Including International Aviation in the EU Emissions Trading Scheme

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Licentiate Thesis

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Stockholm, May 2011

Fredrik Kopsch

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An Overview

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1. Introduction

In an attempt to control emissions of carbon dioxides (CO_2) from international aviation, the European Commission has decided to link the international aviation sub-market to the already existing emissions trading scheme within the European Union, the EU ETS. Starting on January 1st 2012, agents in the international aviation sub-market will be liable to keep track of their emissions of CO_2 on routes to and from the EU. The first year will serve as a test period where the total amount of allocated permits will correspond to 97% of the average emitted quantities between 2004 and 2006. This amount will be reduced to 95% the following year, 2013, which is also the start of phase III of the EU ETS.

International aviation differs from other emission sources currently under the EU ETS cap. One important difference is that emissions from international aviation are not subject to the Kyoto Protocol. Therefore, linking emissions from international aviation to the EU ETS demands answers to a number of questions, not only regarding the response from the air travel market, but also with respect to the performance of the trading scheme, in particular, some certain policy design options.

The aim of this thesis is to shed some light over what effects can be expected from linking emissions from international aviation to the EU ETS, both on the market for air travel and for the EU ETS itself. Including international aviation in the EU ETS introduces an additional cost to air craft operators in form of emission permits. Depending on the response from the supply side, this additional cost will pass through as an increase in fares. Wit et al. (2005) analyses three options to include international aviation in the EU ETS. The option closest to actual policy design would render an increase in fares in the range 0.4 to 1.4 euro for a short haul flight, a Swedish domestic flight for instance. However, Wit et al. (2005) assume that opportunity costs for emissions permits will not be passed on to passengers in the slightest when permits are allocated for free. There is reason to disagree with such an assumption. For example, Wråke et al. (2010) performed an experimental analysis showing that agents do indeed take the opportunity cost of permits into their production decision. Taking into account that opportunity costs will be passed on in the fullest, the increase in fares would be sevenfold according to Wit et al. (2005), suggesting an increase in fares in the range 2.8 to 9.8 euro for a short haul flight. Expecting an increase in fares, a first step to analyse the effects of permit trade for the aviation sector is to study its demand side effects.

Linking several sub-markets for permit trade can be done in different ways. Trade can, for example, be allowed in only one direction. Previous research suggests that damage from emissions stemming from aviation is higher than from other, stationary, land based sources since it is emitted directly into the atmosphere (IPCC, 1999; Lee and Sausen, 2005; Wit et al. 2005). Therefore, it would possibly be beneficial to reduce emissions from aviation more than from other sources. In addition, emissions from international aviation are not subject to the cap under the Kyoto Protocol, and hence, adding emission permits to the EU ETS cap would potentially jeopardize reaching the Kyoto targets. At the same time, a tight cap on international aviation would prevent growth in the market, potentially resulting in very high compliance costs for actors on this market. The solution proposed by the European Commission is to introduce a trade barrier, referred to as the gateway, between the trading sub-markets. This gateway will allow international aviation to cover its emissions with permits issued to the stationary sources, but not *vice versa*. Thus, eliminating the risk of jeopardizing the Kyoto targets will potentially come at a cost of increasing damage from emissions.

Depending on what restrictions are placed on trade for the international aviation sub-market, compliance costs may differ. The current policy design actively places a cap on the permit price that agents on the international aviation sub-market have to face. This price cap is dependent on the rest of the EU ETS as it is equal to the permit price that the stationary sources have to face. Without the possibility for agents on the international aviation sub-market to cover their emissions with permits issued to the stationary sources the price cap, or safety valve, would probably be higher, thus possibly resulting in higher fares for passengers.

2. Data availability and Methodology

The issue of air travel passengers response to changes in fares is highly empirical. Detailed descriptive data is very scarce when it comes to observing individual behaviour, especially over long periods of time. When studying the behaviour of air travel passengers the obvious first choice would be individual specific data on exact routes, so called Origin and Destination (O&D) data, transfers, fare price and other individual characteristics, such as income. This data also exists, at least partially, and would be readily available if air craft operators would make their records official. Data describing individual specific behaviour is, however, classified in accordance with Swedish law.

When focusing the analysis on policy implications of linking two trading sub-markets that lies in the future the obvious approach is a theoretical one. The analysis turns to economic theory, and in particular focuses on the strand of literature on economic regulation stemming from Weitzman (1974, 1978). A simplified setting with partial uncertainty is assumed to study the optimal levels of control variables available to a regulator or government, given certain trade restrictions and heterogeneous damage from emissions.

3. Results

There are two main findings of the analysis, one empirical and one theoretical. Turning to the consumer side of the market, what is interesting to know is how responsive air travel passengers are to changes in fares, as permit trade inevitably will lead to higher costs to some actor in the market. It is not unlikely that this will fall on the passengers. For the Swedish domestic market, the aggregate response is less than unity in the short-run. In the long-run, a larger portion of passengers will find substitutes in other methods of transportation. Any increase in fares will also hit the leisure travel sub-market harder than the more price-insensitive business travellers.

Furthermore, it is found that the proposed gateway may come with a set of problems. This is true when damage from emissions stemming from aviation is higher than for their land based counterparts. Essentially this means that, relatively speaking, high damage emissions are allowed to replace low damage emissions at no additional cost. At the same time, introducing a trade restriction, as the gateway, between the sub-markets when linking international aviation to the stationary sources within the EU ETS may result in a loss in cost-effectiveness for the scheme.

4. Concluding Remarks

When emissions from international aviation will be linked to the EU ETS there are a number of aspects that have to be taken into consideration. This thesis only covers a fraction of these. It should be stressed that the proposed gateway between the international aviation sub-market and the stationary sources is in need of a complementary solution. Furthermore, the gateway should be thought over as it, on the one hand potentially will result in a loss in cost-effectiveness for the EU ETS and on the other might lead to higher damage from emissions than other possible solutions such as an exchange rate or complete separation of the sub-markets. Both these option could potentially result in higher compliance costs for aviation, additional costs that, depending on the response from the supply side of the market, may show as increasing fares for passengers.

While this thesis answers some questions of what can be expected when linking the international aviation sector to the stationary sources already trading within the EU ETS, it also provokes new questions that are in need of attention. In order to fully grasp the impact off permit trade on the aviation sector the supply side has to be analysed. While it has been showed, by for example Wråke et al. (2010), that opportunity costs are indeed considered in the production decision, it is crucial, for a complete understanding off the impact on consumers, to know how large part of permit costs will be passed on.

Furthermore, a formal analysis of policy measures to use when linking different sub-markets is necessary. It is possible, perhaps even in a foreseeable future, that governments will want to expand emissions trading schemes by linking already existing ones to each other. As has been showed in this thesis, when emissions are heterogeneous with respect to damage, some measure should be taken in order not to replace low damage emissions with high damage ones.

Paper I: Aviation and the EU ETS - Lessons learned from previous emissions trading schemes

The aim of this paper is to analyze the strengths and weaknesses of five previous and ongoing emissions trading schemes, the EU Emissions Trading Scheme (EU ETS), the US Acid Rain Program, the UK Emissions Trading Scheme (UK ETS), the Chicago Climate Exchange and the Regional Greenhouse Gas Initiative. From these, lessons can be learned regarding how to avoid potential problems that have showed up in these schemes, but also how to draw advantage of their strengths, when linking the international aviation sector to the EU ETS.

The approach is to study five elements of system design. These elements are

- *Method of Allocation* – How should emission permits initially be allocated?
- *Liability* – Who should be held liable for surrendering emission permits?
- *Inter-temporal trade* – Should banking and/or borrowing of permits be allowed?
- *Hot-spots* – Is there a threat of local hot-spots where emissions gather?
- *Trade barriers* – Should international aviation be fully incorporated in trade or not?

Initially these five elements are discussed from a general point of view. In the following section of the paper, all trading schemes are discussed, keeping the five elements of system design in mind. These five elements have not been present in all trading schemes and some have been more noticeable than others. The review concludes that method of allocation and the trading barrier (the gateway) between international aviation and the stationary sources within the EU ETS need special attention.

Paper II: A demand model for domestic air travel in Sweden

The aim of this paper is to analyse the effects on demand for domestic air travel in Sweden that a potential increase in fares would have. In order to do this, necessary data on passenger quantities, fares and ticket prices for train are gathered from different statistical sources in Sweden. This results in a monthly time series reaching from January 1980 to December 2007. The time series is completed with, what is believed to be, important economical variables such as GDP per capita, population size and price of close substitutes to air travel.

The econometric analysis is based on Baffes (1997) in regards to handling non-stationary independent variables. The estimated models pass the tests proposed by Baffes (1997) and it is concluded that non-stationarity is not a big issue for the analysis. This is also confirmed by similar estimates from a more conventional first difference approach to non-stationarity.

One issue to overcome is the lack of data describing fares for different passenger categories. It is acknowledged that there is no perfect way of getting around this problem. However, one rough estimation method, best viewed as a robustness test of the models, is proposed. Since Swedes traditionally have enjoyed their vacation during summer, and in particular during the month of July, this is used to proxy leisure travellers.

The results of the analysis suggests that, on the aggregate, the demand for domestic air travel in Sweden is fairly elastic in the short-run and as expected more sensitive to changes in fares in the long-run. The proposed robustness test of the models indicate that leisure travellers are indeed, as expected, more sensitive to changes in fares than their business counterparts. Finally, the cross-price elasticity regarding travel by train is found to be positive.

Paper III: Unilateral Linking of International Aviation and Stationary Sources within the EU ETS

This paper analyses the proposed barrier to trade, often referred to as the gateway, between the international aviation sub-market and the stationary sources within the EU ETS. It is also acknowledged that damage from one unit of emissions may differ between the trading sub-markets.

A simplified theoretical model is developed to analyse the problem. The model considers *three* scenarios regarding the damage relations between emissions from different sub-markets.

- *Equal damage*, in which it is shown that the gateway potentially results in a loss in cost-effectiveness.
- *Larger damage from emissions in the aviation sub-market*, in which it is shown that the proposed gateway, without a complementary solution, may result in high damage emissions replacing low damage ones.
- *Larger damage from emissions in the sub-market for stationary sources*, in which it is argued that the gateway would function in reducing damage from emissions but still lead to a potential loss in cost-effectiveness.

The paper concludes that the gateway, as it is proposed, might benefit from a complementary solution, such as an exchange rate for emissions permits. It is however acknowledged that further analysis is needed regarding what policy instruments can be used for similar scenarios in the future.

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Paper I

Aviation and the EU Emissions Trading Scheme

Lessons learned from previous emissions trading schemes

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ABSTRACT

Designing an emissions trading scheme requires in-depth knowledge regarding several aspects. This paper attempts to clarify some important design points of the forthcoming emissions trading scheme for aviation under the EU ETS. Five general key points of system design are acknowledged and comparisons are made to previous and current emission trading schemes. Above all, it is argued that initial allocations of emission permits and the trade barrier between the aviation sector and EU ETS need to be carefully examined.

JEL classifications: *L51, P48, Q52, Q53, Q58*

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1. Introduction

In a constantly expanding global economy, aviation has a key role. There are no other methods of transportation that have the possibility to deliver passengers and goods across regions at the same speed and efficiency. According to Air Transport Action Group, ATAG, (2008) aviation contributes with 1.1 trillion US dollars to the global economy, corresponding to 2.3% of the world total GDP. The air transport sector also generates, directly and indirectly, 32 millions job opportunities globally. However, a large uncontrolled growth rate in the aviation sector also implies a growing impact on the environment.

In accordance to the goals set up by the Kyoto Protocol, carbon dioxide (CO_2) emissions from the members of the European Union decreased by roughly 5% between 1990 and 2003. Emissions from the international aviation sector are however not restricted under the Kyoto Protocol. During the same time period the total contribution of CO_2 emissions from aviation increased by an astonishing 73% (Wit et al, 2005). According to the Intergovernmental Panel on Climate Control (IPCC, 2007) the aviation sector was responsible for 2% of global CO_2 emissions in 2007.

Passenger quantities in the aviation sector grew at a rate of roughly 5% per year during the period 2000 to 2007 according to Lee et al. (2009). Depending on improvements in fuel efficiency and flight frequencies, this might potentially lead to an increase in emissions of greenhouse gases in the range of 3-4% annually given that no effort is put into limiting and reducing the global environmental impact from the sector (IPCC, 2007). Thus, it is crucial to implement some control on emissions coming from the air transport sector. Based on the notion, given by Coase (1960), that ownership regards user rights rather than a physical relationship, theories for tradable permits for emissions emerged as one economical instrument that leads to the sought after efficient market solutions (see Dales, 1968). Trading of emissions permits has been used historically to rectify environmental external costs with varying success.

Starting on January 1st 2012 all emissions from civil international aviation, arriving and departing within the European Union, will be monitored and controlled through issuance of emission permits.

Linking the international aviation sector to the EU ETS arises a few questions regarding the design and the execution of the scheme. There are a few key points that need to be carefully evaluated and discussed. In order to answer these questions and to be able to draw some conclusions, strengths and weaknesses of previous emissions trading schemes will be examined. In section 2, five key points of system design will be discussed more in-depth. Keeping these key points in mind, a brief discussion of the effects and results from five previous and current emissions trading schemes will be given in section 3. Following, in section 4, some concluding remarks on what can be learned from previous systems and what aspects that might be important to consider when designing the system for civil international aviation will be given.

This paper will address the following:

- *Method of allocation* – How should permits be allocated in order to achieve the best possible result from the system? Is there one method of allocating allowances that would be strictly preferred to any other?
- *Liability* – Is it of importance who is held liable for emissions from aviation? What options are available and suitable for the aviation sector?

- *Trade barriers* – Aviation can be either included or excluded (i. e. allowed or not allowed to trade with other sectors) from the EU ETS.
- *Inter-temporal trading* – Both banking and borrowing are considered to be important parameters in the design of an efficient emissions trading scheme. Could trading over time be a problem for the system?
- *Hot-spots* – In accordance with current system design for the aviation sector, is there a potential threat of hot-spots where emissions from ground level sources cannot be counted the same as those from aviation?

2. Key design points

Allocation

Emission permits can either be distributed for free or by charging emitters a price for each allowance that they demand, the latter is normally done by auctioning. There are three main methods of distribution that can be considered when linking the international aviation sector to the EU ETS.

- *Grandfathering* implies that permits are distributed free of charge based on historical emissions. This method of allocation has dominated the previous trading periods of the EU ETS and has also been suggested for the international aviation sector. It is also the most common choice of allocation mechanism from a policy perspective as it is easier to gain political acceptance from the trading sectors (Anderson, 2001). When using grandfathering as the method of allocation one has to be careful in calculating the baselines of emissions. It is possible that historical emissions were unusually high (or low) due to some exogenous force in the economy. For example, the 9/11 terrorist attacks on the United States in 2001 led to a huge decrease in demand for air transport reaching into 2004 (Ito and Lee, 2004; Morell, 2007). If baselines would be calculated using these years, allocation would be a lot lower than actual emissions, thus generating very high market prices. Using baselines of historical emissions can also create competitive advantages for firms with relatively high historical emissions while generating high cost to, for example, low price carriers who have shown a large growth during the past decennium (Frontier Economics[1], 2006; Morell, 2007). It is also possible that grandfathering based on historical emissions lead to perverse incentives for firms to emit more today as they expect to receive more permits in the future by doing so (Hepburn et al, 2006).

- *Benchmarking* is another method of free allocation. It is also, like Grandfathering, based on some baseline of historical emissions, however, it adds a sector specific measure. Morell (2007) argues that one such measure could be passenger revenue tonne kilometers per tonne CO_2 for the aviation sector. If this measure is used, aircraft operators with high efficiency levels, i. e. those ones operating at high capacity without unused space on board the aircraft, will benefit. By using benchmarking, short haul flights would be penalized (due to generally higher emissions per passenger) possibly leading to higher demand for other types of transportation. Morell (2007) acknowledges that this might lead to an unfair allocation for air lines carrying a high number of premium passengers contra air lines with higher capacity. Morell (2007) further argues that a better measure for the aviation sector would be one that considers emissions from both the landing and take-off cycle as well as the whole flight. In this way, air lines with lower capacity would not be penalized.

- *Auctioning* allowances has great support in the scientific literature. Hepburn et al (2006) promote auctioning particularly for the EU ETS stating that it would lead to less competitive advantages for some firms and that it would increase the over all efficiency of the scheme. Auctioning would also eliminate the perverse incentives such as delaying fleet renewal to keep emissions at a high level for future calculations of historical levels. There is a

[1] Frontier Economics prepared the report on behalf of The European Low Fares Airline Association (ELFAA), it is the first industry response to the implementation of aviation in the EU ETS.

strong presence of asymmetric information when calculating base-line emission levels, aviation operators are more likely to accurately estimate their historical levels of emissions than their counterpart. One question that arises with auctioning is how to use the revenue that the auction generates (Andersen, 2001; Morell, 2007). In Morell's (2007) opinion the revenues from an auction should go to CO_2 reducing activities, they could however be used in any way deemed suitable by the controllers.

Currently, all participants eligible to receiving emission permits will have to apply for them, a large part will be issued free of charge by grandfathering based on average historical emission levels between 2004 and 2006 while 15% will be available for auctioning. The general idea with the EU ETS is to increase the number of permits put up for auctioning in each period. The revenues from auctioning can be used quite freely by each member state but it is suggested they should be used in emissions reducing activities such as research for more fuel efficient engines. For the first year of trading, i.e. 1st of January to 31st of December 2012, the total amount of allocated emission permits will sum up to 97% of the historical emissions to decrease to 95% in the following trading period, phase III of the EU ETS.

Liability

Another interesting question regarding emissions trading for the aviation sector is who will be held liable for emissions and surrendering permits? As of now, the proposal of implementing aviation into the EU ETS states that aircraft operators should be held liable for surrendering permits corresponding to their emissions, this is considered a *downstream* approach where the source of emissions is held liable. Bohm (1999) argues that such a *downstream* approach might lead to some potential problems such as (i) high transaction costs and (ii) exclusion of smaller actors for the trading scheme. If we consider these two criterions, to keep transaction costs as low as possible and to include as many emission sources as possible, the most efficient choice should be obtained. It might be more efficient to place liability on some agent prior to the emitting source, a so called *upstream* approach. Another important criteria is that the chosen source directly or indirectly should be able to influence fuel consumption and hence have incentives to lower them (Andersen, 2001; Frontier Economics, 2006). This gives a number of options to consider.

- *Fuel suppliers* would simply include the permit price in the fuel price, making the aircraft operators inevitably bear the cost of emissions. Even though fuel suppliers do not have any influence on actual fuel consumption an increase in fuel prices would generate a reaction from the air craft operators, thus lowering emissions. Andersen (2001) argues that this option could potentially make it less costly for aircraft operators as there would be no need to enter the market for permits. Thus, by making fuel suppliers the liable source all firms, large and small, would be implemented into the system. However, in a non-intra-EU trading system it would be easy for non-EU based aircraft operators to avoid paying for emissions simply by refuelling outside of the EU (Frontier Economics, 2006).
- *Aircraft operators* have the largest direct influence over fuel efficiency and fuel consumption. Flight frequency can easily be adjusted to comply with any emission target. Air craft operators are also in direct control of fleet renewal to increase fuel efficiency. The current proposition that air craft operators should be held accountable for retiring permits limits liability to firm size and thus, does not account for all emissions[2].
- *Airports and Air Traffic Controllers (ATC)* do have some influence on fuel consumption during taxi, take-off and landing. It would be possible to place liability on them instead of aircraft operators. In some cases airports auction their slots to airlines, costs for

[2] See directive 2008/101/EC for more detail on non-liable firms.

emissions permits could simply be added on to the price of these slots and in the end air craft operators and, possibly, its consumers would bear the cost.

Inter-temporal trade

Inter-temporal trade in form of both banking and borrowing is regarded as one of the key design points of emissions trading that help achieve efficient results. Banking allow agents to store permits issued today for future use in order to achieve lowest possible present value of the cost of emissions reduction (Kling and Rubin, 1997; Tietenberg, 1999). Allowing borrowing of permits from future trading periods is a more risky venture. If firms are allowed to borrow permits from future allocations and then leave the scheme these permits will not be accounted for. Rubin (1995) argues that the lowest possible cost of abatement is achieved when the system allows for full inter-temporal flexibility.

Hot spots

The effect on global warming from CO_2 emissions is independent on what altitude they are emitted at, meaning that one tonne of CO_2 from aviation is equal to one tonne of CO_2 from any other emission source. However, other greenhouse gases that are CO_2 related, such as O_3 and NO_x, do not share the same characteristics as CO_2. These gases can have either greater or smaller effect on global warming depending on what altitudes they are emitted at. CO_2 only accounts for 37% of the climate impact from aviation (Lee and Sausen, 2000). Therefore, it is possible that the accumulated effect on global warming and climate change will be larger from aviation when only CO_2 emissions are regulated given that the sector is allowed to purchase permits from other industries, as suggested under the proposed system design. It has been suggested that permits should be subject to some exchange rate when used for aviation (Lee and Sausen, 2000; Sausen et al, 2005; Wit et al, 2005).

Trade barriers

Implementing aviation into the already existing EU ETS can be done in several ways. One could choose to just account for aviation as any other polluter in the market, this is called an *open trading scheme*. However, research is divided on whether or not CO_2 and its associated emissions should be counted the same for aviation and land based emission sources (IPCC, 1999; Lee and Sausen, 2000; Wit et al, 2005). IPPC (1999) suggests that the radiative forcing (RF[3]) from aviation's greenhouse gases compared to that of CO_2 alone has a factor of 2.7[4]. If emissions from aviation are counted differently, aviation could be completely separated from the rest of the EU ETS, a so called *closed trading scheme*. This would mean that a unique trading scheme would be formed for aviation alone. One could argue that a cap on emissions for the aviation sector might hold back economical growth in the sector. However, this limitation would force liable sources to achieve higher fuel efficiency and hence derive more environmental friendly solutions (Cames and Deuber, 2004). A third option, *semi-open trading scheme*, has been suggested by the European Commission since aviation is not included in the Kyoto Protocol. It has been deemed necessary to separate aviation from other trading as to not create any disruption in the abatement of emissions in all other sectors. Therefore, permits will be earmarked to either aviation or other industries in the rest of the EU ETS, with the possibility for participants in the scheme for aviation to use permits issued to all other sectors but not vice versa, hence keeping the same cap for everyone else without risking any excess permits to spill over from the aviation sector. This will effectively introduce a trading barrier, called the gateway, where a net flow of permits is only allowed one way, to the international aviation sector from the stationary sources.

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[3] Radiative Forcing (RF) is used to measure the impact of greenhouse gases on global temperature. For further discussion about RF, see IPPC, 1999.

[4] Measured with the use of Radiative Forcing Index (RFI), simply the total RF from a source divided by the RF of its CO_2 emissions alone. As a comparison, the RFI for all human activities is roughly 1 and the RFI for greenhouse gases alone is 1.5.

3. Previous Emissions Trading Schemes

As previously stated, this section will discuss, and hopefully clarify, some weaknesses and strengths of historical and current emissions trading schemes relating to the five key points discussed in the previous section.

EU Emissions Trading Scheme (EU ETS).

In an attempt to reduce the levels of emitted greenhouse gases in accordance with the goals expressed in the Kyoto Protocol, the European Union initiated a cap-and-trade program intended to cover roughly 45 percent of total CO_2 emissions within the area, thus making the EU ETS the largest emissions trading scheme to date. Phase I of the EU ETS stretched from January 1st 2005 to the end of 2007. In this initial phase of the scheme the focus of emissions reduction was put solely on CO_2 although leaving the door open for implementation of other greenhouse gases in phase II.

Each member country has their own targets for emission reductions and they are allowed to distribute permits to energy intense sectors within the country. Each member country is also responsible for calculating baselines of emissions. In phase I, 95 percent of permits were distributed free of charge with a reserve of 5 percent left for auctioning if the member countries choose to do so, the share of permits intended for auctioning will increase for each compliance period and was 10 percent in phase II. Note that these levels of auctioning refer to how much a member country is allowed to put up for auction, this is an upper ceiling rather than a fixed level. In phase I, only 4 member countries chose to put up any permits for auctioning (Betz and Sato, 2006). Phase III of the EU ETS will start in January 2013 and end in 2020, the current goal is that emissions will be 20% lower than 1990 levels at the end of phase III.

Problems and solutions

Permit prices were highly volatile at the beginning of phase I. By 2006 when data was made available on actual verified emissions and this showed that they were lower than the distributed amount of permits, prices plummeted. According to Rogge et al. (2006) there were a number of contributing factors to the over-allocation of permits that was seen during phase I of the EU ETS. For example, the information on which baseline emissions were calculated could have been uncertain thus leading to miscalculations. Another important aspect was that when calculating future reductions of emissions an optimistic view of growth rates was used, leading to over-allocation.

One major set back for the EU ETS came when the new member states were to be introduced into the trading scheme. There was a dispute of how historical emissions and emission baselines should be calculated for these, primarily eastern European nations. Many eastern European nations rely on fossil fuels for energy production and hence their relatively high historical emissions lead to very demanding emission reductions. The European Commission disregarded these nations own calculations of historical emissions and enforced tighter caps. When this paper was written, both Poland and Estonia had won the dispute and are now in reality allowed to set their own emissions targets. Naturally, they are expected to set more generous reduction targets on national firms thus generating more permits and effectively lowering the market price.

US Acid Rain Program

As the first large scale emissions trading scheme in the world, Title IV of the 1990 Clean Air Act Amendments (1990 CAAA) primarily aimed towards reducing emissions of sulfur dioxide (SO_2) but also nitrogen dioxides (NO_x). Prior to Title IV (known as the US Acid Rain

Program) the Environmental Protection Agency (EPA) aimed at reducing a number of air pollutants. The early programs aimed to reduce emissions were basically ‘command-and-control’ programs where firms received emission targets that they had to follow. In an attempt to lower reduction costs the EPA introduced tradable emission reduction credits. Firms could earn these by abating more than their set up targets and then trade them to other firms who had higher abatement costs or they could bank them for future periods (Tietenberg, 1998).

The US Acid Rain Program focused on emissions from electric utilities relying on fossil fuels. The target for the emissions reduction was set to 8.95 million tonnes of SO_2 and 2 million tonnes of NO_x compared to 1980 emissions, thus, a 50 % reduction of SO_2 emissions. The reduction target was to be reached with a cap-and-trade scheme consisting of two phases. Phase I, beginning January 1st 1995, included the so-called Table A units, or the largest polluters in the scheme. From January 1st 2000 all other electric utilities using fossil fuels would be included. Additional reductions of the total amount of issued permits will be introduced every year, to be fully implemented by 2010 when the total emission reduction target of 8.95 million tons of SO_2 is to be fulfilled.

In 1979 the so called ‘bubble-policy’ was added to the Clean Air Act, this policy limited local emissions under the existing command-and-control scheme but at the same time let firms interact to achieve lowest possible cost of abatement. This also helped in limiting the creation of ‘hot-spots’ as levels of emissions could not increase above certain levels in one particular area while decreasing in another.

Problems and solutions

The initial allocation of permits to Table A listed units were 8.70 millions in 1995, an equivalent of equally many metric tons of emitted SO_2. This initial allocation of permits was based on total emissions from Table A listed units in 1985, a total of 10.68 million tonnes. However, due to unforeseen changes in input prices (deregulation of rail road transport prior to 1995 introduced coal with lower amounts of sulfur that was too expensive compared to its high sulfur substitute before the deregulation (Ellerman et al. 1997)) and earlier attempts to meet emissions targets the total emissions from table A listed units only summed to 5.30 tonnes in 1995. This gap between actual and allowed emissions led to permit prices being much lower than previously anticipated. Prior to the start of the program in 1995 expectations of the price of permits were as high as 1500 dollars according to Bohi and Burtraw (1997). Instead, auction prices in 1995 cleared at around 130 dollars (Bohi and Burtraw, 1997, Conrad and Kohn, 1996) Market volume was also a lot smaller than expected with only 9% of the affected units reporting that they relied on trading permits to fulfill their commitments regarding emissions (Rico, 1995).

Although not limited to small geographical areas, emitters of SO_2 and NO_x contribute to acid rain on a regional, not global, level. Therefore there is some risk of local ‘hot spots’ to form when a national emissions trading scheme is implemented to control a regional problem of this sort. At an early stage of the US Acid Rain program two separate trading zones were considered, one for the western states and one for the eastern (Rico, 1995). However, emissions were already somewhat regulated through local health standards, included in these standards were both levels of NO_x and SO_2 (Rico, 1995).

UK Emissions Trading Scheme

The UK emissions trading scheme (UK ETS) was a voluntary trading program for greenhouse gases initiated in 2002 by the UK government as a part of the UK Climate Change Program. The goal of the UK ETS was to reduce emissions, measured in tonnes of carbon dioxide equivalents (tCO_2e), compared to a baseline of average historical emissions in the years 1997-2000. The UK ETS was an economy wide program with two types of participants, referred to as Direct Participants and Agreement Participants.

Through an initial descending clock auction[5], 32 so called Direct Participants bid future emission reductions in exchange for a subsidy until a market clearing price of 53.37 pounds per reduced tCO_2e in 2006 was established. At this price, given the total budget from the UK government of 215 million pounds in subsidies, resulted in 3.96 million tCO_2e avoided in 2006. The scheme design was that the Direct Participants would increase their reductions of emissions with 20% per year of the final emissions reduction target starting at a level of 20% of the 2006 target in 2002. Hence, total abatement of emissions summed up to 11.88 tCO_2e. Thus, the 32 Direct Participants took part of a cap-and-trade program where each of the firms got endowed with permits equaling their emissions at the baseline subtracted their goal of abatement. The Direct Participants were obliged to report on their total emissions by the end of March every year, starting in 2003. Trading of permits also increased during these periods every year.

The UK ETS also included roughly 6000 firms referred to as Climate Change Agreement Participants (CCA). These were firms who prior to the implementation of the scheme had agreements regarding reductions in emissions with the government stretching to 2010. The

[5] The descending clock auction for the UK ETS was set up such that Direct Participants offered the amount of emission reduction that they were willing to give at a certain price. Such an auction starts with a certain quantity at a certain price and then lowers the quantity gradually until an agreement is reached.

CCA's were, unlike the Direct Participants' cap-and-trade system, subject to a baseline-and-credit system. The CCA's received an economical incentive of 80% reduction of the total payments to the Climate Change Levy (another instrument in the UK Climate Change Program aimed at taxing all energy use by the industrial as well as the public sectors). If the CCA's fulfilled their targets they received permits that they could trade or bank for future use. If they, however, failed to meet their emissions target they had the possibility to purchase additional permits to make up for the difference. The CCA's were to report their total emissions biennially starting at the beginning of 2003. This led to that the majority (as many as 60%) of trades with emission allowances, over the lifetime of the scheme, took place in January and February of 2003 and 2005 (Smith and Swierzbinski, 2007).

Problems and solutions

A report from the National Audit Office (NAO, 2004) suggests that baselines for direct participants were, in some cases, not demanding enough thus resulting in what seemed to be an 'over-achievement' though it was likely due to over-generous allocations. In some cases historical emissions, on which baselines were calculated, drastically dropped in the years prior to the scheme with the following result that baselines and targets were higher than actual emissions at the start of the scheme. This meant that some firms could go on with business as usual, meet their set up targets with ease and receive subsidies from the government. Total abatement from the 32 Direct Participants over the complete lifetime of the scheme summed up to roughly 18.6 million tCO_2e, some 6.7 million tonnes more than initially agreed upon. The over generous allocations that marked the first years of the scheme left a large excess supply of permits in the bank. If abatement from the 32 Direct Participants would have remained at high levels above initial allocations, a large excess supply of permits would have been left in the bank for CCA's to purchase after 2006, when the scheme ended for the Direct

Participants, thus severely damaging the market for tradable permits over the future coming years until 2010 when the trading period ended for the CCA's (Smith and Swierzbinski, 2007). With permit prices of close to nothing there would simply be no incentives for the CCA participants to reduce emissions further. However, in 2004 the 6 largest over-achievers took upon themselves to further reduce emissions by 8.9 million tCO_2e thus retiring a large part, but not all, of the excess supply of permits in the bank.

One clear flaw of the design of the UK ETS was the two differentiated participating groups. Letting the DP's and the CCA's trade on the same market although they were bound to different time frames. A system design like this leaves no room for error from one part of the trading groups. Had there instead been a trading barrier limiting trade between DP's and CCA's the potential threat that the large excess resulting from over-compliance would have been avoided. A large part of the problem was the possibility for DP's to bank permits for future use after 2006 when the last compliance period had ended for them, thus potentially leaving a large portion of permits in the bank for the CCA's.

Chicago Climate Exchange

The Chicago Climate Exchange (CCX) is another voluntary, yet legally binding, emissions trading scheme where companies can join to help reduce emissions. CCX is planned to have a life span over 7 years, starting in 2003 and ending in 2010. The scheme, a cap-and-trade system, is divided into two phases, phase I and II. Participants of the CCX took upon themselves to reduce their emissions by 1 % each year below baseline (average of emissions between 1998 and 2001). Thus the aim of phase I of the CCX was to reduce emissions to a level of 4 % below baseline emissions. For companies choosing to continue in phase II emission targets were set to 6% below baseline in 2010. For companies who choose to join after the initiation in 2003, thus joining phase II, linear annual reduction targets were set up resulting in a 6% reduction below baseline emissions.

The CCX is open to participants all over the world, but a majority of participating members are based in the US. As opposed to the UK Emissions Trading Scheme where the government created an economical incentive to participate through pay-outs under compliance, the CCX has no such economical incentive. Instead the CCX offers a good marketing possibility and a head start to potential future obligatory emissions trading schemes.

There are 4 ways of participating in the CCX.

- *Members* are companies and organizations with large greenhouse gas emissions who commit to reduce their emissions within the two phase program.
- *Associate members* are companies and organizations with minor greenhouse gas emissions who commit to offset all of their indirect emissions from energy consumption and transportation.
- *Participant members* can be divided into sub groups. Offset providers and offset aggregators are allowed to create emissions reductions through, for example, reforestations projects and trade them on the market. Members are also allowed to create offsets. Therefore one criterion is that the offset providers and offset aggregators do not have large emissions of their own. Offset aggregators are umbrella organizations for small offset providers. Liquidity providers are participants who do not take part of any emissions reduction activities but solely want to trade on the market for other reasons.
- An *Exchange participant* is anyone who enters the market to purchase Carbon Financial Instruments to account for their emissions.

Permits to emit, called Carbon Financial Instruments (CFIs), can be acquired in two ways. At the beginning of each year members and associate members are given (free of charge) the number of CFIs corresponding to their baseline of emission minus the promised reduction for that year. Offsets providers and offset aggregators can also generate CFIs through verified emissions reduction activities (ICAO, 2007). Worth to mention is that members are not allowed to offset more than 50% of their annual emissions reduction targets and hence the market is somehow protected against flooding of CFIs (Hamilton et al, 2008).

Problems and solutions

As in the case with UK Emissions Trading Scheme the first years of the CCX were marked by over-compliance. As of June 2009 results of emissions reductions had been released for all phase I compliance periods and the first compliance period of phase II, meaning 2003-2007. The first period resulted in 11.5% lower emissions than aimed for, the corresponding number for the second period is 14%. The third and fourth periods had over-compliance of 12.2% and 9.2% respectively. In 2007 actual emissions were 4.2% lower than promised. As a result of this, the price for CFI's has been generally low in the CCX. Market clearing prices at the beginning of trading in 2003 were 98 cents for each tonne of CO_2.

The Regional Greenhouse Gas Initiative

The Regional Greenhouse Gas Initiative (RGGI) is a relatively new mandatory emissions trading scheme that caps CO_2 emissions from the power sector in ten US states. Each member state auctions their permits thus raising revenues that are used for renewable energy sources and consumer benefits in the local economy. Auctions for emission permits are held quarterly with the first one in September 2008. The first compliance period, consisting of three years, started on January 1st 2009. Currently the scheme has a proposed lifetime of three compliance periods resulting in a total of 10 percent lower emissions in 2018. Since the RGGI is at the beginning of the first compliance period, and no data on abatement and the successfulness of the scheme has been released, it is hard to draw any conclusions from the scheme. So far, five auctions have been held and the market clearing prices have ranged between 2.19 and 3.51 US dollars per tonne CO_2. Since the RGGI relies solely on auctioning to distribute their allowances it will be interesting to follow the results of the scheme in the future.

4. Lessons learned and concluding remarks

As a concluding remark, what has been seen in previous emissions trading schemes and how their weaknesses and problems can be avoided in the coming trading scheme for aviation under the EU ETS will be discussed.

Allocation

Over all, emission reductions have, sometimes greatly, succeeded the set out targets in all of the trading schemes subject to this analysis. It is interesting, and above all, important to know the reasons for this in order to design efficient trading schemes in the future. There are two possibilities to why actual emissions would exceed targets. Firstly, baselines and emission quotas can be calculated too generously. This could be done with or without the regulators knowledge. One could expect emission targets to be more generous in voluntary emission trading schemes to attract more participants for example. It is also possible that information on historical emissions is hard to obtain thus resulting in error margins, large or small. Some variables used to calculate targets, such as growth rate, can be optimistic estimates leading to higher than normal emission targets. When emission targets are too generous, some firms might be able to continue with business as usual while receiving permits that they can trade on the market. In this case permits become a pure wealth transfer and the market for emissions will not regulate the emissions of these firms. In the second case, firms might over-achieve their targets. This is to be considered positive since emissions are actually decreasing, more so than they were set out to do initially.

The current proposition for the trading scheme for aviation states that 85% of permits should be allocated for free using an average of emissions during the years 2004 to 2006. This proposition leaves 15 percent of permits to be allocated through auction, if the participating member states choose to do so. It is important that baselines, based on historical emissions, are calculated correctly. There are a number of distortions in the market that have led to lower demand for air transport and thus to lower emissions for some periods. The terrorist attacks on 9/11, 2001 led to a down shift in demand that, at least, stretched into 2003 (Ito and Lee, 2004). The financial crisis starting in 2008 also had a negative impact on air travel.

If a larger part of permits for the aviation sector would be allocated through auctioning, over-allocation might potentially be avoided since agents on the market rarely would purchase far more permits than needed. However, auctioning does not guarantee the avoidance of over-allocation. This might incur if permit prices are low but can be avoided with a reservation price, however, this has not been observed in any of the previous schemes that have been examined. A natural price ceiling will however apply as no agent in the aviation sector would bid higher than the market price for emission permits in the EU ETS. Hepburn et al (2006) suggest that auctioning should be implemented to a greater extent for the whole EU ETS. Further, they argue that auctions could be held roughly every six months to create price stability of permits. Auctions, as contrary to grandfathering, are harder to implement on a political level possibly due to the common misunderstanding that they will induce higher consumer prices.[6]

Method of allocation is also interesting from a distributional point of view. Distribution of emission permits is a distribution of wealth. Ultimately the different allocation methods distribute this wealth to different groups. Auctioning gives a good possibility to use the revenues for additional environmental improvements, such as deforestation or research for fuel efficient engines. Of course, revenues can also be used in any other way, such as tax reliefs for example.

Liability

All of the previous schemes have chosen to hold the direct source of emissions liable for retiring permits, thus implementing a *downstream* approach in allocating liability, in all cases these same agents have also recieved permits allocated to them. However, these choices are not always explicitly clear. In the US Acid Rain program similar results would probably have been achieved by placing liability on coal suppliers. Again, the choice to allocate liability and permits to the direct source of emissions might be due to the fact that it is easier to win political acceptance in this way or simply because transaction costs are at the lowest. Ultimately, the importance does not lie in where the liability and permits are allocated but rather that the allocated amount of permits is correct in regard to the emissions reduction targets.

Air craft operators have been suggested by the Commission as the liable source of choice. However, this leads to smaller agents being excluded from trade and thus not covering all

[6] This misunderstanding is not uncommon and probably stems from disregarding economic theory and in particular opportunity costs. For a further discussion and empirical evidence of the contrary please see Wråke et al. (2010).

emissions. Airports (or air traffic controllers) could be an alternative to air craft operators. Given some certain assumptions[7], the choice of liable agent should not affect the outcome of trade, the interesting criterions are instead to minimize transaction costs and to make the scope of the scheme as large as possible, i. e. to include as much emissions as possible (Bohm, 1999). There are no clear advantages or disadvantages with either air craft operators or airports (air traffic controllers) that lead to the conclusion that one is strictly better than the other. Both options can easily be implemented. Airports have the clear advantage that, since all air crafts fly to and from them, all flights can be included while air craft operators have the advantage that they are in greater control over fuel consumption and therefore emissions. The question of importance is what alternative would generate the lowest transaction costs of the two. A combination of these two alternatives as liable agents is also a possibility. Air craft operators could, for example, be held liable for the cruise part of the flight, where they have exclusive control over fuel use and thus emissions. In addition, airports (or air traffic controllers) could be held liable for taxi, take-off and landing, areas where they have influence on emissions.

Inter-temporal trade

The idea behind tradable emissions permits is that the market will allocate permits as to achieve the lowest cost of abating a certain given amount. The same statement also holds over time where an individual firm can allocate its present and future emission permits as to achieve the lowest possible cost of abatement. However, looking at previous systems for emissions trading, none has allowed borrowing from future permits while already issued permits have been allowed to be banked for future use in all of the schemes. Naturally, borrowing poses a problem of asymmetric information where the legislators do not know

[7] Under perfect competition the permit price will simply be added on to each step of trade, thus ultimately showing up in the consumer price.

whether or not the firm will stay in the scheme for the following period. Thus, allowing firms to borrow from future allocations introduces a risk that these borrowed permits will not be accounted for in the future due to market exits for example. Banking posed a huge threat to the UK ETS where a large excess of permits would have been left in the bank after 2006 (i. e. the last trading period of the DP's) potentially ruining the whole system. Fortunately, drastic measures saved the scheme from this. However, this problem cannot be blamed entirely on banking but rather on over-generous initial allocation leading to the creation of this huge excess supply. It is possible that, if borrowing is allowed, air craft operators will use a greater part of their permits today and strive for new fuel efficient technology to account for the lower supply of permits tomorrow. That is, allowing for full inter-temporal trade within the system might lead to more fuel efficient air crafts in the future. [8]

Hot-spots

Since emissions of CO_2 do not have any impact on climate at a local level but rather on a global level there are usually no hot-spot problems regarding trade of CO_2 permits. But, whereas emissions of CO_2 can be accounted for on a one-to-one basis between emitting sectors the impact from other greenhouse gases from aviation on global warming is supposedly larger due to the high altitudes where most of the emissions occur. Evidence suggests that the impact on global warming from aviation is greater than from other sectors because emitting takes place at higher altitudes (IPCC, 1999; Lee and Sausen, 2000; Delft, 2005). Allowing the aviation sector to use permits issued for other sectors might increase the negative impact on climate that the systems aims to avoid. Hence, there is a potential threat of "hot-spots" in some sense when implementing aviation into the EU ETS. There was a potential threat of local hot-spots forming under the Acid Rain program, at an early stage two

[8] The International Air Transport Association (IATA) issued a statement in 2010 that they aim at carbon neutral growth in the medium run.

separated trading zones were discussed as a measure to eliminate the threat but the Clean Air Act already included policies prohibiting local air qualities to be lower than a certain level. In a similar way, the problem under the trading scheme for aviation in the EU ETS could be avoided by not allowing the aviation sector to trade with other sectors or by establishing an exchange rate for permits, however, there is no empirical evidence to support any specific size of such an exchange rate.

Trade barrier

The European Commission has decided to introduce a gateway prohibiting a net flow of allowances going from the international aviation sector to the stationary sources. If one of the sectors has a high marginal cost of abatement without having the possibility to purchase additional emission permits from firms with lower cost of abatement the same emission reduction will apply, but it will be more costly as the firms with higher costs still have to abate instead of covering emissions with permits. One can of course argue that the international aviation sector probably will face higher costs of abatement, and by allowing them to purchase and use emissions from other sectors this problem will never emerge. However, there are other explanations for a trade barrier in the EU ETS between aviation and the stationary sources. The EU ETS is the tool to achieve the European goals of emissions reduction under the Kyoto Protocol. Since emissions from the international aviation sector is not controlled under the Kyoto Protocol, allowing the sector to trade under the same regime would jeopardize achieving the goals that are set up under the Kyoto Protocol. For this reason, the Commission has decided to impose this one-way trade barrier such that the aviation sector will be able to use permits from the other sectors but not vice versa. The barrier to trade might be a pure political instrument, with a growth rate exceeding increases in fuel efficiency aviation is expected to have a harder time complying with the goals of the emissions trading scheme, meaning that aviation as a sector probably will be a net purchaser of permits rendering a non-binding trade barrier.

None of the other emissions trading schemes analysed here has used any trading barriers between sub-groups, although it was discussed at an early stage of the Acid Rain Program. Legislators estimated that without a trading barrier eastern utilities would sell a large portion of their permits to western utilities thus creating local hot-spots of emissions in the west. Title 1 under the Clean Air Act does however include restrictions on local air qualities so the proposition of two separated trading zones was abandoned (Rico, 1995, Tietenberg, 1998). In the UK ETS we saw two sub-groups that were allowed to engage in trade with each other. The over generous allocation to the DP's posed a threat to ruin the market for permits under the trading scheme. One could argue that separated markets would have avoided this problem altogether but when looking at the reason for this large over-achieving actually creating the problem it can easily be seen that more strict allocations would have avoided the problem as well.

Concluding Remarks

The trading system for aviation is unique and different from all the previous systems that we have looked at. Nonetheless, lessons can be learned from previous systems and some conclusions can be drawn from their designs. First of all, as has been seen, initial allocations have played a key role in creating efficient markets for trading of permits. All of the previous schemes analyzed here have had problems where actual emissions have been lower than expected. Even though this is a desirable scenario it has resulted in different problems later on in the schemes, extremely low market prices for example. It is understandable that it is hard to achieve political acceptance for a trading scheme and at the same time impose tight emissions caps. This was shown in particular by the law suits from some member states of the EU against the Commission regarding too strict emissions targets where the Commission has lost some if its authority and thus damaging the credibility of the scheme.

Secondly, the controversial gateway of trading between aviation and the stationary sources should be carefully examined since there is reason to believe that greenhouse gases from aviation will lead to greater environmental impact than those from the stationary sources. It is, however, understandable that the Commission does not want to put emission targets under the Kyoto protocol in danger by introducing additional tradable permits on the market.

No emissions trading scheme will ever be free from problems at its initial stage but lessons can be learned from previous mistakes as well as successes in order to minimize the initial problems. It is also important to ensure that any potential problems that can arise within the trading schemes also are allowed to be solved within the boundaries of the scheme.

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Paper II

A Demand Model for Domestic Air Travel in Sweden

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ABSTRACT

The aim of this study is to estimate the price elasticity of demand for domestic air travel in Sweden. Using national aggregated data on passenger quantities and fares, price elasticities of demand are estimated with an unbalanced, in terms of stationarity, yet well performing model. The analysis also includes estimates of cross-price elasticities for the main transport substitutes to air travel, rail and road. The robustness of the results is enforced by a primitive division of business and leisure travellers. The results indicate that aggregated demand for domestic air travel in Sweden is fairly elastic (-.84) in the short-run and more elastic (-1.13) in the long-run. The robustness test of the model show that leisure travellers, as defined in the data, are more sensitive to price changes than are business travellers. Furthermore, the cross price elasticity between train and air travel is found to be .44.

JEL classifications: *C22, D12, Q58, R41.*

Key words: *Aviation, elasticity, transport, demand.*

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1. Introduction

When evaluating the future of the national passenger air transport market it is important to understand what drives demand. For instance, in the light of the forthcoming trade of emission permits for the international aviation sector, even though this does not regard the domestic market directly, some new estimates of price elasticities are called for. The demand for air travel has received quite substantial attention in the literature during the past four centuries. The empirical literature contains numerous studies on the determinant of air travel demand. Besides fares, population and income (or GDP where disaggregate data is not available) have been shown to have an impact on air travel demand[1]. However, when studying the price elasticity of short haul flights, i.e. on routes where other modes of transport exists as substitutes to air travel, the price and availability of these will likely be of great importance in determining the demand. For example, if it is relatively cheap to travel by train where air travel is also an option one might expect less people to fly this particular distance. The availability of a substitute to air travel is closely related to the distance of the trip and hence some destinations in Sweden will have more substitutes than others. Of course, the monetary price of other transport modes is not the only factor determining the substitutability of air travel as travel time and other characteristics, such as comfort, play an integral role.

The aim of this study is to, with help of time series analysis, estimate the price elasticity of demand for domestic air travel in the short, as well as the long run in Sweden. As a test of robustness of the estimated models, the elasticities for business and leisure travel will be estimated. Control variables for close substitutes, car and train, will also be included to find cross-price elasticities.

[1] See for example Fridström and Thune-Larsen, 1989. Ba-Fail et al., 2000. Abed et al. 2001. Brons et al. 2002

This paper is structured as follows, section 2 contains a brief discussion about the demand for air travel, the aim of the following section 3, is to describe and clarify the data used for the analysis. In section 4 the econometrical models used are discussed while section 5 contains a presentation the results. In section 6 the results and their implications are discussed.

2. Literature Review

Jung and Fujii (1976) used a quasi-experiment of cross-sectional city-pair data. The data consisted of travel demand from three cities to a number of destinations during the second quarters of 1972 and 1973. Some of these routes were subject to increases in fares and no city pairs were allowed to differ in schedule frequency. All routes considered in the study were located in the southeast and south central regions of the US with distances ranging between 50 and 500 miles (80 to 800 kilometres). They found that the price elasticity of demand was in the range -1.77 to -3.15.

Straszheim (1978) discusses potential problems with data when estimating the price elasticity of demand for air travel. It is argued that it is hard to separate the effects of changes in price and changes in service provided when using city-pair data over a long period of time as travel demand changes for one destination if other routes become available. The problem can be corrected if the origin and the destination is known for all passengers, it is however very hard to come by data this specific. Another solution is to use aggregated data for the whole market, then all trips by all passengers will be captured. Straszheim used the latter form of data on the north Atlantic region and found evidence of relatively inelastic price elasticity of demand for first class fares, however more elastic than expected. As for economy fares, the price elasticity of demand was found to be elastic and even more so for discounted low fares.

In a related, at least from a geographical point of view, study Fridström and Thune-Larsen (1988) provides estimates of different air transport related elasticities. It was found that the fare elasticity in the short- to medium-run was -.82 and in the (undefined) very long-run was -1.63. The analysis is performed using link volumes at Norwegian airports, thus resulting in a double counting of passengers transferring flights. This distorting problem was corrected by accounting for the number of transfers at each airport, which is known.

Brons et al. (2002) collected 204 estimates of price elasticities of demand for air travel and conducted a meta-analysis on these previous estimates. One interesting hypothesis in the study was that the price elasticity for Europe ought to be slightly higher than for the US and Australia because of the larger substitutability in passenger travel. This was, however, not found to be the case. Among the results it was shown that passengers get more price sensitive over time, i.e. long run elasticities tend to be higher than short run elasticities. The logic behind this finding is that it takes time to change behavior. It is argued that when price elasticities are used for policy implications, this has to be taken into account.

Anger and Köhler (2010) reviewed several previous studies that had performed estimates of the impact on ticket prices and demand for air travel from the inclusion of the aviation sector into the EU ETS. It is argued that estimates of increases in fares at the higher end, where permit prices in the range of 30-60 euro per tonne have been used, are unlikely to be realised. Furthermore, it is concluded that changes in quantity demanded for air transport will, due to relatively small changes in air fares, be insignificantly small.

3. Data

The data for the analysis stems from several different sources. A national monthly aggregate on departing passengers has been gathered from the Swedish Transport Agency. Unfortunately Origin and Destination (O&D) data for individual passengers have not been available. This essentially means that passengers engaging in one trip with a connecting flight inevitably will be counted twice. To try to account for this, a variable describing the share of total passengers in domestic air travel that pass through Arlanda Airport in Stockholm will be included. [2] The logic behind this is simple, if there are fewer direct services between other airports, the number of passengers transferring at Arlanda Airport will increase. The price variable, obtained from Statistics Sweden, is an indexed series of average monthly fares where no distinction is made for different fare categories, e. g. business or leisure travel. In an attempt to distinguish between business and leisure travel, mainly as a test of robustness of the model, a variable explaining price in July will be used. [3] July has traditionally been the month where most Swedes enjoy their vacation, hence it is assumed that business travel is at a minimum during this month and any effect from a price change on demanded quantity would be explained by leisure travellers demand. This will not provide correct point estimates of business and leisure travel but rather a useful illustration of their differences. Furthermore, a similar series, also gathered from Statistics Sweden, of average price of train tickets as well as the cost of driving (an indexed series including price of gasoline) is included. These will account for the two main substitutes to air travel, namely rail and road transportation. A number of economic and demographic variables are included, such as GDP and population size. The data set concerns a time period from January 1980 to December 2007 and contains

[2] Arlanda serves direct routes to all of the Swedish domestic airports, serving as a hub, and an increase in the share of passengers travelling to, or thorugh, Arlanda will serve as a good measurement of direct services between other airports.

[3] Combinations of June, July and August have been subject to this study, however, a wider definition of time of vacation will likely include more business travel.

335 observations in total. A brief summery of the most important variables is presented in table I.

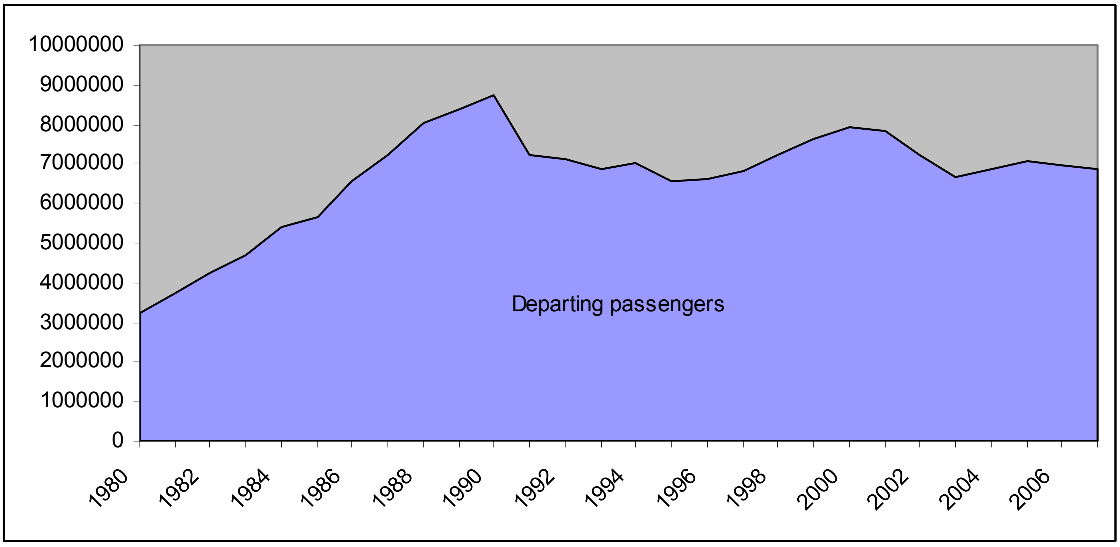
Table I. Descriptive statistics, yearly averages

Variable	*Mean**
Departing Passengers	554713.2 (130634.8)
Index of fares	260.75 (111.05)
Index of train ticket prices	312.12 (126.32)
Index of the Cost of driving	254.21 (98.12)
GDP per Capita	22480 (3454)
Population	8699237 (271270)
Share Arlanda	.3691 (.1112)

* standard deviations within parenthesis.

During the 1980's the total number of passengers in domestic air travel (shown in Figure I) increased quite dramatically. However, the trend of increasing demand for air travel seems to have been broken in the beginning of the 1990's. There are numerous reasons that can help explaining the decreasing number of passengers in air travel from 1990 and onwards, for example the introduction of high speed rail in 1990, the gulf war and financial crisis and later on, 9/11.

Figure 1: Departing passengers in domestic air travel, Sweden 1980-2007



Source: Swedish Transport Agency

Ideally, all time series used should be integrated of order 0 (I(0)). In other words, they should be stationary. The augmented Dickey-Fuller test for a unit root will help provide evidence of whether or not the time series used are indeed stationary. Results are presented in Table II. All variables but the share of passengers at Arlanda Airport are in logs.

Table II: Results for the augmented Dickey-Fuller test for a unit Root

Variable	*Stationary*	*Trend-Stationary*
Departing Passengers	*	
Index of Fares	-	*
- Detrended	*	
*Index of Fares*Vacation*	*	
Index of Train ticket prices	*	
Index of the Cost of driving	*	
GDP per Capita	- (*)	-
Population	- (*)	-
Share Arlanda	- (*)	-
	- (*)	-
	- (*)	-

Reject null at 1% significance level, ** Reject the null at 5% significance level, – Falure to reject the null, () First differences. Appropriate variables are in logs.

The two crucial variables are indeed stationary, i.e. integrated of order 0 (I(0)), the number of departing passengers (logged) strictly so while the logged index of fares is stationary allowing for a trend. By applying the Hodrick-Prescott filter the series can be separated into the trend and the detrended series, which is stationary. The null hypothesis of a unit root cannot be rejected for all other variables, hence, these variables are integrated of order 1 (I(1)). They can however be made stationary by differentiation.

4. Model

The demand for any transport mode can be generalized as

$$z_i = f\left(P_i...P_k, x_l...x_m\right) \qquad (1)$$

where z_i is the demand for that particular mode of transport (in this case air travel), $P_i...P_k$ are prices of transport services (own price as well as price of substitutes and complements to the particular transport mode of interest) and $x_l...x_m$ are other determinants of air travel demand such as income, population or availability of substitutes. Assuming that other transport modes are substitutes to air travel, which is not far fetched for short haul flights, the cross price elasticity of demand is expected to be positive. Also, the income elasticity is expected to be positive and the own price elasticity is expected to be negative, i.e.,

$$\frac{\partial z_i}{\partial P_i} < 0$$
$$\frac{\partial z_i}{\partial P_j} > 0, i \neq j \qquad (2)$$
$$\frac{\partial z_i}{\partial x_l} > 0$$

where P_j is the price of any particular substitute, x_l is income and P_i is the price of air fares for domestic flights. The latter relationship is the most interesting for this study but the first one is also important.

A logged version of the demand function (1) will deliver the wanted elasticities for air travel. Following the specification of demand for air travel made in equation (1) the model can be specified as:

$$\begin{aligned} \ln(z_t) &= \alpha_t + \beta_t \ln(P_t) + \beta_{t-k} \ln(P_{t-k}) + \delta_t \ln(P_t * vacation\ ) \\ &+ \phi_t \ln(P_t^{Substitutes}) + \gamma_t \ln(GDPPC_t) + \kappa_t \ln(population_t) \\ &+ \varphi_t (sharearn_t) + \sigma_t (dummies) + u_t \end{aligned} \qquad (3)$$

Where P_t is the fare, P_{t-k} is the lagged effect of fares and P_t * *vacation* is the variation in price during vacation, i.e. July. The dummy variables used describe the introduction of high speed rail in 1990 as well as the terror attacks on September 11th, the latter assumes that the effect wore off in 2004. [4] In addition, seasonal dummy variables are included. The primary interest lies in the estimates of β_t and β_{t-k}. δ_t is interesting from a robustness point of view. These three parameters will provide both the short-run (SR) and the long-run (LR) price elasticities for business (sub index B) and leisure (sub index L) of demand for domestic air travel, in particular;

[4] See Ito and Lee (2004) for a further discussion on this topic.

$$
\begin{aligned}
SR_B &= \beta_t \\
SR_L &= \beta_t + \delta_t \\
LR_B &= \beta_t + \sum \beta_{t-k} \\
LR_L &= \beta_t + \delta_t + \sum \beta_{t-k}
\end{aligned} \tag{4}
$$

Due to multicollinearity in the lagged fare variables individual effects from each lag might show as insignificant. To account for this a simple variable transformation will allow for estimation of the total effect of the lagged fares. This can be illustrated with an example using two lags;

$$\ln(z_t) = \alpha_t + \beta_t \ln(P_t) + \beta_{t-1} \ln(P_{t-1}) + \beta_{t-2} \ln(P_{t-2}) \tag{5}$$

The long-run effect can be defined as the sum of the lags given by;

$$LR \equiv \theta = \beta_t + \beta_{t-1} + \beta_{t-2} \tag{6}$$

The total long-run effect can be estimated with;

$$\ln(z_t) = \alpha_t + \theta \ln(P_t) + \beta_{t-1} \ln(P_{t-1} - P_t) + \beta_{t-2} \ln(P_{t-2} - P_t) \tag{7}$$

Even if the individual β's in (5) show as insignificant due to multicollinearity, the total long-run effect (θ) in (7) may be significant.

5. Empirical Analysis

A possible problem using a time series model to estimate the price elasticity of demand is that it might be hard to separate effects on the number of departing passengers from price on the one hand, and changes in available services on the other (Straszheim, 1978). During the time period from which data is available, new routes might have been added while other routes have been abandoned. Such changes in service availability that are not necessarily combined with a change in price would most definitely change the number of departing passengers. These disturbances are due to changes on the supply side. As previously discussed, a variable of the share of all passengers who pass through Arlanda each year is included to account for this.

A Prais-Winsten regression (Prais and Winsten, 1954) is applied to correct for serially correlated error terms that were detected when applying classical linear regression analysis. [5] The regression output is presented in table III.

[5] First difference equations have also been estimated with essentially the same results. Output from these are left out and can be found in Appendix A.

Table III: Results from Prais-Winsten Regression

Variables	I	II
Fares	-.8457	-.6653
	(0.000)	(0.000)
*Fares*Vacation*		-.2030
		(0.000)
Train ticket price	.5376	.4474
	(0.000)	(0.001)
Cost of driving	.0915	.1431
	(0.676)	(0.504)
GDP per Capita	.3384	.3973
	(0.083)	(0.036)
Population	-7.77	-7.31
	(0.001)	(0.001)
High speed rail	.0467	.0525
	(0.468)	(0.408)
Nine11	-.0515	-.0537
	(0.023)	(0.012)
Share Arlanda	1.10	1.17
	(0.000)	(0.000)
January	.1902	-.9193
	(0.000)	(0.000)
February	.2478	-.8603
	(0.000)	(0.000)
Mars	.4002	-.7066
	(0.000)	(0.000)
April	.3361	-.7700
	(0.000)	(0.000)
May	.3391	-.7671
	(0.000)	(0.000)
June	.3104	-.7963
	(0.000)	(0.000)
August	.2957	-.8103
	(0.000)	(0.000)
September	.3788	-.7268
	(0.000)	(0.000)
October	.4394	-.6668
	(0.000)	(0.000)
November	.4155	-.6900
	(0.000)	(0.000)
December	.2356	-.8693
	(0.000)	(0.000)
R^2	0.8980	0.9098
Orig. DW statistic	1.01	1.01
Adj. DW statistic	2.14	2.28
ρ	.49	.51

p-Values within parenthesis.

Two models are estimated, one with and one without the proxy for leisure travellers. As can be seen the original Durbin-Watson (DW) statistic is far from the wanted 2. The adjusted Durbin-Watson statistic suggests that the Prais-Winsten regression successfully corrects for this. Aligned with prior expectations the price elasticity decreases when the proxy for leisure travellers is included. Furthermore, as expected, the cross-price elasticity between air and rail travel is positive, if train ticket prices increase demand for air travel would increase. GDP per capita show a positive and expected coefficient. As mentioned, earlier literature points toward population having a positive effect. This is not the case here, which may be explained by the correlation between GDP per capita and population size. The terrorist attacks on September 11th 2001 show a significant, negative, effect on domestic air travel. Lastly, the proxy for direct flights, the number of passengers passing through Arlanda airport is significantly greater than 0. This result is expected as a greater portion of travellers passing through Arlanda indicates fewer direct services between other airports, thus resulting in a higher number of trips. It is important to keep in mind that the analysis concerns equilibrium points. This essentially means that the price variable used in this analysis is probably endogenously given. In a perfect world, the analysis would model both demand and supply sides of the ecenomy. However, it is hard to find sufficient data to allow for modelling of the supply side. Inclusion of a dummy variable describing the deregulation of the domestic air traffic market (from 1992 onwards) shows no result, possibly because of the numerous of other factors occurring at the same time (e.g. financial crisis, gulf war, etc.).

Keep in mind that several of the variables on the right hand side of the equation are I(1) while the dependent variable is I(0) thus resulting in an unbalanced regression. This can potentially lead to biased results and unreliable t-statistics and R^2. One way to correct for this is to estimate the model using first differences of the variables, as long as these first differences are I(0).[6] However, Pagan and Wickens (1989) state that a minimum criterion for an unbalanced regression is that the error term inherits the stationary property of the dependent variable. Baffes (1997) expands on this and further suggests that if the dependent variable is I(0) and at least two of the independent variables are I(1) the model can still be considered well

[6] Results from a first difference Prais-Winsten regression are presented in Appendix A.

performing if the predicted value of the dependent variable is also I(0) and the variance of the observed and predicted dependent variable are equal. This proposes three criteria for the model to fulfil.

Table IV: Tests of stationary properties and equal variances.

Stationarity tests	I		II
Error term	-10.5*		-10.3*
Predicted value	-6.2*		-6.5*
Variances	Observed	I	II
Variance	.0758	.0606	.0605
Ratio of variances	1	1.25	1.25

In our stationarity tests * denotes rejection of the null of an existing unit root at the 1 percent significance level, ** denotes rejection of the null at the 5 percent significance level.

The test results, as seen in table IV, are somewhat ambiguous. On the one hand, the error term has inherited the stationary properties of the dependent variable suggesting that the model is well behaved. The stationary properties of the predicted values that each model produce, point towards the same conclusion. In all cases, the null of equal variances can be rejected, i.e. the ratios are significantly different from 1, however, not far from 1. The critical F-statistical values are 1.2 which suggests that the models come very close. These tests indicate that the models are reliable.

Now short-run, or immediate, price elasticities of demand for both business and leisure travel in Sweden have been successfully estimated. In order to assess the long-run effect, an optimal number of lags need to be included in the model. From the Schwarz's and Bayesian Information Criterion (SBIC) the optimal number of lags is six.[7]

[7] Akaike's Information Criterion and the Hannan Quinn Information Criterion suggest 8 and 7 lags respectively. However, the point estimates do not vary significantly in comparison to 6 lags. 6 months does however seem like a reasonable time frame.

Table V: Long-run price elasticities of demand.

Variable	*SR Fare*	*LR Fare*	*LR Fare*
Fare	-.5817	-1.13	-1.00
	(0.000)	(0.000)	(0.000)
*Fare*Vacation*	-.2060		-.2060
	(0.000)		(0.000)
Fare lag 1	-.0875	-.0244	-.0875
	(0.385)	(0.822)	(0.385)
Fare lag 2	-.1041	-.0629	-.1041
	(0.413)	(0.636)	(0.413)
Fare lag 3	.0958	.1414	.0958
	(0.369)	(0.207)	(0.369)
Fare lag 4	-.0355	-.0216	-.0355
	(0.718)	(0.841)	(0.718)
Fare lag 5	-.1487	-.1493	-.1487
	(0.095)	(0.112)	(0.095)
Fare lag 6	-.1467	-.1982	-.1467
	(0.141)	(0.069)	(0.141)
Train ticket price	.4338	.5038	.4338
	(0.001)	(0.000)	(0.001)
Cost of Driving	-.0148	-.1080	-.0148
	(0.936)	(0.551)	(0.936)
GDP per Capita	.4693	.4433	.4693
	(0.003)	(0.006)	(0.003)
Population	-6.09	-6.05	-6.09
	(0.001)	(0.001)	(0.001)
High speed rail	.0938	.0982	.0938
	(0.064)	(0.050)	(0.064)
9/11	-.0455	-.0454	-.0455
	(0.019)	(0.028)	(0.019)
Share Arlanda	1.19	1.14	1.19
	(0.000)	(0.000)	(0.000)
R^2	0.9175	0.9047	
Orig. DW statistic	1.02	1.04	
Adj. DW statistic	2.28	2.18	
ρ	.50	.48	

p-Values within parenthesis.

Since there is strong multicollinearity between the lagged price variables, the variable transformation from (7) is used to estimate the summed long-run effect of a permanent price change. The regression output from the long-run estimates, as seen in table V, points towards higher elasticities in the long-run than in the short-run. As discussed, this is the expected result. Other than that, all other point estimates are close to what they were in the static model[8]. The same three test criteria for an unbalanced regression are applied. The results point towards the same direction as earlier, the ratio of variances is, however, slightly higher.

[8] The model is still corrected for seasonal changes in departing passengers but this is left out from the table. Estimates and p-values are the same as before.

Table VI: Summary of price elasticities of demand

	SR	LR
Business	-.6653	-1.00
	(-.9184, -.4122)	(-1.37, -.6421)
Leisure	-.8683	-1.20
	(-1.18, -.5539)	(-1.64, -.7832)
Aggregated	-.8457	-1.13
	(-1.15, -.5407)	(-1.52, -.7375)

A summary of the estimated price elasticities is of demand for domestic air travel for both business and leisure passengers in the short- and the long-run presented in table VI (confidence intervals within parenthesis), an aggregated estimate is also provided. Noteworthy is that the short-run elasticity for business is indeed statistically different from -1 providing evidence that the Swedish market for business air travel is indeed price insensitive.

The approach to handling unbalanced regressions with many non-stationary variables used in this paper is unconventional and has not been substantially tested in the literature. A more conventional approach to handling non-stationarity is to use a first-difference model. In addition to the model presented in this paper one such first-difference model has also been estimated. The results from this estimation can be seen in appendix A. Over all, the results from the first difference approach differ from the earlier results by 1 or 2 decimal points. The point estimates for the aggregated travel demand as well as for leisure from the first difference model both fall within the confidence intervals of the earlier results. The first difference point estimate for business falls just outside of the corresponding confidence interval. These results further strengthen the earlier analysis provided here.

6. Concluding remarks

The aim of this study was to estimate the price elasticity of demand for domestic air travel in both the short- and the long-run in Sweden. In order to do this, a time series model was constructed. The individual effects of increases in fares on business and leisure travel were estimated by including a price variable for the month of July, when Swedes traditionally enjoy their vacation. While this method does not give exact point estimates it provides useful evidence to the difference between the two travel groups. The specific choice of July as the month of vacation can be questioned. Combinations of the months June, July and August can also act as good proxies for vacation time but a wider definition of the time for vacation will likely also include more business travellers resulting in less distinguished estimates. The findings of this study correspond to what earlier studies have concluded[9]. Two general finding is that the fare elasticity is larger (in absolute numbers) for leisure than for business travellers and also that the fare elasticity in the long-run is larger (in absolute numbers) than in the short run. Fridström and Thune-Larsen's (1988) estimates for Norway provide a good base for comparison of the point estimates because of the similar estimation method as well as similar geographical characteristics as Sweden. They provide an aggregate short-term direct fare elasticity of -.82, very close to the aggregated fare elasticity of -.84 presented in this study. The aggregated long-run fare elasticity of -1.13 presented in this study is lower (in absolute numbers) than the very long-run fare elasticity presented by Fridström and Thune-Larsen. The long-run results from this study might not be comparable to the ones presented by Fridström and Thune-Larsen since different time horizons might have been used. Furthermore, the cross price elasticity for train, one of the closest substitutes to domestic air travel in Sweden came out positive.

[9] There are some exisiting evidence of fare elasticity in Sweden from before. The are in the range -.1 to -1.13 and -.2 to -1.0 for business and leisure travel respectively. For more information see for example SIKA Rapport 2002:19 or SIKA PM 2006:2 (both in Swedish).

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APPENDIX A

In contrast to this unbalanced regression, an estimation where all variables are integrated of the same order, specifically I(0), would be interesting to see. In order to achieve this, the first difference approach will be used, i.e. all variables are differentiated. Again some first order serial correlation is detected in the error term and hence the Praise-Winsten regression is used to correct for this yet again.

Table V: Results from first difference Praise-Winsten Regression

Variables	I	II
Fares	-.7457	-.4001
	(0.000)	(0.000)
*Fares*Vacation*		-.3082
		(0.000)
Train ticket price	.3619	.2040
	(0.004)	(0.006)
Cost of driving	-.0774	-.0045
	(0.620)	(0.973)
GDP per Capita	.3464	.6200
	(0.441)	(0.094)
Population	-4.98	-5.37
	(0.113)	(0.031)
High speed rail	.0441	.0475
	(0.014)	(0.009)
Nine11	-.0366	-.0486
	(0.087)	(0.093)
Share Arlanda	.0097	.0418
	(0.922)	(0.596)
January	.1912	-1.49
	(0.000)	(0.000)
February	.2229	-1.43
	(0.000)	(0.000)
Mars	.4056	-1.27
	(0.000)	(0.000)
April	.3433	-1.33
	(0.000)	(0.000)
May	.3464	-1.33
	(0.000)	(0.000)
June	.3163	-1.36
	(0.000)	(0.000)
August	.2971	-1.38
	(0.000)	(0.000)
September	.3832	-1.29
	(0.000)	(0.000)
October	.4430	-1.23
	(0.000)	(0.000)
November	.4186	-1.26
	(0.000)	(0.000)
December	.2378	-1.44
	(0.000)	(0.000)
R^2	0.6960	0.7755
Orig. DW statistic	2.71	2.88
Adj. DW statistic	2.25	2.29
ρ	-.36	-.50

p-Values within parenthesis.

Paper III

Unilateral Linking of International Aviation and Stationary Sources within the EU Emissions Trading Scheme

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ABSTRACT

Starting on January 1st, 2012, the international aviation sector will be included into the already existing EU ETS. All air crafts departing and arriving within the European Union will be obliged to hold permits corresponding to their total emissions of CO_2 for those routes. Since emissions from the international aviation sector are not included under the Kyoto Protocol, the European Commission has decided to introduce a trading barrier between the sectors in order not to jeopardize the Kyoto targets. The purpose of this paper is to analyse the potential loss in cost-effectiveness of introducing such a trading barrier between two sectors taking into account that damage from emissions is not necessarily uniform. A theoretical model is developed to address the question and it is found that, at least for the case with linking the international aviation sector to the stationary sources within the EU ETS, the trading barrier might be unwarranted as it might lead to higher damage from emissions as compared to alternative ways to link the trading sectors. However, it should be stressed that this finding is not general and caution should be taken in the future when linking emission trading schemes as, depending on the heterogeneity of emission damage, a trading barrier might very well be justified.

JEL Classifications: *F13, F18, L51, P48, Q53, Q54, Q56*

Key words: *Aviation, Climate Change, Emissions Trading, Gateway, Policy*

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1. Introduction

In January 2005 phase I of the EU emissions trading scheme (ETS) was initiated, covering roughly 45% of total CO_2 emissions from the European Union. In order to further reduce emissions from the European Union, the European Commission has decided to link emissions from international aviation to the stationary sources within EU ETS. Starting on January 1st 2012, actors in the international aviation sector with routes either landing or departing within the EU are obliged to hold emission permits corresponding to how much they emit. During the first year, agents from the international aviation sector will be allocated 97% of historical emissions.[21] Allocation is to be conducted using both grandfathering and auctioning, [22] essentially the same way as in EU ETS to date. Starting January 1st 2013, with the start of phase III of the EU ETS, agents from the international aviation sector will be allocated 95% of their historical emissions. Emissions from international aviation (departing and arriving in EU member states) amounts to a small proportion of the EU ETS cap. It is therefore unlikely that the linking of the international aviation sector will have a noticeable impact on permit prices. [23]

The purpose of this paper is to analyse the effects of introducing a trading barrier (called the gateway) between the two trading sub-markets, the stationary sources already within the EU ETS and international aviation, taking into account that damage from emissions can be heterogeneous between the sub-markets. In section 2, the problem will be discussed and explained in detail. In section 3, a theoretical model will be developed. In section 4, a discussion of the possible values of the interesting control variables will be given. Lastly,

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[21] Historical emissions for the relevant routes and agents are calculated using an average of emissions during 2004 to 2006.
[22] The share of emission permits allocated through auctioning is meant to increase over time in the EU ETS. For a discussion of allocation methods, see for example Wit et. al. (2005) and Hepburn et. al. (2006).
[23] For a more in depth discussion about the effects on permit prices from linking the international aviation sector see Wit et al. 2005.

policy recommendations for unilateral linking of different emitting sources will be provided in section 5.

2. The Problem

Linking international aviation to the stationary sources within the EU ETS arises some questions about policy design. In particular, should emissions be considered the same for all sub-markets? And should all sub-markets be allowed to trade freely with each other? Since emissions stemming from international aviations are not a part of the Kyoto Protocol the European Commission has decided to only allow a net flow of emission permits from the stationary sources to international aviation as this will prevent jeopardizing the goals set under the Kyoto Protocol and at the same time allow the international aviation market to grow.[24] This barrier to trade is usually referred to as the gateway. The gateway is graphically illustrated in figure 1. The initial allocations (q_E and q_A), given the total cap (Q), to the two submarkets will establish the gateway. Any solution of emitted quantities (e_E* and e_A*) from the two sub-markets that lies on the right hand side of the gateway will be impossible to reach through trade after the initial allocations are decided upon. Hence, if the permit price is higher for the stationary sources than in the market for international aviation, $P_E > P_A$, the markets will not clear. This will result in a loss in cost-effectiveness, illustrated by the shaded triangle in figure 1. If the permit price is higher for the stationary sources within the EU ETS than for the international aviation sector, the stationary sources would, given no gateway, purchase emission permits from the international aviation sector.

[24] In a sense, the gateway problem can be viewed as a safety valve for the international aviation sub-market, placing a cap on the permit price for the international aviation market, P_A, equalling the permit price faced by the stationary sources, P_E.

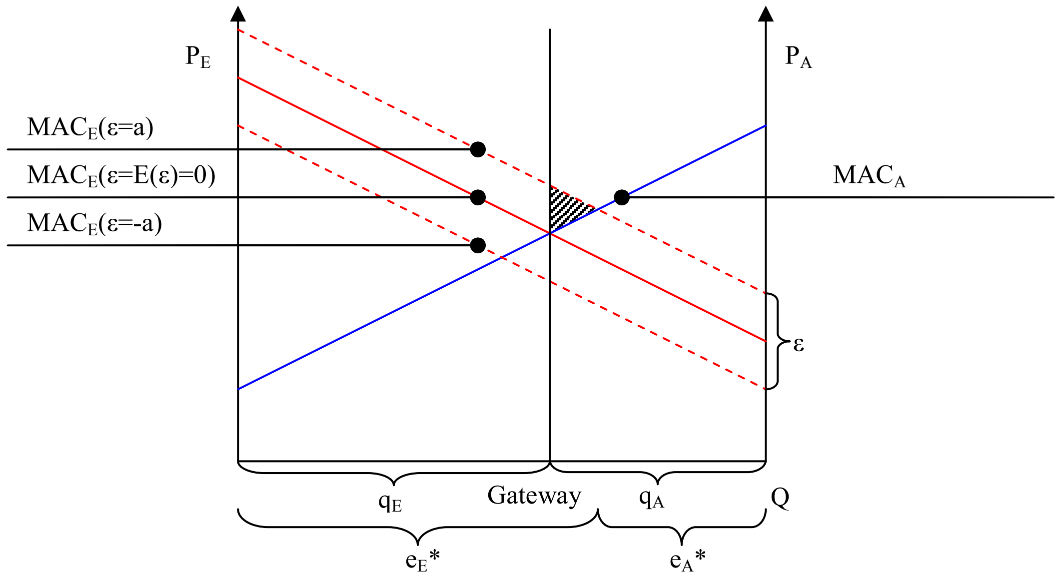

Figure 1. *A graphical illustration of the gateway problem.*

Emitted at higher altitudes, some greenhouse gases have a larger negative impact on climate change. How much more damage is however unknown. This introduces an additional problem where the damage potentially differs between the two sub-markets.

Mendelsohn (1986) show that when emissions are truly heterogeneous it might be better to separate the markets, if not, the total damage from emissions might be greater than if the markets would be treated as separate trading schemes. This depends on the potential benefit of separation that in turn depends on the dispersion of damage from the different emissions (or emitting sources). The heterogeneity can stem from either emitting sources in population dense areas or from different damage from different pollutants.

Wit et al. (2005) mentions the gateway as a possible part of the policy design when linking the international aviation sector to the stationary sector in the EU ETS. It is recognized that the effects of such a gateway are likely to be small since abatement is assumed to be more costly for the faster growing international aviation sector than for stationary sources. It is acknowledged that a gateway might lead to inefficiencies but also that they probably will be small.

Scheelhaase and Grimme (2007) recognize a potential problem with including emission permits meant for the international aviation sector in the EU ETS. As permits within the EU ETS (EAUs) are compatible with permits under the Kyoto Protocol (AAUs) additional permits allocated due to the inclusion of the international aviation sector would have to be exclusively ear market for the EU ETS. They suggest that a solution to this would be to include emissions from the international aviation sector through an amendment in a future climate policy negotiation, thus counting emissions from international aviation as any other emissions.

So far, there has been no formal evaluation of restricting the trade possibilities between the sub-markets. It is, however, important to analyse the potential problems (and of course potential benefits) of the introduction of a gateway between trading sectors in the same emissions trading scheme, even if it will turn out to be negligible for the case of linking the international aviation sector to the stationary sources of the EU ETS it might be important for future linking of emissions trading schemes or trading sectors.

3. The Model

The model presented here intends to capture the effects of introducing a gateway between two emissions trading schemes. In the following, it is assumed that the markets within the emissions trading schemes are perfectly competitive, that all agents on the markets strive to maximize their profits and that both transaction costs and income effects are negligible.

It is assumed that the regulator is not perfectly informed regarding the marginal costs of abatement when setting the levels of the control variables. A simplified setting is used for illustration purposes, where only the marginal abatement cost of one sector is uncertain. This uncertainty follows from the fact that the regulator has to reveal the decisions regarding the control variables (such as allocations) prior to the initiation of the scheme. Following Weitzman (1974, 1978) the marginal abatement costs are assumed to be linear and the stochastic uncertainty is additive, the marginal abatement costs for the two emissions trading schemes are represented as

$$MAC_E = f - ge_E + \varepsilon \tag{1}$$

and

$$MAC_A = k - le_A \tag{2}$$

where e_E denotes emissions from the stationary sources within the EU ETS and e_A denotes emissions from international aviation. ε is a stochastic variable assumed to be uniformly distributed over the range $(-a, a)$. The marginal abatement cost functions should be thought of as strictly non-negative and decreasing in emissions, hence, the parameters f, g, k and l are all non-negative.

For simplicity the total number of emissions permits, $Q=q_E+q_A$, is assumed to be exogenously given. This is not a crucial assumption but one that can be made as Q does not affect the primary focus of this analysis. Furthermore, the following substitution will be made throughout the analysis

$$q_A = Q - q_E \tag{3}$$

That is, allocated quantity to aviation is a residual. The regulator weighs the expected benefits to the expected costs of reducing emissions. That is, when deciding upon the optimal quantities of emission permits to be allocated to the two sub-markets the regulator has to account for a total damage function. Following Weitzman (1974), the total damage function is assumed to be quadratic and described by

$$TD_{Tot} = \frac{s(e_E + \alpha e_A)^2}{2} \quad (4)$$

where α captures the additional damage from one unit of emissions stemming from aviation. Since total damage is expected to increase in emissions *s* is a non-negative parameter.

The regulator decides how much to allocate to the two emissions trading schemes. The two schemes then have the possibility to trade in order to cover their emissions with permits, trade has to fulfil two conditions, the first one is given by

$$e_E + e_A \leq q_E + q_A \quad (5)$$

where q_E is the initial permit allocation to the stationary sources within the EU ETS and q_A is the initial permit allocation to the international aviation sector. In addition to (4) the following condition must be fulfilled

$$e_E \leq q_E \quad (6)$$

Condition (5) is assumed to be binding, that is, the sum of emissions will equal the total allocated quantity of permits. This is justified by assuming that it is always costly to reduce emissions and that the cap is binding. Implicitly, this assumption also prohibits both banking and borrowing in the scheme. The second condition (6) is where the problem subject to this analysis lies. This condition states that emissions from the stationary sources can never be larger than their allocated quantity of emission permits, essentially, this means that there cannot be a net flow of permits from the international aviation sector to the stationary sectors of EU ETS. Condition (6) also implies that the gateway is decided by the initial allocations to each sector.

Due to the gateway, trade between the two sectors will never take place as long as the permit price is higher for the stationary sources within the EU ETS. This means that for certain realizations of ε, the permit price will be higher for the stationary sources than for international aviation which will result in a situation where profitable trade, that would occur in absence of the gateway, is not allowed. This establishes a threshold value for ε, ε_T. The threshold value is such that for realizations of $\varepsilon \leq \varepsilon_T$ the permit price will be lower (or equal) for the stationary sources than for the international aviation sector, thus making it attractive for the international aviation sector to purchase such permits. On the other hand, for realizations of $\varepsilon > \varepsilon_T$, the permit price will be higher for the stationary sources than for the international aviation sector.

Given that the gateway is decided by the initial allocations, the threshold value, ε_T, is given by equal marginal abatement costs between the sectors

$$\varepsilon_T = k - f + gq_E - l(Q - q_E) \tag{7}$$

The total emitted quantities for each sector can differ depending on whether trade is allowed or not. If trade is not allowed and a cost effective solution cannot be reached, the emissions from each sector will simply equal the initial allocation to respective sub-market, i.e., $e_i=q_i$[25]. On the other hand, if trade is allowed, the cost-effective level of abatements from each sector is given by equal marginal costs across the sub-markets, i.e., prices are equal in both sectors. Setting (1) equal to (2) and substituting $e_A = Q - e_E$ yields

$$e_E^* = \frac{f - k + lQ + \varepsilon}{g + l} \tag{8}$$

As can easily be seen from (7) optimal emissions from the stationary sources depend on the realization of ε. If ε was known with certainty the regulator could simply allocate emission permits covering e^*_E to the stationary sources. The cost-effective level of emissions from each

[25] The assumption given in (5) still holds.

sector can only be achieved if the allocations of emission permits are exactly equal to these cost-effective levels, or, through trade.

It lies in the regulator's interest to minimize the expected sum of damage of emissions and total costs to achieve the emission targets. The total cost of abatement is given by the difference of emitting at some *business as usual* scenario and the decided quota in the trading scheme. The *business as usual* emissions are given by a marginal cost of abatement equal to zero. This yields the following (for the stationary sources and aviation respectively)

$$e_E^{BAU} = \frac{f+\varepsilon}{g} \tag{9}$$

and

$$e_A^{BAU} = \frac{k}{l} \tag{10}$$

Now, all necessary elements have been presented to specify the regulator's objective function, i.e. the expected sum of the loss in cost-effectiveness and the total damage as

$$\begin{aligned} E\{DWL+TD\} = {} & \frac{1}{2a}\int_{-a}^{\varepsilon_T}\left(\int_{e_E^*}^{e_E^{BAU}} MAC_E de_E + \int_{e_A^*}^{e_A^{BAU}} MAC_A de_A + TD_{Tot}\right)d\varepsilon + \\ & \frac{1}{2a}\int_{\varepsilon_T}^{a}\left(\int_{q_E}^{e_E^{BAU}} MAC_E de_E + \int_{q_A}^{e_A^{BAU}} MAC_A de_A + TD_{Tot}\right)d\varepsilon \end{aligned} \tag{11}$$

where the first row express the sum of the expected efficiency loss and the total damage for scenarios where trade is allowed, i.e., when $\varepsilon \leq \varepsilon_T$. Correspondingly, the second row concerns scenarios where an optimal solution cannot be reached, i.e., when $\varepsilon > \varepsilon_T$.

4. Optimal allocations

In this section, the optimal level of the control variables will be discussed. The regulator is interested in reaching an allocation of permits between the trading entities that will minimize (11). Thus the interesting control variables are q_E and q_A.

Substituting (1) through (4) and (7) through (10) into (11) and solving the integrals gives an expression for *E{DWL+TD}*. Minimizing this expression with respect to q_E yields

$$\hat{q}_E = \frac{a + f - k + lQ - 2Qs\alpha + 2Qs\alpha^2}{g + l + 2s(1 - 2\alpha + \alpha^2)} \qquad (12)$$

Expression (12) is the optimal allocation, $\hat{q}$, to the stationary sources taking both the expected efficiency loss of the gateway and the total damage from different emitting sources into account. From expression (12) several observations can be made, these are divided into 3 cases, for different values of *α*. [26]

1. When α = 1 (i.e. the damage from one unit of emissions is independent of source) the optimal initial allocation of permits is such that the gateway never enters into force.

In this case expression (12) becomes

$$\hat{q}_E\big|_{\alpha=1} = \frac{a + f - k + lQ}{g + l} \qquad (13)$$

which can be recognized as the allocation where the two MAC curves intercept given the highest possible realization of *ε*. From (13) it can easily be seen that q_E should be set such that the gateway never enters into force, even though the highest possible value of *ε* is realized. This means that the permit price for the stationary sources is never higher than the permit price for international aviation, independent of the realization of *ε*. This result can easily be

[26] There is a vast literature assessing α, see for example IPCC (1999). In the specific case of emissions from the aviation sector α is thought to be greater than 1 meaning that emissions from aviation have greater damage than other, stationary, land based emission sources.

seen in figure 1 as the solution where $\varepsilon = a$. If the allocation to the two sectors would be set such that the highest realization of the marginal cost of abatement for the stationary sources intercepts the marginal abatement costs for international aviation there are no scenarios where the stationary sources would demand more permits that they were initially allocated. From this, it can be concluded that there is a potential loss associated with a binding gateway.

2. When $\alpha > 1$ (i.e. when the damage is larger for emissions stemming from aviation) the regulator should increase q_E.

Intuitively, if the damage from emissions is greater when they stem from international aviation it would lie in the regulator's interest to minimize emissions from that sub-market. Therefore, when $\alpha > 1$, q_E should be set even higher than in the case where $\alpha = 1$. This result is somewhat puzzling as nothing prevents agents on the international aviation market from emitting as much as they want by simply purchasing permits from stationary sources. In order to maintain such an initial allocation, the regulator would instead want to either reverse the gateway or alternatively introduce an exchange rate for permits. However, given that the gateway prohibits exports of permits from international aviation to the stationary sources, the best the regulator can do is to allocate more to the stationary sources.

3. When $\alpha < 1$ (i.e. when the damage is less from emissions stemming from aviation) the regulator faces a trade-off.

In this case the expected efficiency loss from the gateway will still be minimized if q_E is set such that the gateway never enters into force. However, (12) now suggests setting q_E at a lower point due to the relatively high damage from emissions stemming from the stationary sources in the EU ETS. This means that the regulator faces a trade-off between the expected efficiency loss of the gateway and the expected total damage of emissions. In this case, depending on how large the additional damage is from the stationary sources, the gateway would work in an appropriate way.

5. Policy implications

Based on the results presented above, given that α is larger than 1, it can be concluded that the proposed gateway between the stationary sources in the EU ETS and international aviation may not be justified from an efficiency point of view. The model clearly states that the larger is α, the more should be allocated to the stationary sources. A one-way gateway allowing international aviation to purchase emission permits from the stationary sources combined with higher damage from their emissions will potentially result in a scenario where total damage is higher than if the sub-markets were completely separated. In order to prevent that high damage emissions from international aviation replace low damage emissions from stationary sources, a reversed gateway, alternatively, an exchange rate could be used. The possibility to simply separate the sectors into two exclusive trading schemes could also be an alternative. However, considering that allocating all permits to the stationary sources within the EU ETS might jeopardize the Kyoto targets the gateway is functional.

However, for future unilateral linking of emissions trading schemes or inclusion of additional sectors into already existing schemes it should be noted that the results regarding linking of the international aviation sector and the stationary sources within the EU ETS cannot be generalized. If evidence would have pointed towards an α significantly smaller than 1 (contrary to existing evidence) a similar gateway to the one analysed in this paper could very well be justified.

Caution should be taken when unilaterally combining several emissions sources with heterogeneous emissions, or unequal damage. Depending on how emission reductions are measured a unilateral linking may, instead of decreasing total emissions (or at least the damage from total emissions), increase them. Jaffe et al. (2009) discuss this point as one of the large concerns with linking emission trading schemes. This is particularly interesting in the case of aviation where it is assumed that several greenhouse gas emissions have a larger impact when emitted at high altitudes.

In conclusion, the gateway between the stationary sources within the EU ETS and the international aviation sector cannot be justified if the regulator's goal is to achieve cost-effectiveness. It has however been pointed out that the international aviation sector is more likely to be a net buyer of emission permits thus rendering the gateway ineffective (Wit et al. 2005; Scheelhaase and Grimme, 2007).

Further research is called for regarding what policy measures can be used when linking several sub-markets or emissions trading schemes to each other when damage from emissions may be heterogeneous between markets.

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