effects of more drastic price changes (based on rough approximations) implies that this back-of-the-envelope calculation should not be interpreted literally. What could be concluded, though, is that a tax on aviation would most likely have a clear effect on the demand for aviation and thus on emissions. The argument that an aviation tax would just make people pay more for their holidays without affecting the environment can thus be refuted.

What could be a risk, however, is that people avoid the tax by flying from airports of neighbouring countries instead. Especially for people in the south of Sweden, close to the large international airport of Copenhagen, this could be an attractive option even at low tax levels. For people with a larger distance to the closest non-taxed airport, tax levels must be higher to compensate for the cost, including time cost, to reach that airport by other transport modes. In terms on emissions, this may still lead to a small reduction in emissions if people change part of their journey from airplanes to trains or tightly packed cars, but it could also lead to people flying more or less the same distance but adding a longer car journey to that. However, unless people start taking very long detours, it seems that although such evasive measures could definitely decrease the environmental effectiveness of taxing aviation, it seems unlikely that it would turn the expected environmental gains into losses.

The result that richer households spend a larger share of their total expenditure on international air travel should refute the argument that such a tax would hit poor people the hardest, and that the rich would fly just as much as before. Actually, Brons *et al.* (2002) find a negative correlation between GDP and price elasticity (expressed as a negative number), implying that travellers with a higher income tend to be more price sensitive than travellers with a lower income.

Elasticities of domestic air travel are not studied in this thesis, but the results from Kopsch (2012a) suggest that an aviation tax could be regressive for domestic air travel. However, an income elasticity derived from a GDP coefficient in a demand estimation arguably says less about the distributional effects than an income elasticity derived from household data, and in any case the absolute price change from internalising the emissions costs of domestic air travel is much lower than for international travel. In addition, international flights make up the majority of total flights, so the overall effect of an aviation tax would be progressive. As for the price elasticity, Kopsch's domestic demand is also elastic at least in the long run, so it seems an aviation tax would have a clear environmental effect for domestic travel as well, although the lower uninternalised cost means that effect would still not be very dramatic.

5 Conclusion

The results of this thesis show that aviation indeed pays a very low fraction of its emissions costs. The climate cost is internalised to 4–5 per cent for typical flights within the EU and 0 per cent for flights to destinations outside of the EU, where the ETS does not apply. For air quality, the degree of internalisation spans from 4 per cent for a typical long-haul flight to 13 per cent for a typical domestic flight. In total then, the degree of internalisation of emissions costs spans from practically zero for a long-haul flight to 6 per cent for a domestic flight.

If the emissions costs currently not paid for by the airlines would be internalised by means of taxation or other price instruments, the effective tax per passenger for the three typical flights studied would be SEK 156 for Arlanda–Gothenburg, SEK 493 for Arlanda–Madrid and SEK 2,914 for Arlanda–Bangkok. Such a price increase would have a dramatic effect on the demand for long-distance flights. The price elasticity of Swedes' demand for international leisure air travel was estimated to -1.88 or -2.53 depending on the price measure used. Although these surprisingly high elasticities should be interpreted very cautiously due to data limitations, the results support other findings that demand for leisure travel is price elastic, if not quite as elastic as was found here. Also, the high income elasticity estimated here – 2.03 or 2.04 – highlights that increasing incomes will in itself increase the demand for international air travel. Therefore, price instruments at symbolic levels would not be enough to compensate for the demand increase from rising incomes.

Although the main challenge when tackling the emissions of aviation is not lack of scientific knowledge but rather of political courage, there are certainly areas for future research. Since the emissions cost of aviation depends heavily on the valuation of climate impacts, narrowing the range of cost estimations would give a clearer picture of the total emissions cost. On the other hand, the problem is not primarily caused by a lack of economic valuation studies, but rather by the inherent uncertainty of the consequences of climate change.

Air quality, on the other hand, is an area where more economic valuation studies would certainly be useful. Although representing a lower cost than climate change, the non-uniform dispersion properties of air quality pollutants means that valuation studies must account for the dispersion patterns of the pollutants and the exposed population at different sources. While damage costs are expressed as average values, actual damage costs will vary between, say, Bromma airport with a large population in its vicinity and other airports in less populated areas. If these differences were better understood, the emission charge could be geographically differentiated to reflect the differences in population exposure. This is perhaps of less interest for international flights, where the local effects make up a very small share of the air quality costs, but could be more interesting for domestic flights, which also concern a wider range of airports.

When evaluating the consequences of price instruments that internalise the emissions costs not currently paid for by the airlines, more robust estimations of the price and income elasticities of the demand for air travel are needed. This would require better data, such as a more reliable price index, ideally expressed in units that are comparable to the uninternalised costs, and a longer time series of household expenditure data, where air travel would have its own category. If instead estimating elasticities from price data and some aggregate income measure, so that business as well as leisure travel can be studied, a measure of the quantity of air travel that reflects the average distance and not only the number of journeys would be helpful.

For the time being, though, the exact effects of completely internalising the emissions costs of aviation seem to be of more academic than practical interest. Unless political preferences change rapidly, it seems unlikely that any Swedish government would dare to propose an aviation tax of SEK 3,000 for a one-way trip to Thailand in the immediate future. Given the fierce debates spurred by proposed taxes at levels one tenth of this, it seems likely that if a tax on aviation would be introduced in Sweden, its initial level would not be very close to the level suggested by the results of this thesis for longer trips. Thus, economists would still have time to improve the accuracy of the above estimations while trying to increase public acceptance of internalising the full external costs of aviation, in Sweden as well as internationally, and while cooperating with legal expertise to find the best possible designs of these price instruments under current legal constraints.

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7 Appendix

7.1 Appendix A

Air pollution from typical flights

Inflation 2010-2015	1.0465
Exchange rate kr/€	10
Allowance price €/tonne	7

Short haul, Arlanda–Gothenburg

Aircraft	Boeing 737-600
Engine	CFM56-7B20/3
Number of seats	123
Load factor	65%
Great circle distance km	394
Correction factor km	50
Flight distance km	444
EMEP/EEA distance km	463
Emission charge	275
Allowance cost	534

	NO_X	SO_X	NMVOC	$PM_{2.5}$	Σ pollutants	CO_2	CO_2 low	CO_2 high
LTO emissions kg	7.65896	0.605737	0.91	0.04914		2,271.516	2,271.516	2,271.516
LTO cost €/kg	5.247	5.389	0.974	14.578		0.109	0.058	0.203
LTO cost €	40.2	3.3	0.9	0.7	45.1	247.6	131.7	461.1
Cruise emissions kg	27.97276	1.42705		0.185387		5,351.431	5,351.431	5,351.431
Cruise cost €/kg	5.247	5.389	0	0		0.1635	0.087	0.3045
Cruise cost €	146.8	7.7	0	0	154.5	875.0	465.6	1,629.5
Total cost € 2010	187.0	11.0	0.9	0.7	199.5			
Tot cost € 2015	195.7	11.5	0.9	0.7	208.8	1,122.6	597.3	2,090.6
Total cost SEK 2015	1,957	115	9	7	2,088	11,226	5,973	20,906
Total cost/passenger SEK	20	1	0	0	26	140	75	261
Total cost/pkm SEK	0.04	0.00	0.00	0.00	0.06	0.30	0.16	0.56
Internalisation					13%	5%	9%	3%
Uninternalised cost/passenger					23	134	68	255
Tot uninternalised cost/passenger						156	91	277
Uninternalised cost/pkm						0.34	0.20	0.60

Medium haul, Arlanda–Madrid

Aircraft	Airbus A320
Engine	V2527-A5
Number of seats	168
Load factor	70%
Great circle distance km	2,597
Correction factor km	100
Flight distance km	2,697
EMEP/EEA distance km	2,778
Emission charge	499
Allowance cost	1,956

	NO_X	SO_X	NMVOC	$PM_{2.5}$	Σ pollutants	CO_2	CO_2 low	CO_2 high
LTO emissions kg	10.76448	0.733532	0.51	0.120588		2,750.744	2,751.744	2,752.744
LTO cost €/kg	5.247	5.389	0.974	14.578		0.109	0.058	0.203
LTO cost €	56.5	4.0	0.5	1.8	62.7	299.8	159.6	558.8
Cruise emissions kg	110.2454	6.715665		1.994820		25,183.70	25,184.70	25,185.70
Cruise cost €/kg	5.247	5.389	0	0		0.200	0.106	0.372
Cruise cost €	578.5	36.2	0	0	614.6	5,032.6	2,678.0	9,373.4
Total cost € 2010	634.9	40.1	0.5	1.8	677.3			
Tot cost € 2015	664.5	42.0	0.5	1.8	708.8	5,332.4	2,837.6	9,932.2
Total cost SEK 2015	6,645	420	5	18	7,088	53,324	28,376	99,322
Total cost/passenger SEK	49	3	0	0	60	453	241	845
Total cost/pkm SEK	0.02	0.00	0.00	0.00	0.02	0.16	0.09	0.30
Internalisation					7%	4%	7%	2%
Uninternalised cost/passenger					56	437	225	828
Tot uninternalised cost/passenger						493	281	884
Uninternalised cost/pkm						0.18	0.10	0.32

Long haul, Arlanda–Bangkok

Aircraft	Boeing 777-300
Engine	GE90-115B
Number of seats	299
Load factor	80%
Great circle distance km	8,290
Correction factor km	125
Flight distance km	8,415
EMEP/EEA distance km	8,334
Emission charge	3,360

	NO_X	SO_X	NMVOC	$PM_{2.5}$	Σ pollutants	CO_2	CO_2 low	CO_2 high
LTO emissions kg	63.25719	2.02346	0.59	0.145644		7,587.972	7,588.972	7,589.972
LTO cost €/kg	5.247	5.389	0.974	14.578		0.109	0.058	0.203
LTO cost €	331.9	10.9	0.6	2.1	345.5	827.1	440.2	1,540.8
Cruise emissions kg	1,540.68	58.76836		7.372216		22,0380.8	22,0381.8	22,0382.8
Cruise cost €/kg	5.247	5.389	0	0		0.273	0.145	0.508
Cruise cost €	8,084.0	316.7	0	0	8,400.7	60,055.7	31,956.4	111,847.8
Total cost € 2010	8,415.9	327.6	0.6	2.1	8,746.2			
Tot cost € 2015	8,807.2	342.8	0.6	2.2	9,152.9	60,882.8	32,396.5	113,388.6
Total cost SEK 2015	88,072	3,428	6	22	91,529	608,828	323,965	1,133,886
Total cost/passenger SEK	368	14	0	0	383	2,545	1,354	4,740
Total cost/pkm SEK	0.04	0.00	0.00	0.00	0.05	0.31	0.16	0.57
Internalisation					4%	0%	0%	0%
Uninternalised cost/passenger					369	2,545	1,354	4,740
Tot uninternalised cost/passenger						2,914	1,723	5,109
Uninternalised cost/pkm						0.35	0.21	0.61

7.2 Appendix B

Household expenditure data from SCB, with consumer price index as comparison, also from SCB. “Travel expenditure” refers to expenditure on “travel abroad, part paid in Sweden”. Deciles are grouped according to household income per consumption unit.

Income decile	Year	Household income	Total expenditure	Travel expenditure	Consumption units	Consumer price index
1	2003	112,930	160,560	2,180	1.62	278.10
1	2004	113,510	177,050	4,040	1.61	279.20
1	2005	97,470	199,760	3,310	1.45	280.40
1	2006	99,790	167,080	2,540	1.44	284.22
1	2007	106,690	180,760	2,860	1.51	290.51
1	2008	114,430	178,210	2,730	1.54	300.61
1	2012	102,950	217,450	4,360	1.50	314.20
2	2003	162,570	168,850	1,430	1.62	278.10
2	2004	170,450	172,450	2,100	1.65	279.20
2	2005	163,370	179,770	2,770	1.53	280.40
2	2006	164,530	179,050	1,750	1.55	284.22
2	2007	164,800	176,550	2,620	1.46	290.51
2	2008	172,800	177,270	1,910	1.43	300.61
2	2012	181,310	194,810	3,970	1.45	314.20
3	2003	193,330	194,900	1,210	1.65	278.10
3	2004	196,380	193,470	2,680	1.65	279.20
3	2005	196,960	201,920	2,380	1.57	280.40
3	2006	190,480	202,100	2,990	1.52	284.22
3	2007	202,170	197,530	2,950	1.50	290.51
3	2008	216,750	215,810	3,240	1.54	300.61
3	2012	214,090	219,350	4,440	1.42	314.20
4	2003	217,100	210,600	2,780	1.64	278.10
4	2004	214,650	217,450	3,080	1.61	279.20
4	2005	230,440	224,760	3,050	1.63	280.40
4	2006	233,890	223,400	3,010	1.64	284.22
4	2007	250,150	226,740	4,670	1.62	290.51
4	2008	273,230	266,500	5,250	1.69	300.61
4	2012	274,550	242,920	4,760	1.57	314.20
5	2003	252,470	239,430	3,600	1.72	278.10
5	2004	257,490	240,950	3,340	1.74	279.20
5	2005	266,490	251,880	4,280	1.69	280.40
5	2006	272,720	280,630	5,880	1.72	284.22
5	2007	303,700	268,460	5,560	1.73	290.51
5	2008	299,090	272,130	6,390	1.64	300.61
5	2012	333,570	287,450	4,260	1.65	314.20
6	2003	260,740	247,770	3,800	1.61	278.10
6	2004	265,960	235,930	4,410	1.62	279.20
6	2005	288,270	259,980	4,900	1.63	280.40

6	2006	283,390	268,150	4,550	1.60	284.22
6	2007	322,570	265,160	6,560	1.64	290.51
6	2008	333,160	296,540	5,550	1.63	300.61
6	2012	384,340	327,680	6,530	1.68	314.20
7	2003	296,420	270,520	4,300	1.65	278.10
7	2004	302,620	271,790	4,240	1.66	279.20
7	2005	310,850	286,500	6,010	1.58	280.40
7	2006	324,900	285,900	6,050	1.66	284.22
7	2007	352,700	292,860	6,310	1.59	290.51
7	2008	391,410	316,910	8,230	1.70	300.61
7	2012	417,370	339,710	9,230	1.62	314.20
8	2003	307,510	266,270	4,490	1.52	278.10
8	2004	339,140	283,120	6,480	1.65	279.20
8	2005	359,880	305,560	6,470	1.62	280.40
8	2006	349,290	312,260	7,410	1.60	284.22
8	2007	401,620	316,870	8,110	1.58	290.51
8	2008	396,200	333,820	8,980	1.51	300.61
8	2012	482,080	372,990	13,220	1.64	314.20
9	2003	361,560	316,520	6,430	1.57	278.10
9	2004	363,670	319,010	7,790	1.53	279.20
9	2005	399,140	333,640	8,870	1.53	280.40
9	2006	383,760	308,580	7,390	1.52	284.22
9	2007	448,170	343,790	9,610	1.50	290.51
9	2008	480,390	364,430	10,270	1.56	300.61
9	2012	548,610	397,510	13,780	1.61	314.20
10	2003	523,260	376,890	9,480	1.57	278.10
10	2004	550,630	349,840	8,180	1.49	279.20
10	2005	562,180	403,310	13,020	1.50	280.40
10	2006	617,760	410,950	13,640	1.55	284.22
10	2007	782,320	385,600	12,190	1.50	290.51
10	2008	816,240	497,960	18,690	1.51	300.61
10	2012	808,980	481,640	16,680	1.54	314.20

7.3 Appendix C

SCB price index in real terms, SAS yield in nominal terms and SCB consumer price index.

Year	SCB price	SAS yield	Consumer price index
2003	107.43	1.27	278.10
2004	96.34	1.11	279.20
2005	92.87	1.10	280.40
2006	94.89	1.12	284.22
2007	98.78	1.25	290.51
2008	98.30	1.27	300.61
2012	95.14	1.09	314.20