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The Environmental Impacts of Increased International Air Transport

Past trends and future perspectives

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FOREWORD

This paper was prepared by Dr. Eric Pels of VU University, Amsterdam, the Netherlands, as a contribution to the OECD/ITF *Global Forum on Transport and Environment in a Globalising World* that will be held 10-12 November 2008 in Guadalajara, Mexico.

The paper discusses the environmental impacts of changes in international aviation activity – past trends and future perspectives. Minor modifications have been made to the paper in the aftermath of the Global Forum.

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THE ENVIRONMENTAL IMPACTS OF INCREASED INTERNATIONAL AIR TRANSPORT – PAST TRENDS AND FUTURE PERSPECTIVES

1. Introduction

1. The environmental impact of air travel gets a lot of attention in the media as well as in the policy debates. Air travel contributes to climate change, and causes environmental and economic damage by its CO₂, NO_x, noise and other emissions. In economic terms, air travel causes external effects, which somehow need to be accounted for in the price of air travel. A number of countries (*e.g.* the U.K., France and the Netherlands) have therefore implemented a departure tax. But whether such a tax covers the environmental cost of air travel, not included in the ticket price, is a difficult question. This leads to heated debates about, for instance, the ticket taxes. Opponents of such taxes argue that a ticket tax is harmful for the economy, while the effect on the CO₂ emissions is questionable if passengers can easily switch to an airport in a nearby country which does not levy such a tax.

2. In this paper we review the literature on the environmental impact of aviation, discuss trends in emission patterns, and see how the external cost of aviation is determined in various studies. Fuel consumption and CO₂-emissions grew 2 to 4% in the period from 1990-2004, and are expected to grow further (Schlager *et al.*, 2007). Next to the economic growth, we discuss technological and network developments as determinants of aviation emissions. The purpose of the paper is to determine how developments in the aviation sector in the last few decades have impacted on the environment, and what this means for transport and environmental policy. Global aircraft emissions influence the climate in various ways. The Intergovernmental Panel on Climatic Change (IPCC) completed a report on the effects of aviation on the global climate, and is a much cited reference in this field (Penner *et al.*, 1999). Lee (2004) reports that new insights indicate that the effects may be larger than reported by IPCC in 1999. This is a technological issue that we do not touch upon in this paper.

3. The paper is organized as follows. Section 2 summarizes developments in the aviation sector since the Second World War. Section 3 discusses the literature on the environmental impact of aviation. Section 4 concludes.

2. Effects of deregulation of aviation markets in the U.S. and E.U

4. This section discusses some historical developments in the aviation sector. These insights are necessary to understand some of the environmental effects discussed in section 3, and to discuss the policy implications.

2.1 Aviation and the economy

5. Passenger numbers have steadily increased over the last decades. Table 1 below summarizes the growth rates of the gross domestic product and air traffic measured in revenue passenger kilometres (RPK) (Boeing Aircraft Company, 2007). In the past 20 years, the growth rate in revenue passenger kilometres

exceeded GDP growth. This pattern is expected to continue in the next 20 years. In Asia, growth in RPK is relatively high compared to Europe and the U.S. because of the more rapid economic development. Many researchers report a strong correlation between the growth rates of the gross domestic product and air traffic measured in revenue passenger kilometres (see *e.g.* Doganis, 2001), so that the high expected economic growth translates to high expected growth in demand for aviation services.

Table 1 GDP and Revenue Passenger Kilometres growth rates

	North America		Europe		China		Southwest Asia	
	1987-2006	2007-2026	1987-2006	2007-2026	1987-2006	2007-2026	1987-2006	2007-2026
GDP growth rate	3.2%	2.8%	2%	2.1%	9.9%	6.6%	5.6%	5.7%
RPK growth rate	4.1%	4.0%	5.7%	4.2%	11.0%	8.0%	6.2%	6.9%
GDP-to-RPK multiplier	1.3	1.4	2.9	2.0	1.1	1.2	1.1	1.2

Source: Boeing Aircraft Company (2007).

6. IATA reports that aviation contributed an estimated US\$ 3.557 billion to the global economy in 2007; which was roughly 7.5% of world GDP.¹ Air transport has a direct impact on GDP through the airlines and all suppliers. But also air transport also impacts on the economy in the regions surrounding airports. For instance, Button and Taylor (2000) find empirical evidence that areas surrounding U.S. airports (hubs) that have attracted international air services (to the EU), retained or internally generated relatively more employment than those without such services. Although additional gains tend to decline as airports continue to grow, most national governments and operators of hubs find it important to acquire or maintain a hub-status for their most important airport, as they consider this an important asset to the economy. Economic growth stimulates aviation demand, but as we have seen above, airline network developments also impact on aviation demand, and thus emission patterns. We therefore discuss this further below.

2.2 Airline network development

7. In the last two decades, the deregulation of aviation markets in the U.S. and E.U. led two interesting developments in international aviation networks. As a result of concentration in international aviation markets, large passenger flows fly indirectly, and therefore relatively long distances. In this section we discuss the background of this trend, while in Section 3 we discuss the environmental impact.

8. At the Chicago convention of 1944 the future of the international aviation markets was discussed. It was decided that capacity and frequency were to be negotiated in bilateral agreements, and that fares were to be regulated by the International Air Transport Association (IATA). Airlines were limited in their ability to compete.

9. In essence, there was no market mechanism that would lead to economically efficient prices and frequencies. As a result, costs were high and prices did not reflect demand. Customer preferences, frequencies and routes operated had become a political issue rather than an outcome of market forces. Already in 1960, the Economist wrote: “The basic trouble remains that the world has too many airlines, most of them inefficient, undercapitalized and unprofitable”.

10. Also within the United States markets were closed. The Civil Aeronautics Authority, later renamed as the Civil Aeronautics Board (CAB), determined routes and regulated fares in the U.S. to protect the carriers from “destructive” competition and protect consumers, while allowing airlines to obtain a reasonable return on ticket sales. During the 1960s and 1970s it became more and more clear that government regulations were too restrictive for the airline industry. In 1978 the Airline Deregulation Act

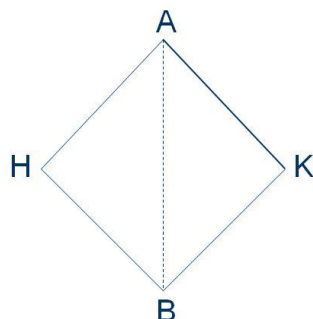
¹ www.iata.org/pressroom/facts_figures/fact_sheets/economic_social_benefits.htm.

was passed. All restrictions on (domestic) routes, fares and schedules were to be removed. Increased airline operating efficiency and competition were expected to benefit both airlines and passengers.

11. Following deregulation of the U.S. aviation market, there was a large scale entry of new carriers, followed by the rapid departure of almost all of them. Immediately after the deregulation, there were about 40 major carriers, while some 15 years later there were six or seven. It thus appears that competition did not increase following the deregulation, albeit that fares decreased in real terms since the deregulation. The decline in fares from 1976 to 1985 represented a savings of \$11 billion U.S. to passengers in 1986 (Kahn, 1988). The disciplining effect of competition was, however, geographically unevenly distributed. Airlines were free to operate their most efficient networks, and most airlines decided to operate the hub-and-spoke network, which allows for the exploitation of density economies, and reduces fixed cost per link. The number of competitors may have actually decreased on routes starting or terminating at a hub. On routes between hubs and on long haul, connecting flights, there may, however, be fierce competition. These developments meant that passengers in long-haul markets within the U.S., and in international (intercontinental) markets often had to make detours; *i.e.* use indirect flights with relatively long flight distances and two take-offs.

12. The hub-and-spoke systems allow for the creation of so-called fortress hubs. Zhang (1996) shows that airlines using hub-spoke networks may not have an incentive to invade each other's network, because this may lower profits in the 'original' network. Zhang uses the network depicted in Figure 1 to make this point, where airline 1 uses H as a hub, serves AH and BH directly, and AB indirectly, while airline 2 uses K as a hub, serves AK and BK directly, and serves AB indirectly. This network is not realistic since the market between hubs is missing, but similar results are obtained when this market is included.

Figure 1 Network configuration



13. When airline 1 invades markets AK and BK, the price decreases because of increased competition. Airline 2 responds by increasing its output in the AB market; : lowers average costs on the AK and BK links because of density economies. Airline 1 loses output in AB-market (airline 2 captures part of the AB-market of airline 1), so that average costs on the AH and BH links increase. As a result, flights on the AH and BH markets get more expensive, and the number of passengers in these markets decreases. Because output is decreased in the original network (HAB), the additional profits of the new AK and BK markets have to be balanced against losses in the original network. When density economies are strong (effects mentioned above are strong) and willingness-to-pay is high, attacking the network of airline 2 decreases profits for airline 1. Therefore, entry in competitor's network may lead to lower overall profits. Instead, more often than not, airlines choose to enter alliance agreements rather than to enter a competitive game. This means that in the 1980s and 1990s there was a geographical concentration of airline networks around limited number of hub airports. Goetz and Sutton (1997) found that from 514 locations with one or more regular connections in 1978, 167 locations lost these connections in the period until 1995. Only 26 new locations got regular connections, and connections to 77 locations were subsidized by the government.

Again, this implies that many passengers on long-haul or international flights necessarily fly on indirect flights, resulting in relatively long flights.

14. The deregulation of the E.U. aviation market was far more gradual compared to the U.S. case. But the outcomes are similar. Many European airlines were state companies with radial networks. The potential for transfer existed, but airlines did not fully exploit the possibilities offered by transfer traffic (Dennis, 1998). A shift from the radial network to the hub-spoke network by a better timing of flights to allow for more convenient transfers allows for the exploitation of density effects. Airlines with hub-spoke networks did not invade each other's networks, and also in the E.U. there was concentration: some airlines went bankrupt (Swissair, Sabena), while other airlines entered alliance agreements (the Air France-KLM merger being the most far reaching). In the most profitable international markets (between Europe and the U.S.), concentration becomes apparent through the formation of various alliances. Airlines enter such agreements to exploit density effects and reduce competition. For international passengers, alliances can be beneficial. Before alliances were created, European airlines had restricted access to U.S. destinations. Following an alliance agreement with a U.S. partner, European airlines could offer far more destinations to its passengers within the U.S. Again, such international passengers more often than not fly indirectly. For instance, about 65% of KLM's passengers are international passengers transferring at KLM's hub (Amsterdam airport, Schiphol).² Thus, alliance agreements led to growth in international markets, measured in passengers and in passenger-kilometres due to longer distances.

15. A recent development is the agreement between the U.S. and the E.U. to form the Open Aviation Area, which grants airlines from the U.S. access to E.U. markets, and vice versa. While it remains to be seen whether there will be large scale entry by new competitors, it is evident that competition will increase in certain markets where demand is very high (*e.g.* London-New York). American airlines are already spending large sums of money to obtain landing slots at London Heathrow, where capacity is very scarce. Other, less congested airports may be available, but such airports do not offer the status or extensive number of connections and airlines offered by Heathrow. Furthermore, yields on flights from Heathrow are on average higher than from alternative airports, because of the status of the airport, and the connections with the City of London.

16. To summarize, the deregulation of aviation markets led to the adoption of hub-spoke networks by full service carriers. Such networks, and the formation of alliances that followed this development, caused concentration in aviation markets. This concentration implies that networks of major airlines are centred on the major airports, which face a large amount of traffic. Many international passengers fly indirectly via these hubs, so that travel times and distances are relatively long. In the Section 4, we discuss the environmental effects.

3. Technological developments

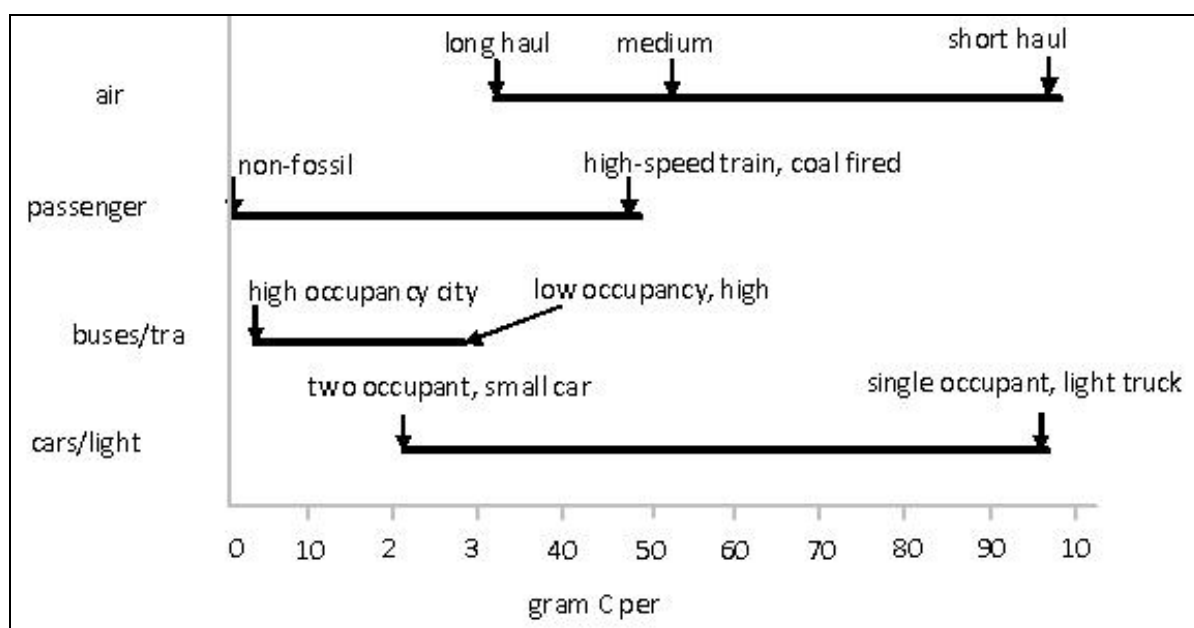
17. Two major innovations in air transport were the introduction of jet engines, which considerably shortened travel times, and the introduction of wide-bodied aircraft, which gave airlines the opportunity to reduce the cost per seat. Both developments reduced the generalised cost of travel, so that they had a positive impact on demand.

18. Jet engines allowed for much faster travel, although fuel consumption increased. When we only consider the jet engines, the energy efficiency improved in recent decades (piston engines were more fuel efficient compared to the early jet engines). IATA reports that fuel burn and CO₂ emissions were reduced by 70% per passenger-kilometre compared to 1970s (www.iata.org). The sector's goal for a 10% improvement in fuel efficiency (and relative CO₂ emissions) between 2000 and 2010 will most likely be

² Source: www.klm.com.

met, while IATA forecasts a 25% reduction in fuel consumption per RTK between 2005 and 2020. Figure 2 shows that air transport may be as fuel efficient per kilometre as road traffic, as suggested by IATA. Two remarks are in order, though. Firstly, aircraft emit CO₂ and NO_x at cruising altitude, which is close to the tropopause (the transition between the troposphere and stratosphere). Depending on the cruising altitude, emitted NO_x can contribute to the production of the greenhouse gas ozone (troposphere) or the destruction of ozone levels, which leads to increased UV radiation exposure (stratosphere) (Royal Commission on Environmental Pollution, 2007). IPCC reported that ozone increased at cruising altitudes for sub-sonic aircraft, while predicted changes in UV-radiation are minimal (Royal Commission on Environmental Pollution, 2007).

Figure 2 CO₂ intensity of passenger transport



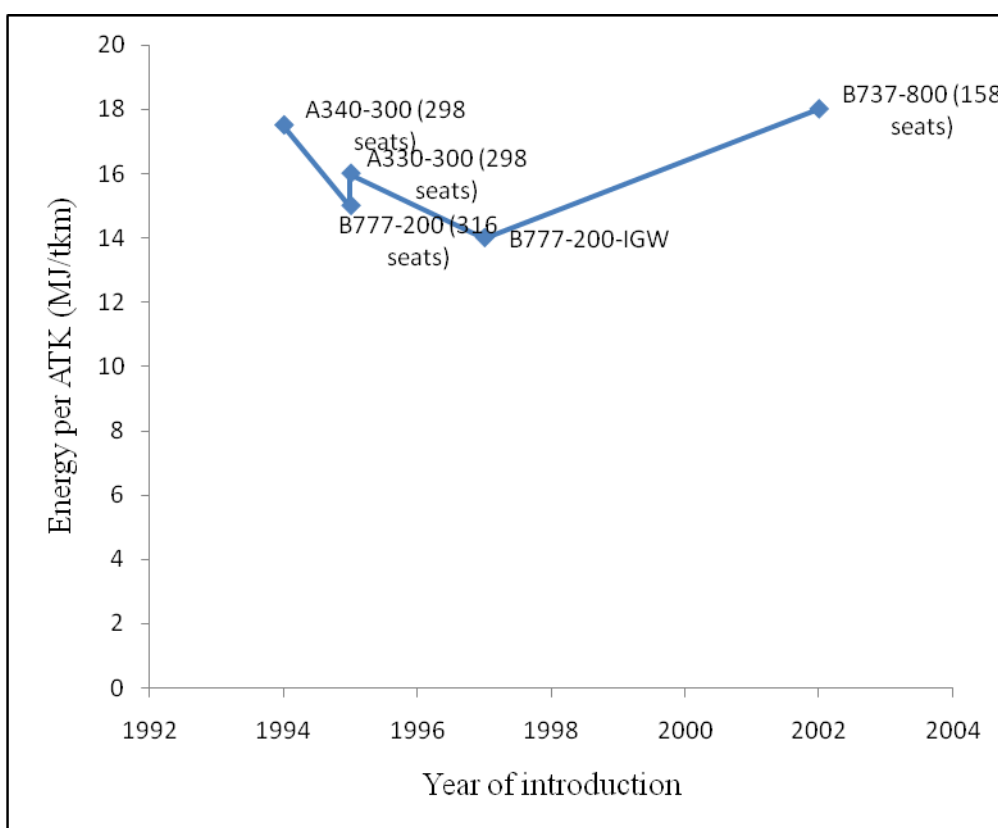
Source: Penner *et al.* (1999).

19. Secondly, air travel in most cases covers far longer distances than road travel. Although one can argue that because of these longer distances, the environmental impact of aviation is bigger, we need to look at total passenger-kilometres. IATA reports that all modes of transport together account for 23% of global CO₂ emissions (www.iata.org). Road traffic accounts for the vast majority, 74%, of the transport sector's CO₂ emissions because of the sheer magnitude of road use worldwide. Air transport accounts for 12% transport sector's CO₂ emissions; or about 3 to 4% of global carbon emissions (Penner *et al.*, 1999). Even though the availability of international air travel at low prices (*i.e.* low-cost travel and indirect flights) can cause an increase in CO₂ emissions, the ever-increasing demand for short-haul car trips (*e.g.* for commuting) apparently causes an even higher increase in CO₂ emissions. Finally, as we have seen above, the concentration in the aviation markets caused an increase in flight distance and the need for two landing and take-off cycles, which have different fuel burn rates (Pejovic *et al.*, 2008), for many passengers. Fuel burn during the take-off and landing cycle is much higher than during climb, cruise and descent cycle, so that network configurations with indirect travel have a relatively large environmental impact. Globalization can lead to an increase in demand for international air travel, which causes environmental damage. Globalization and the changes in international regulations also allow for the formation of alliances, so that the concentration in the aviation sector as discussed above continues, and can lead to further damage because of the need for indirect travel.

20. The environmental effects of growth in aviation may be mitigated by technological developments, such as more efficient engines. In the literature, an increase in fuel efficiency of 70%

between 1960 and 2000 is often mentioned. Peeters *et al.* (2005) argue that the often cited 70% improvement in fuel efficiency as reported by the IPCC (Penner *et al.*, 1999) is somewhat optimistic because it uses a De Havilland Comet 4 as the reference aircraft, while this aircraft was only used for a brief period and gained little market share. If the successful Boeing 707 is used as the reference rather than the De Havilland Comet 4, fuel efficiency improved by 55% rather than 70% over the same period. Although the analysis of Peeters *et al.* (2005) confirms that jet aircraft fuel efficiency increased over time, the authors also conclude that the research target for 2020 as mentioned by ATAG (2005), and based on an annual reduction of fuel consumption per ASK on 3%, is probably too optimistic. Peeters *et al.* (2001) point out that technological developments in the last decades were mostly made for small and medium sized aircraft. Under the simple assumption that these aircraft are used in short to medium haul markets, it then appears that in long-haul (international) markets there were relatively few gains. But newer aircraft (the latest B777 and A380) now allow for gains to be made in international markets.

Figure 3 Fuel use per available tonne-kilometre

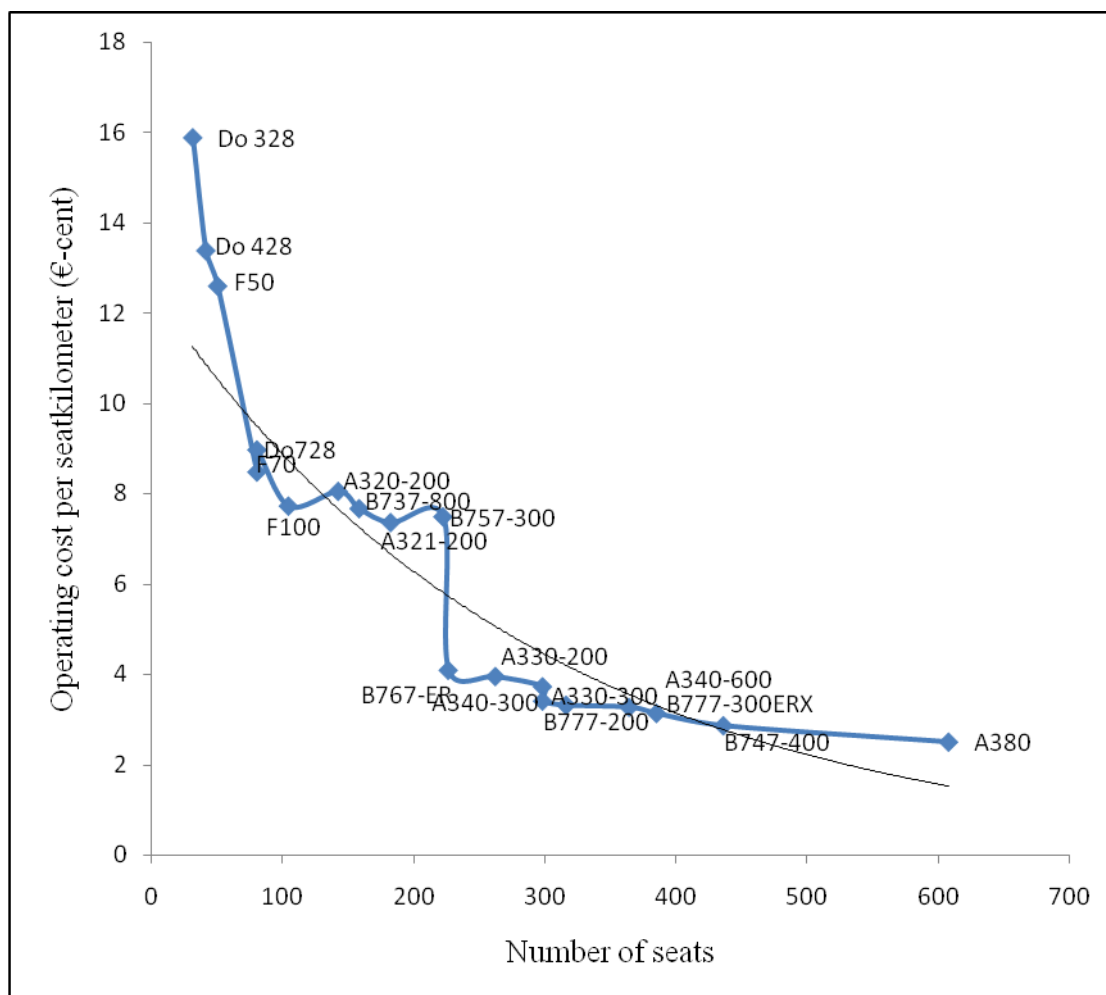


Source: adapted from Peeters *et al.*, (2005).

21. When we consider the fuel burn per available tonne-kilometre of a number of popular aircraft (Figure 3), then it appears that smaller aircraft (in terms of passengers carried) have higher energy use, although the number of observations is too small to find a reliable statistical relation.

22. The adoption of hub-and-spoke networks meant that an increasing number of passengers was concentrated on a relatively small number of links. Because larger aircraft are cheaper to operate per seat (see Figure 4), airlines could reduce their cost. Moreover, if there are economies of scale in environmental terms (see *e.g.* Schipper, 2004), meaning that an aircraft with 300 seats emits less noise or CO₂ per seat than two aircraft with 150 seats, as is suggested by Figure 3, larger aircraft also provide environmental benefits.

Figure 4 Operating cost per seat



Source: adapted from Connekt, (2001).

23. Interestingly, the average plane size in the transatlantic markets peaked at about 320 seats in 1985, after which it rapidly decreased to about 260 seats in 1995. After 1995, there was a steady increase, with an expected size of about 300 in 2010 (Penner *et al.*, 1999). Brueckner and Zhang (1999) indicated that the frequency of service in hub-and-spoke networks may be increased to attract additional traffic in the face of competition. When a number of competitors offer a high frequency, this may create over capacity in the market. Airlines can encounter this by using smaller aircraft. At a later stage, following the bilateral agreements between the U.S. and various European countries, airlines used alliance agreements to encounter over-capacity and to exploit density economies.

24. To summarize, we described two major innovations. The introduction of jet engines meant faster travel, but also a decrease in fuel efficiency. The fuel efficiency of jet aircraft increased over the last decades, although one can wonder whether the 70% improvement compared to the De Havilland Comet 4 (IPCC, IATA) provides useful information. If more successful early jet aircraft are used as the base for the comparison, the efficiency improvement is less. The introduction of wide bodied aircraft meant that the cost per seat decreased due to density economies, and that the environmental cost per seat could be reduced due to economies of scale in environmental terms. The formation of hub-and-spoke networks concentrates large passenger flows on a limited number of links, allowing for the use of relatively large aircraft. Hub-and-spoke networks thus offer potential reductions in environmental damage per seat because of the possibility to use larger aircraft. On the other hand, hub-and-spoke networks are centred on large airports,

which are often congested, while passengers travelling indirectly cause a relatively large amount of pollution because of the detour, and more importantly, the double take-off.

4. Environmental effects of aviation

25. In the previous sections we reviewed recent developments in the aviation sector. In this section we discuss the environmental effects. This will be done by reviewing the relevant literature. The literature on this topic is quite diverse. In this section we first discuss the general relation between aviation and the environment (section 4.1). In section 2 we discussed the relation between GDP growth and aviation demand. Furthermore, we discussed the deregulation of aviation markets. What does this mean for the environment? In section 4.2 we specifically consider hub-and-spoke networks. Finally, we discuss the local effects of air travel in section 4.3, when we consider the relation between aviation noise and house prices.

4.1 Growth and the environment

26. In Section 2 we discussed the increasing demand for aviation services. It is expected that demand for aviation services will continue to grow faster than GDP. De Haan (2007), based on GDP growth, speed of maturation of aviation markets and network development, predicts that in the most pessimistic *economic* scenario air travel in 2050 will have increased by a factor 2.5 in 2050, compared to 2004. In the most optimistic *economic* scenario, air travel in 2050 has increased 9 times compared to 2004. De Haan (2008) discusses potential reductions CO₂ emissions due to technological developments. Reductions of 15-25%, or even 50% for radically new designs, are not enough to compensate for the increased demand.

27. Table 2 shows past and expected trends in emissions in CO₂ and NO_x, as reported by Penner *et al.* (1999). According to NASA's calculations, NO_x emissions grew by 46% between 1976 and 1984, 41% between 1984 and 1992. NO_x emissions were expected to grow by 174% between 1992 and 2015. ANCAT and DLR present somewhat more moderate expectations, with NO_x emissions expected to grow by 111% and 113% between 1992 and 2015. The expected growth in CO₂ emissions reported by NASA is similar to the growth reported by ANCAT and DLR: 121%, 118% and 120% respectively. These numbers show that the growth in international aviation lead to increased environmental damage.

Table 2a: Calculated NO_x Emission (Tg as NO₂).

	NASA 1976	NASA 1984	NASA 1992	ANCAT 1992	DLR 1992	NASA 2015	ANCAT 2015	DLR 2015
Civil Subtotal	0.70	1.02	1.44	1.60	1.60	3.95	3.37	3.41
Military	0.28	0.25	0.23	0.20	0.20	0.18	0.16	0.16
Global Total	0.98	1.28	1.67	1.81	1.80	4.12	3.53	3.57

Source: Penner *et al.* (1999). Tg = teragrams (tonnes*10⁶)

Table 2b: Calculated CO₂ Emissions (Tg C).

	NASA 1976	NASA 1984	NASA 1992	ANCAT 1992	DLR 1992	NASA 2015	ANCAT 2015	DLR 2015
Civil Subtotal	55.36	74.44	97.91	98.22	96.52	247.72	234.21	232.63
Military	30.67	25.59	21.98	14.68	14.71	17.71	12.50	12.47
Global Total	86.03	100.03	119.89	112.92	111.23	265.43	246.71	245.10

Source: Penner *et al.* (1999). Tg = teragrams (tonnes*10⁶)

28. Table 3 shows the expected growth in CO₂ emissions between 2002 and 2030 in various scenarios (Horton, 2006). Horton (2006) assesses the growth of CO₂ emissions from civil aircraft to 2030. An important aspect in this analysis is the effect of a carbon tax. The same growth in traffic was applied to all cases, implying that the only effect of a carbon tax is an efficiency improvement. The study therefore does not include the airlines' option of passing a carbon tax on to the passengers, so that demand is influenced (reduced).

Table 3 CO₂ emissions calculated for each case for years 2002 and 2030.

	CO ₂ emissions 2002 (Tg)	CO ₂ emissions 2030 (Tg)	Ratio of CO ₂ emissions to 2002
Case 1	489.29	1609.74	3.290
Case 2	489.29	1395.06	2.851
Case 3	489.29	1247.02	2.549
Case 4	489.29	1100.15	2.248
Case 5	489.29	969.96	1.982

Source: Horton (2006). Tg = teragrams (tonnes*10⁹)

Case 1: No technology improvements to fuel efficiency

Case 2: 2005 and 2008 best available technology: Boeing 787/Airbus 350/Airbus 380 technology levels

Case 3: Fuel efficiency improvements (1.3% per annum to 2010, 1.0% per annum to 2020, 0.5% per annum beyond)

Case 4: Fuel efficiency improvements as in 3, with additional efficiency improvements driven by a \$50 per tonne CO₂ cost.

Case 5: Fuel efficiency improvements as in 3, with additional efficiency improvements driven by a \$100 per tonne CO₂ cost.

29. Total distance covered by civil aviation aircraft is predicted to increase by 149% from 2002 to 2030, while the number of available seat-kilometres is predicted to increase by 229% over the same period. These numbers imply that aircraft size is expected to increase. In the scenario which is best for the environment (case 5), CO₂ emissions in 2030 are 22% less than in the scenario which does not have incentives for technological development (case 3). But even in this environmentally favourable scenario, CO₂ emissions are almost twice as high in 2030 compared to 2002. This confirms the claim by de Haan (2008) that technological developments are not enough to compensate for the increased demand. Because technological development is not enough to reduce the environmental impact of aviation, additional measures are necessary, such as environmental charges or emission trading. In any case, aviation will continue to cause environmental damage. Various studies tried to put a price on the environmental damage caused by aviation.

30. Long term predictions of traffic demand and emissions are uncertain because of unpredictable changes in demand patterns and technological innovations. For instance, some of the assumptions used for IPCC-scenarios (Leggett *et al.*, 1992), are that i) fuel prices will not increase significantly relative to other costs; ii) infrastructure can accommodate all demand; and iii) there are no significant impacts from other modes, such as high speed rail. Recent evidence shows that these assumptions are not met: fuel prices have risen, airports are becoming more and more congested, and high speed rail may become a substitute for aviation in short haul markets.³ The debate over the use of market exchange rates or purchasing power parities in the IPCC scenarios also illustrates the difficulties in forming scenarios. However, to formulate long term policy goals, it is necessary to use all currently available information to predict future demand and emissions. Long term studies which are often cited are from ICAO's Forecasting and Economic support group (FESG), The UK Department of Trade and Industry and (DTI) and the Environmental Defense Fund. The results are summarised in Table 4 below.

31. FESG uses high (Fe) and low (Fc) economic scenarios, combined with two different technology scenarios. The Fe and Fc scenarios are based on the IPCC scenarios IS92e and IS92c used by EDF (Penner *et al.*, 1992). The technology scenarios assume that NO_x reductions in aircraft emissions result from current design philosophies (scenario 1); or that a more aggressive approach to NO_x reductions result in smaller fuel efficiency gains (scenario 2). DTI uses its own forecast models for traffic predictions, and extrapolates Greene (1992) to obtain forecasts for fuel efficiency. The results reflect the strong assumptions on reductions in NO_x-emissions (assumed to be the result of technological developments

³ High speed rail captured a significant proportion of the London-Paris market, while airlines may also substitute high speed rail for flights in short haul markets to avoid the relatively high cost of such short flights.

induced by regulations). EDF specifically accounts for demand growth in developing countries, and uses IPCC scenarios for developments in economic indicators and emissions. Base level and high demand scenarios are used. Fuel efficiency is extrapolated from Greene (1992), while NO_x-emissions are extrapolated from NASA numbers. Penner *et al.* (1999) report that the emission index for NO_x indicates that emissions reflect an ultra-low technology regime. Roughly speaking, DTI and EDF seem to have comparable expectations on trends in NO_x emissions. The differences in emission levels are then mainly caused by fuel use levels.

Table 4 Long term emissions from aviation, Tg, excluding military

	FESG FC1 2050	FESG FE2 2050	DTI 2050	EDF IS92c 1990	EDF IS92c 2050	EDF IS92e 1990	EDF IS92e 2050
Fuel use (Tg)	253.8	757.7	633.2	179	837	179	2297
CO₂	218.2	651.6		154	720	154	1975
NO_x	3.9	8.7	4.45	1.96	5.77	1.96	15.84

Source: Penner *et al.* (1999).

32. Table 5 shows the average external costs of transport in the EU 17 countries as reported by INFRAS (Schreyer *et al.*, 2004). Scheyer *et al.* (2004) provide an extensive report about external costs (total, average and marginal) of transport: road (passenger and freight), rail (passenger and freight), air (passenger and freight) and waterborne (freight) transport. In this report almost all cost categories are discussed: accidents, noise, air pollution, climate change, costs for nature and landscape, additional costs in urban areas, up- and downstream processes and congestion costs. For the accident costs a value of a statistical (1.5 million euro) life approach is used, using ICAO database to determine fatalities per passenger-kilometre. For noise costs, a willingness to pay procedure (for disturbed persons only) is used, using a database from OECD (OECD, 1993). These costs also include the valuation of health risks and medical costs. Marginal costs of air transport are based on the available road and railway noise models. For road and rail advanced models exist to accurately predict noise emissions. For aviation such models do not exist, so that Scheyer *et al.* (2004) use insights from road and rail models to determine the marginal cost of aviation.

33. The costs of air pollution are determined using a top-down approach, based on willingness to pay surveys. In this approach, existing estimates are used, and transferred to other countries (correcting for various indicators). Climate change costs are determined as follows. Greenhouse gases emissions at global scale are included. Costs of CO₂ emissions are calculated by multiplying the amount emitted by a cost factor. This cost factor is the shadow price in currency per tonne CO₂. They use, based on literature review, 140 euro per tonne as upper value, and 20 euro per tonne as a lower value. Costs for nature and landscape use an expert valuation approach. The state of nature in 1950 is seen as sustainable by experts; any damage since then needs to be compensated. To determine the compensation for aviation, Schreyer *et al.* (2004) look at airport surface. The surface of the airport (aviation infrastructure) is the main cost component in this category.

Table 5 Average external costs of transport in the EU17 countries in 2000
 [Euro / 1000 pkm for passengers and Euro / 1000 tkm for freight].

	Road Passengers	Rail Passengers	Aviation Passengers	Road Freight	Rail Freight	Aviation Freight
Accidents	32.4	0.8	0.4	7.6	0.0	0.0
Noise	5.1	3.9	1.8	7.4	3.2	8.9
Air Pollution	13.2	6.9	2.4	42.8	8.3	15.6
Climate change high	16.5	6.2	46.2	16.9	3.2	235.7
(Climate change low)	(2.4)	(0.9)	(6.6)	(2.4)	(0.5)	(33.7)
Nature & Landscape	2.6	0.6	0.8	2.9	0.3	3.8
Up- and down stream	5.0	3.4	1.0	8.8	2.4	7.4
Urban Effects	1.5	1.3	0.0	1.5	0.5	0.0

Source: INFRAS/IWW (Scheyer *et al.*, 2004).

34. The average external cost per passenger-kilometre using the high climatic impact scenario is about 5 €-cent. With the low climatic impact scenario, the average external cost per passenger-kilometre is less than 2€-cent.

35. Dings *et al.* (2003) quantify “the external costs of air transport, and in particular the costs of climate change, air pollution and noise”, and “to provide insight into the principal factors determining these external costs”. No policy recommendations are provided. Also risks are not accounted for as an external effect. Apart from environmental costs which are not (directly) paid for by airports, airlines or passengers, aviation also may cause accident costs, for instance due to fatalities. These costs are not included by Dings *et al.* (2003). The report estimates shadow prices based on damage and abatement costs (direct costs approach, WTA approach, WTP approach and prevention costs approach). It defines the costs at the level of airplane type (number of passengers and flight distance). It uses existing databases to come up with these numbers. Table 6 report the average external costs (per passenger-kilometre) for different aircraft types, distances and climatic impacts. These numbers are of the same order of magnitude as the numbers reported by INFRAS.

Table 6 Average external costs.

	Shadow price for climatic impact of per tonne CO ₂ -equivalent		
	€ 10	€ 30	€ 50
Fleet-average technology, in € cent per passenger-kilometre			
50 seats, 200 km	5.7	6.4	7.0
100 seats, 500 km	1.8	3.0	4.2
200 seats, 1500 km	0.7	1.5	2.2
400 seats, 6000 km	0.3	0.7	1.1
State-of-the-art technology, in € cent per passenger-kilometre			
50 seats, 200 km	2.8	3.3	3.9
100 seats, 500 km	1.2	2.2	3.3
200 seats, 1500 km	0.5	1.1	1.8
400 seats, 6000 km	0.2	0.5	0.9

Source: Based on Dings *et al.* (2003)

36. The empirical studies mentioned above determine the environmental cost of aviation. More theoretical (simulation) studies are also available in the literature. The deregulation of aviation markets led to lower real fares (see *e.g.* Kahn, 1988). Lower fares cause an increase in demand, so that deregulation may lead to increased environmental damage. In this case, the welfare gains of deregulation have to be balanced against the welfare (environmental) damage of increased demand. Schipper *et al.* (2007) conduct an equilibrium analysis in a spatial competition model. In the equilibrium analysis the environmental external costs are dependent only on total flight frequency in the total market. Given a constant marginal

environmental flight cost, aggregate environmental costs can be determined in the analysis.⁴ Using empirically calibrated parameters, Schipper *et al.* (2007) shown in a simulation exercise that the liberalization of the European airline markets resulted in:

- Frequency increases (welfare +)
- Fare decreases (welfare +)
- Lower profits (welfare -)
- Increase environmental costs (welfare -)

37. Consumer welfare gains exceed (environmental) welfare losses. Because welfare increased, but at the expense of airline profits and the environment, (part of) the increase in welfare can be used to compensate airlines and the population for their losses. Compensation regulation in a liberated market can therefore become a useful policy instrument, particularly around airports in densely populated areas. For instance, noise surcharges can be used to compensate home owners for noise damage. The simulation exercise uses empirical inputs from Schipper (2004). Schipper (2004) estimates the environmental costs in European airline markets in 1990. The following costs are included:

- Noise (hedonic pricing and contingent valuation methods are used to determine noise annoyance). In hedonic pricing methods, the price of, for instance, a dwelling is related to all kinds of neighbourhood characteristics, including aviation noise. Using contingent valuation methods, people are asked what they are willing to pay to experience less aviation noise. Both methods are used to put a price on aviation noise.
- Emissions (Marginal Damage Functions for global warming and Value of Statistical Life [VOSL] for local emissions (mortality)). Several methods can be used to determine the cost of local air pollution, *e.g.* damage to human health, damage to buildings, reduced visibility, damage to forests, crops and fisheries etc. Schipper (2004) values air pollution emissions using the health damage pathway, which is identified as a dominant cost effect of air pollution. Using available information on how emissions may lead to increased fatalities and a statistical value of life, the cost of emissions is determined.
- Accident risks (again VOSL)

38. It appears that environmental costs are only a small fraction of total internal costs as measured by the ticket price (2.5%). Because prices have decreased since 1990, this may be an underestimate. Noise is the dominant external effect (75% of the total external cost). This is probably due to the fact that noise damage is experienced directly by the surrounding population, while the cost of emissions, calculated using the marginal damage functions for global warming and value of statistical life, is only experienced indirectly. This shows the difficulty of combining effects. The value of statistical life should include all costs that are made to avoid a fatality. But difficulties in estimating this value can make the comparison difficult. There are environmental economies of scale at the route level; environmental costs are decreasing in aircraft size, and size is related to distances: large aircraft may be used on short distances, but it is not always possible to use smaller aircraft on longer distances.

39. Scheelhaase and Grimme (2007) analyze the predicted growth of international air transportation in relation to internationally coordinated instruments for the reduction of greenhouse gas emissions. Global (Kyoto) and European emission trading schemes are mentioned. For European airlines, the European system is more likely to be realized (the E.U. initiated the European emission trading scheme). Scheelhaase and Grimme (2007) calculate the economic impacts for low cost carriers (Ryanair), full service

⁴ One may expect the external cost per flight to increase with the number of flights; *e.g.* a large number of flights with small aircraft may result in higher environmental costs than a relatively small number of flights with large aircraft. This makes the effects discussed below only stronger.

(Lufthansa), holiday (Condor) and regional airlines (Air Dolomiti) using the EU – ETS emissions trading scheme. Different scenarios are analyzed, in which aviation allowances to emit 1 tonne of CO₂ are needed by airlines. Scenarios are favourable for airlines (€15 per allowance, allowances only needed for intra-E.U. flights), or less favourable (€30 per allowance, allowances needed for all flights departing from or arriving at E.U. airports). Following an initial allocation based on grandfathering rights, airlines need to purchase allowances, and pass the cost on to the passengers. It is concluded that the introduction of such a scheme generates competitive effects: the financial impact for low cost carriers and regional carriers (without hub-spoke networks) is larger than network carriers, because airlines with hub-spoke networks have better opportunities to pass the cost on to the passengers; the cost per passenger of an allowance is a relatively small proportion of the ticket price on a long haul flight, so that given the price elasticity of demand, which is relatively low in absolute value on long haul flights, airlines with large networks suffer ‘less’. The impact on intercontinental traffic can therefore be expected to be relatively low. The financial impacts for airlines will be marginal: costs will increase approximately with 1 till 3 percent.

4.2 *Hub-and-spoke networks*

40. In section 2.2 hub-and-spoke networks were discussed. The concentration in aviation markets means that airline networks are centred on major hubs, which handle a relatively large share of all flights. Hub-and-spoke networks can lead to environmental benefits because of economies of scale in environmental terms (section 2.3). Passengers are concentrated on a few routes, so that larger aircraft may be used. But transfer passengers fly longer distances, and take-off twice, so that they have a relatively large environmental impact. International (intercontinental) passengers can fly relatively cheap using indirect tickets, so that this may stimulate demand, while these passengers often have a short haul flight, with relatively high environmental costs, included in their long haul route. Moreover, the environmental damage of aviation at the ground level is concentrated on a few airports and the surrounding areas. In section 4.3 we look at the impact of aviation (noise) on house prices. In this section we consider the environmental effects of hubbing.

41. Peeters *et al.* (2001) find that point-to-point networks have the lowest environmental impact, even though larger aircraft may be used in hub-spoke networks. Furthermore, hubs have larger environmental impacts than non-hub airports, and the number of hubs (in Europe) and the geographical distribution have a strong influence on the environmental impact of the total network. It should be pointed out that hubs are important for international traffic. Passengers from different origins in Europe are collected at hubs, and then transported to their final international or intercontinental destination (and vice versa). Collecting passenger from different origins on a single intercontinental flight may be beneficial for the environment compared to different intercontinental flights, but the short-haul flights are relatively damaging (see Figure 2). Interestingly, Peeters *et al.* (2001) find *no* environmental economies of scale (contrary to Schipper, 2004). They point out that technological developments in the last decades were mostly made for small and medium sized aircraft. Combining passenger flows from different origins may lead to financial benefits for airlines (Figure 4), but if the fuel efficiency of such aircraft per passenger kilometre did not really improve compared to smaller or medium sized aircraft, there may be little gain for the environment. Peeters *et al.* (2001) mention that the results may change when technological progress is made with large aircraft. Recently, new large aircraft emerged (such as the Airbus A380), which will probably offer environmental economies of scale. But such aircraft can only be used between very large airports (intercontinental hubs), so that demand will be relatively low compared to smaller aircraft. Interestingly, Boeing chose not to develop such a large aircraft, focusing instead on a smaller aircraft, to be used in point-to-point flights, rather than in a hub-and-spoke structure.

42. Morell and Lu (2007) examine noise disturbance and engine emissions in two network structures: hub-spoke networks and hub-by-pass structures (*i.e.* networks in which passengers do not transfer at a hub). The noise social cost model is based on HP methods; total aggregate noise disturbance is allocated to

individual flights based on real impact of noise nuisance (aircraft type etc). The (input for the) engine emissions social cost model is based on literature review. Given the analyzed networks - using the airports London Heathrow, Glasgow, Frankfurt, Hamburg, Chicago O'Hara, San Diego, Dallas and Tokyo- it is concluded that the hub-by-pass routes generate considerable savings in both noise and engine emissions costs. This confirms the result of Peeters *et al.* (2001) that hub-and-spoke networks have a relatively high environmental impact, compared to point-to-point networks. This means that also in long haul, international markets, it may be better for the environment if direct flights are used, rather than the indirect flights used by many passengers. Indirect flights may be cheap, because airlines use them to exploit density economies, but are relatively speaking harmful for the environment.

43. Nero and Black (1998) find that hubbing increases external costs (congestion, aircraft noise and emissions). The paper analyses the effects of introducing environmental costs on airport charges to hubbing airlines by formulating a model based on Schmalensee's model, but adapted to allow for monopolistic firms. After formulating that model, they perform a simulation exercise to show the optimal level of environmental taxes from a welfare perspective. From this exercise, the authors conclude that the hub-spoke network could be abandoned in favour of a fully connected network if the environmental tax is relatively high. No real empirical evidence is present, but the 'polluter pays principle' suggests that taxes for indirect flights or for international passengers transferring at hubs should be relatively high, given the observations made above. The results of Nero and Black (1998) then suggest that airlines will no longer use such a network. Interestingly, the ticket tax implemented by a few European is only for origin-destination passengers. Transfer passengers pay nothing, to safeguard the competitive position of the hub airport as a transfer airport in international or intercontinental markets. But this is 'bad' for the environment. Carlsson (2002) extends the analysis by Nero and Black (1998) by relaxing symmetry restrictions. An optimal charge is defined for two types of networks (fully connected and hub-and-spoke) and for both a monopolistic and a duopolistic market situation. In this model, the environmental effects are solely dependent on number of flights offered in the equilibrium outcome of each market. Again, no empirical estimations are present.

4.3 *The effect of aviation on house prices*

44. It was already mentioned above that hub-spoke networks lead to relatively large noise (and other) emissions around the hub airport. Various authors tried to determine the impact of airports on the surrounding region by looking at property prices. Such studies do usually not consider CO₂ and other emissions, but only focus on the relation between property prices and noise.

45. Schipper *et al.* (1998) consider noise nuisance around airports. A comparison of hedonic pricing (HP) and contingent valuation methods (CVM) to determine the cost of aviation noise shows that CVM noise cost estimates are significantly higher than HP noise cost estimates. An explanation might be that HP methods report only 'use values', while VCM methods also uncover other value categories. Moreover, HP methods do not use information on consumers not willing to consider properties because of noise nuisance. Nineteen HP studies (related to property values), resulting in 30 noise depreciation indices (NDI), are analyzed using meta-analytical techniques. The NDI gives the percentage change in property value due to a decibel change in noise exposure. Wealth and other neighbourhood characteristics, such as accessibility, have a positive impact on the NDI.

46. Morell and Lu (2000) provide an empirical case-study about the implicit social costs of aircraft noise (via decline in property values) in the Amsterdam Schiphol area. Using a social cost of noise function, based on hedonic pricing methods and the property values, and the belonging parameters for the Amsterdam area (number of houses in noise contours etc.), the average social noise cost in 1999 is calculated as €326.8 per landing. From this knowledge the marginal social cost function is obtained. The

authors claim that the figures are in line with previous related studies. It is concluded that the current noise charges (€157.3 per landing) are too low to compensate the social noise costs.

47. Morrison *et al.* (1999) provide an economic assessment of the benefits (higher property values for homeowners) and costs (airplane's reduced economical life) of the 1990 ANCA (Airport Noise and Capacity Act). Under noise regulation the fleet of an airline operator has to be renewed faster than without regulation. According to the authors, this accelerated (non-optimal) depreciation of the fleet is the source of the costs of regulation. Benefits of the regulation are taken as the increase in housing values (based on WTP). At the end, they come up with these figures: 5 billion (1995 dollars) benefits and 10 billion (1995 dollars) costs: therefore they are wondering if airplane noise regulation is justified from an efficiency perspective.

5. Conclusion

48. In this paper we discussed the environmental impact of aviation. Aviation demand grew rapidly in the past decades, and it is expected that this growth will continue (Boeing, 2007; de Haan, 2008; Horton, 2006). Expected technological innovations cannot prevent an increase in CO₂ emissions from aviation due to the increase in demand (de Haan, 2007). Depending on the technology and scenario used, the average external cost of air travel is about 1-5 €-cent per passenger-kilometre.

49. The deregulation of the aviation markets had profound effects on network developments. Major airlines use hub-and-spoke networks, which means that selected airports receive a relatively large share of all take-offs and landings in the network. As a result, noise pollution in the surrounding area is relatively high, and passengers travelling indirectly have to make a detour. But hub-and-spoke networks might also have environmental benefits because of environmental economies of scale: larger aircraft, with lower emissions per seat, can be used because passenger flows are concentrated on a few links. The literature shows that negative environmental effects of hub-and-spoke networks exceed the positive effects. Concentration is therefore bad for the environment. It is expected that the trend of concentration will continue. For instance, when Ryanair celebrated the fact that it had flown 1 million passengers to Bratislava (early November 2007), its CEO, Michael O'Leary claimed that within 5 years there will be 4 major airlines left in Europe: British Airways, Air France, Lufthansa and Ryanair. If British Airways, Air France and Lufthansa and their alliance partners will focus their networks on a few intercontinental hubs, traffic levels will increase at these hubs due to the general expected increase in demand, but also because more people need to make transfers.

50. The increasing consolidation of aviation markets, together with the continuing growth, means that the environmental damage caused by aviation will continue to grow. As mentioned above, technological development cannot prevent this. Therefore, new alternative policy measures are necessary. A number of countries in Europe introduced ticket taxes. If such a ticket tax would approximate the marginal external cost, this would be a sensible strategy. In this case one tries to influence the individual passenger's travel behaviour. As long as passenger do not face the full cost of travel (*i.e.* including external cost), demand will be too high. A ticket tax might fix this. It appears, however, that in some countries the ticket tax is used to raise general funds, so that it is not necessarily true that the tax is equal to (or approximates) the marginal external cost. If the tax is too low or too high, improper incentives are given. For instance, if transfer passengers do not pay the tax, the ticket price is relatively low, and demand relatively high. As a result, the environmental damage can also be relatively high. Moreover, other countries have not introduced such a tax, and in most cases passengers travelling indirectly (and thus causing relatively high external cost) are exempt from the tax. The E.U. will introduce emissions trading. Scheelhaase and Grimme (2007) find that such a scheme will have only marginal effects on airline cost.

51. Air travel connects regions to the world economy, and gives individual travellers the opportunity to explore the world. But as long as the full external cost is not covered by the ticket price, environmental damage caused by aviation will continue to grow.

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