Environmental impacts of hub and spoke networks in European aviation.

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Abstract.

Deregulation of aviation has economic effects such as changes in prices and in frequencies of flights. In addition, there may be effects on the number of hubs operated by the main carriers. In the present paper we focus on the possible impacts of changes in the number of hubs on the environmental performance of aviation. A smaller number of hubs obviously leads to a concentration of noise nuisance in a limited set of regions. The effects on energy use are less evident, however, since economies of scale in aircraft operations might compensate for the larger detours made in concentrated hub and spoke networks. The conclusion of our empirical study is that point to point networks tend to perform better than hub and spoke networks. The more focussed a hub and spoke network, the less favourable the effects on the global environment. An important implication of this study is that deregulation policies at the level of the EU may have very distinct implications for the relative economic positions of airports in the EU. In addition deregulation will have an impact on both local and global environmental aspects.

1. Introduction.

International aviation has long been dominated by bilateral agreements between national governments. A basic reason was that national governments wanted to protect their national carrier against the competition of foreign carriers. But also in domestic aviation many governments have strongly regulated entry, capacity, prices and network structures. The economic crisis of the 1930's led to a deep mistrust of free markets which were associated with risks of wasteful and destructive competition. Also safety considerations were used as a reason to argue against a free market (Schipper, 1999). In the course of time, however, the view gained support that government regulation had substantial negative effects on the efficiency of the aviation sector so that consumers were not provided the services they needed and were charged prices that were too high.

In the US deregulation was introduced in a drastic way at the end of the 1970's. It led to considerable turmoil in terms of new entries, price competition and changes in network structures. As time passed a process of mergers and take-overs took place leading to strongly focussed hub-and-spoke networks (Button, 1991).

In Europe, a more gradual approach was followed. Between 1984 and 1997, various restrictions on intra EU traffic were lifted, both bilaterally and multilaterally. One of the differences between the US and the EU is that in Europe a hub-and-spoke system already existed before the deregulation. The obvious reason was that national carriers used the national airport as their hub. The main question about the effects of deregulation on airline networks was therefore not whether or not hub-and-spoke networks would emerge in Europe, but to what extent the existing hub-and-spoke network would be replaced by a more concentrated hub-and-spoke network. In this new network the relative position of main hubs such as London, Paris and Frankfurt would be more dominant as a consequence of concentration tendencies in the airline sector.

Another issue that has received much attention during the past period are the environmental effects of aviation. Especially at the local level the adverse effects of aviation on the quality of life (noise) have been evident. Also the global effects of aviation in terms of its emissions of CO_2, NO_x, etc. are important. The problem with aviation is that, although the environmental costs are high, fiscal measures to correct for these external costs have been limited (see Levinson et al. (1998). In this respect there is a clear difference between the pricing of fuel for aviation (low taxes) and of road transport (high taxes).

A striking point is that the two issues (deregulation and environmental effects) are usually addressed separately. This is a pity since a decrease in prices and an increase in frequencies as a possible consequence of deregulation would have adverse environmental effects (for a detailed study see Schipper, 1999). Of particular interest is the question what would be the environmental consequences of a shift towards a more concentrated hub-and-spoke system. On the one hand one may argue that a more concentrated hub-and-spoke system leads to high pressures on the environmental conditions near airports. In addition, hub-and-spoke systems imply that a large share of passengers make detours so that the total mileage of passengers increases. On the other hand, a more concentrated hub and spoke system may be expected to lead to the use of larger aircraft with higher load factors, and this may be beneficial for the environmental burden (Schipper and Rietveld, 1997).

This trade-off between environmental advantages and disadvantages of hub-and-spoke systems has received little attention thus far. (See for an exception Nero and Black, 1998). It is an important theme, however. For example, if strongly focussed hub-and-spoke systems would be beneficial for the global environment, one might consider the construction of large hub airports in regions where local effects are of little importance (for example, rural areas or a sea location).

We conclude that regulatory reform in aviation may have important spatial implications, not only for environmental quality, but also for the development of metropolitan areas. The changes in hub-and-spoke systems would have effects on the relative accessibility of airports which in turn may have large impacts on the development of regions (Rietveld and Bruinsma, 1998).

The aim of our paper is to investigate the environmental consequences of alternative hub structures for European aviation. In section 2 we give a short review of the literature on deregulation and network structures. In section 3 a number of alternative network configurations are discussed. Empirical results are presented in section 4. Policy implications are formulated in section 5. Section 6 concludes.

It is important to be explicit about some limitations of our approach. A first point is that we assume that demand for transport is given. Thus, when discussing alternative network structures we assume that these do not lead to changes in transport volumes between origins and destinations. A second point is that we only deal with the environmental consequences of alternative hub structures. We do not elaborate on the economic forces that may make some hub structures more attractive to airports or airlines than other hub structures. The neglect of these two aspects makes our analysis rather partial. The advantage is, however, that the total environmental effect can be related immediately to the network structure so that there is no need to disentangle the effect of network structure and that of other factors such as the effects of pricing strategies of airlines or airports.

2. Deregulation and aviation networks.

The literature on the economic effects of deregulation in aviation has been reviewed among others by Button (1991) and Schipper (1999). These effects pertain to among others market structure (entry, mergers, alliances), prices, frequencies, and changes in network structures.

Deregulation has consequences for the degree of competition including the entry of new airlines and concentration in terms of mergers, take-overs and alliances. The experience in the USA since the 1970's and in Europe in the 1990's indicate that in the early phase after regulatory reform, there is an increase in the number of suppliers that challenge the position of incumbent carriers. Well-known examples in Europe are Easy Jet and Virgin that offer cheap tickets. A relatively recent phenomenon is the emergence of global alliances meaning that large carriers start co-operating by co-ordination of their services. This leads to an enormous expansion of the number of destinations offered by each carrier joining an alliance. For example the code sharing of KLM and North-West gave KLM the opportunity to advertise with more than 100 destinations in the USA for flights via the North-West hubs at the other side of the Atlantic.

Prices have decreased as a consequence of deregulation, but the extent to which this has happened varies. For example, Borenstein estimates for the USA that the deregulation has led to a decrease of ticket prices of about 10%. Price changes have been rather diverse, however, and one may also find price increases. For example, Goetz and Sutton (1997) find that in the USA the price of tickets from a hub origin to particular destinations has gone up as a consequence of emergence of more focussed hub-and-spoke structures. An interesting implication of this finding is that regions near hub airports have the advantage of a high level of accessibility, but at the same time face at least two disadvantages: the burden of high local environmental nuisance and the higher level of ticket prices. In the case of Europe, Schipper (1999) does not find such a positive hub effect on ticket prices, however.

Deregulation of aviation appears to have a positive effect on the frequency of services supplied by airlines (Schipper, 1999). Apparently frequencies are one of the instruments airlines use to maximise their profits. There is also a secondary effect, since the negative effect of deregulation on prices leads to an increase in demand which in its turn will have an impact on frequencies. Schipper also finds that the relationship between frequency and volume of passengers is less than proportional: a growth of traffic volumes leads to a combination of higher load factors and larger aircraft.

Concerning network structures. Goetz and Sutton (1997) have analysed the spatial consequences of deregulation in the USA. In addition to a change to focussed hub-and-spoke systems, they observe a clear decrease in the total number of airports served. For example, of the 514 locations that has one or more regular connections with other airports in 1978, there are no less than 167 locations where operations have been terminated in the period until 1995. The number of new locations with an airport was only 26. To guarantee continuation of services the government gives subsidies to services on 77 connections that would otherwise not be operated. Thus, deregulation in the USA led to a substantial restructuring of aviation networks where smaller airports lose market shares or even have to stop their activities. In Europe these effects have been more limited. Most airlines did already use hub-and-spoke networks, although most of them do not yet fully exploit the opportunities to attract transfer passengers (see Dennis, 1998). The formation of airline alliances has strong impacts on network structures since it will lead to the formation of secondary hubs. One of the reasons why airlines are interested in joining alliances is that it makes them less dependent on one particular airport, implying among others that congestion problems may be alleviated.

An important factor determining whether these changes in prices, frequencies and network structures will have adverse effects on the environment is the issue of economies of scale in environmental terms. As is well known in the literature, there are substantial economies of size in airport and airline operations: large aircraft are characterised by low cost per passenger km, and also airports face substantial economies of scale (Doganis, 1991, 1992). An important question is to what extent this also holds for the environmental burden of air transport. An example of economies of size in aircraft would be that one large aircraft with 300 passengers would give less noise nuisance than two medium sized planes with 150 passengers each. As data for the 1990 fleet used on a sample of intra EU routes reported in Schipper (1999) suggest, large aircraft have lower environmental per pass.km. costs than small aircraft. It should be noted, however, that this effect is not present when only the subset of newer, so called 'Chapter 3', aircraft is considered. When the formation of more concentrated hub-and-spoke networks means that larger aircraft are used, the existence of environmental economies of scale would imply that hubbing is good for the environment. This is one of the points that will receive attention in our empirical study on alternative network forms in the rest of this paper.

3 Networks and methods

In this section we describe the ingredients of our analysis of the environmental consequences of alternative hub-and-spoke networks in European aviation. A full report on this study is available in Dutch (Peeters et al., 1999) First we describe a number of alternative networks ranging from strongly concentrated networks towards fully connected networks (section 3.1). The consequences of the alternative networks for the services supplied by the carriers and the routes chosen by the passengers are discussed in section 3.2. The basic assumption of our analysis is that origins and destinations of trips remain unaltered, it is only the routing of carriers and passengers that changes. In section 3.3 a number of classes of aircraft are defined ranging from small to large, including their energy/environmental performance. These will be used to estimate the environmental consequences of the alternative networks. Some data issues are finally discussed in section 3.4

3.1 Alternative networks

In section 2 we formulate alternative assumptions on how passengers are allocated. The following networks are defined:

1 ***Network 1 (reference):*** gives the current situation; the national airports of the European countries function more or less like a hub (a total of sixteen hubs exist; see Figure 1); other airports function as a spoke.

2 ***Networks 2a and 2b (increased 'hubbing'):*** Of the sixteen hubs only four remain (see Figure 2 and Figure 3). The other former hubs will be large airports near a large concentration of population. All hubs have direct connections with all other hubs, all continents and all other international airports around. Also the nearest regional airports are serviced from the hubs. The two variants 2a and 2b are defined as follows:
   - a Four geographically dispersed hubs
   - b Four geographically concentrated hubs

3 ***Network 3 (multi-hub):*** now again sixteen hubs exist, but these are operated by four big alliances of airlines (see Figure 4). Each alliance geographically spreads his connections per continent over its hubs (i.e. the continents to the west are served by the western most hub).

4 ***Network 4 (fully-connected):*** This network contains as many direct connections as possible; real hubs do not exist.

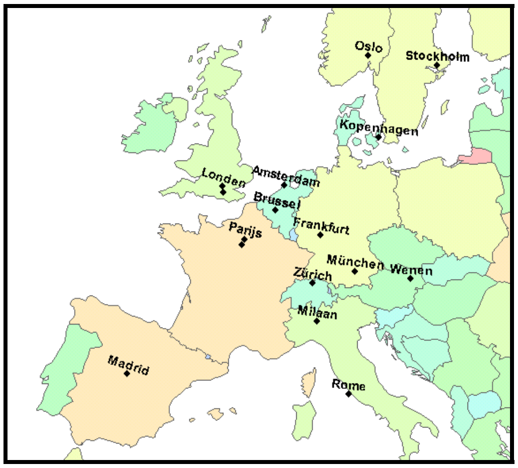

Figure 1: The 16 hubs in Network 1.

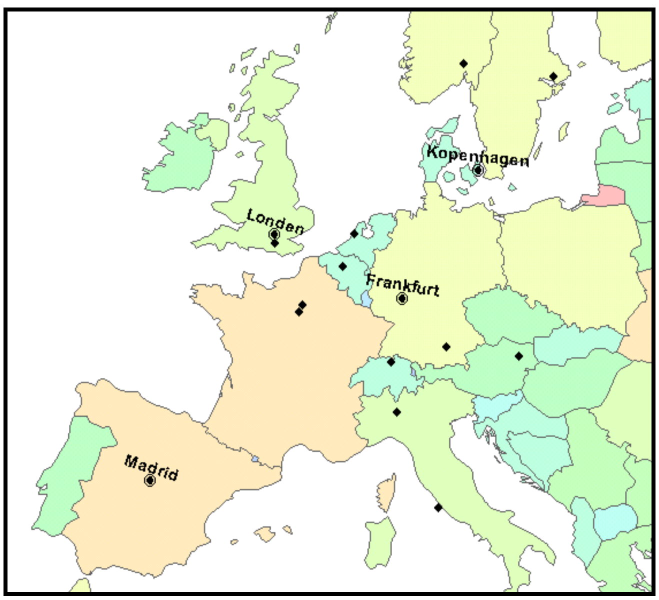

Figure 2: Network 2a: increased 'hubbing', geographically dispersed. Hubs are indicated with a circle round the dot.

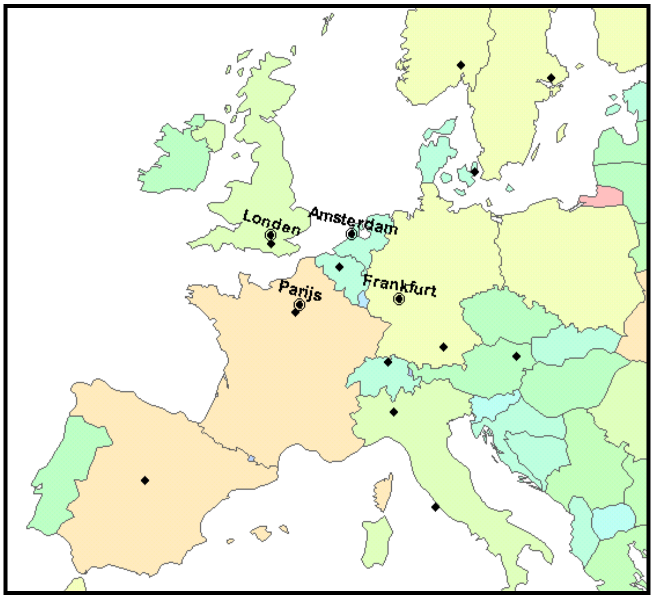

Figure 3: Network 2a: increased 'hubbing', geographically concentrated. Hubs are indicated with a circle round the dot.

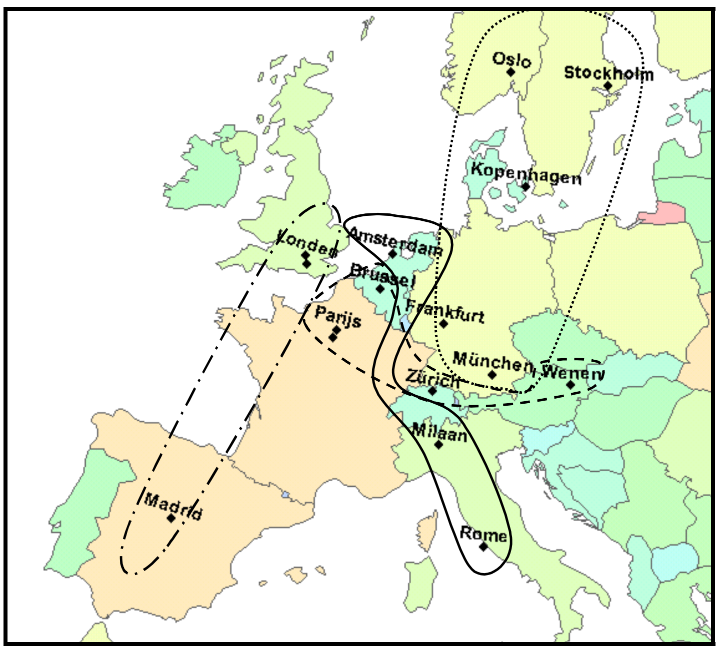

Figure 4: Network 3: multihub; the lines encompass the hubs for the alliances.

3.2 Alternative policies of carriers

When decreasing the number of hubs it must be decided what to do with transfer passengers and with thinner connections. Therefore all networks are developed on two airline policy levels:

A. During re-arranging the hubs all lines of Network 1 are sustained; when a hub airport is changed to a non-hub airport, only the existing transfer passengers are moved to an alternative hub

B. During rearranging the hubs not only current transfer passengers are moved but also thin lines will be removed and their direct flying customers will have to fly indirectly via one of the hubs.

The second policy is the most realistic one: airlines try to reduce cost and improve service level (frequency of the connections) by removing direct low-frequency flights on thin lines and increasing the connectivity via hubs. The series A has also been calculated because the available model system is not able to calculate series B directly. The results for series A are reliable but less realistic, those for series B are more realistic, but less reliable.

3.3 Aircraft types and their environmental features

In this pilot-study the features of only five typical airliners are used. See Table 1 for an overview of these aircraft.

Aircraft type	Maximum payload	Range	Number of seats
	Kg	Km	-
Turboprop	6080	Ca 1800	50
Boeing 737-400	19640	3800	129-180
Boeing 757-200	26081	5000	219
Boeing 767-300 ER	26000	10200	272
Boeing 747-400.	79082	13500	424-516

Table 1: features of the five typical aircraft used.

Also the High Speed Train (HST) has been defined. One should expect the larger aircraft will be relatively more fuel efficient as the smaller ones due to scale effects. However, for the five examples this seems not to be the case (see Figure 5). The reason for this is the very large differences between the age of the designs. The mid-class aircraft are designed in the late eighties, the largest aircraft has been designed in the sixties.

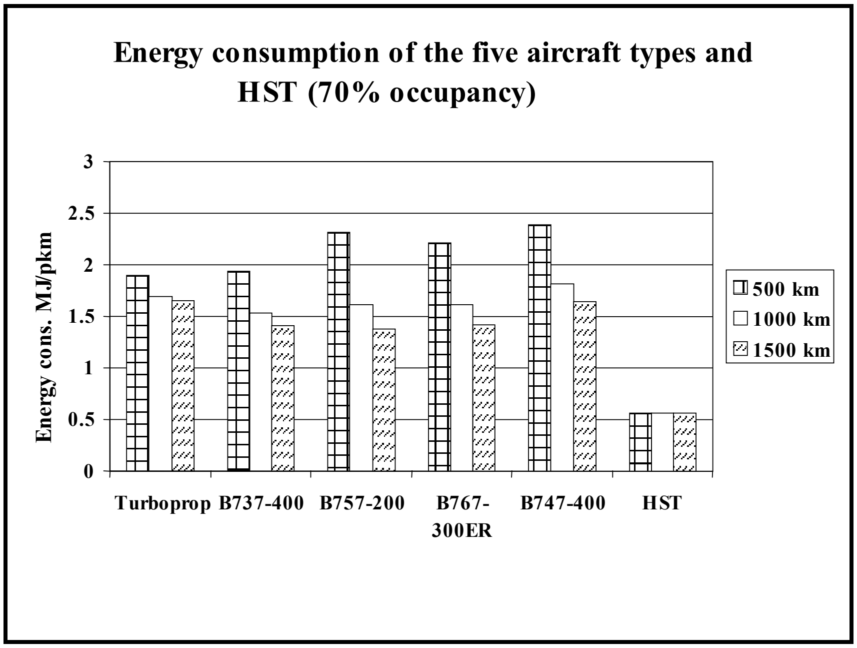

Figure 5: energy consumption per seat kilometre for the five aircraft studied plus the HST.

3.4 Data and models

To calculate the origin-destination table (O/D-table) data of the OAG (Official Airline Guide) for the third week of July 1998 are used. These data contain information on all civil airports of 27 countries in Europe. The data have been translated to a real O/D table with use of the O&D model of RAND Europe. This model gives the total of available seats per city pair. Then these data are translated to a level of service (frequency) using the F&D model (Frequency&Demand) of RAND Europe. This model gives the frequency as a function of the number of available seats and the competition level on the line considered.

Differences between the networks are realised by shifting transfer passengers to other hubs or to combine passenger flows. As has been stated above, two series of calculation have been made. In series A only the existing transfer passengers are shifted from existing hubs to new hubs, depending on the desired network. In series B the same has been done, but calculations have been extended to include the cancellation of thinner direct routes to 'hubbing' indirect routes. The following minimum number of passengers per week have been defined before a route is cancelled:

Network	Threshold for removing a line	
	EU	ICA
1	none	none
2a and 2b	>630	>3150
3	>210	>1050
4	>30	>150

4 Empirical results

4.1 Total Traffic

The total traffic in numbers of passengers travelling from A to B is constant for all networks. The total traffic in passenger kilometres differs per network because passengers will have to make more or less detours (see Figure 6). The total number of trips differs only in series B, because extra transfer passengers are created, causing one journey to be divided over two trips (flights). It is clear from Figure 6 that the total passenger kilometres vary particularly in series B.

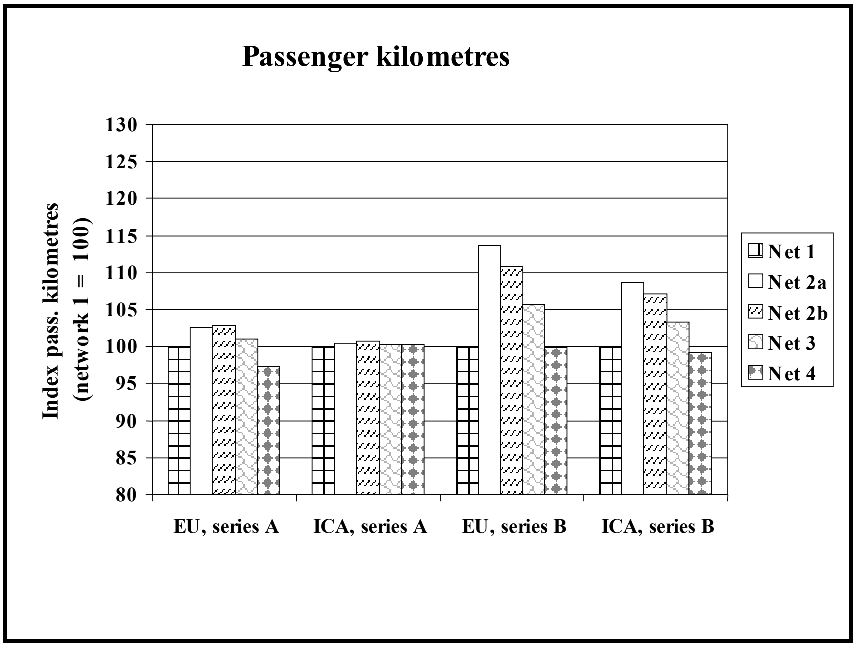

Figure 6: number of available seats per network (index network 1 = 100).

4.2 Aircraft Size

The mean aircraft size is given in Figure 7. The aircraft size is depending on the number of passengers travelling on the route. This effect can be seen for the ICA flights: the less hubs, the larger the traffic and the larger the aircraft used. For the EU market, the effect of a low number of hubs exists as well in series A, but is on average cancelled out by the effect of the smaller aircraft used on thinner routes not going into a hub.

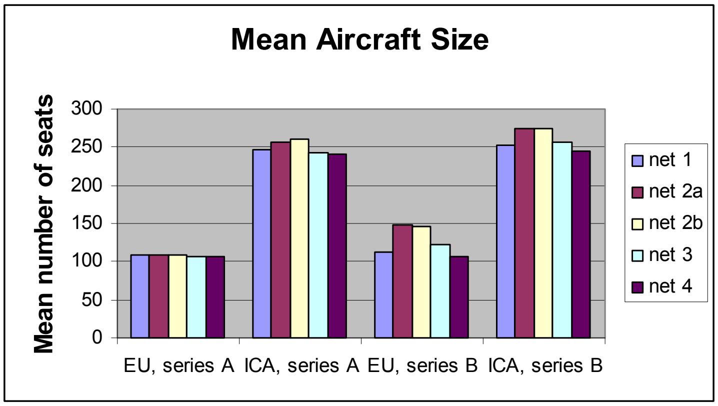

Figure 7: mean number of seats per aircraft.

4.3 Global Environmental Impact

The global environmental impact depends on the number of aircraft kilometre travelled and the specific energy consumption and emission factors for the aircraft used. Therefore it is not surprising that the environmental impact in series A is not very pronounced (see Figure 8). For series B the effect of cancelling thin routes and making detours via hubs has a major effect on the environmental impact (see Figure 9).

Under the assumptions of this pilot study it is clear the point-to-point network has the lowest environmental impact. Hubbing increases energy consumption and emissions. The possible effect of a much higher frequency on total traffic volume has not been included in these calculations. This may increase the traffic volume and thus the environmental impact.

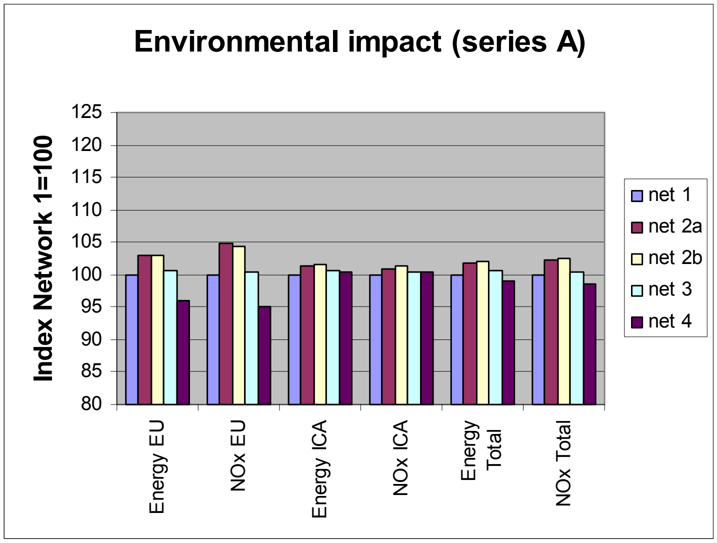

Figure 8: Global environmental impact of the networks in series A.

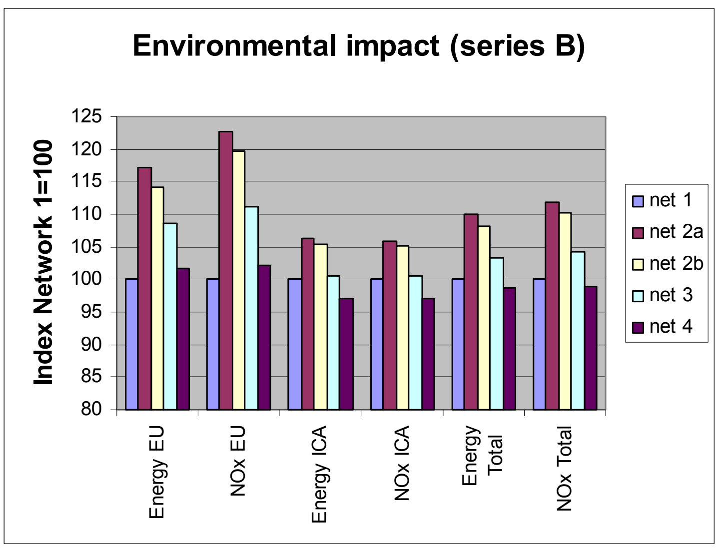

Figure 9: Global environmental impact of the networks in series A.

4.4 Local environmental impact

Hubbing has a major impact on the distribution of the local environmental impact like noise and air quality. If the number of hubs is decreased, the traffic on one hub will increase strongly, while the total number of LTO-cycles (the number of landing and take off) also will increase. Therefore the number of LTO-cycles on the non-hub airports will not decrease much with respect to the current situation (network 1). Figure 10 and Figure 11 show the effect of the changes in LTO-cycles on the total LTO-emissions for the sixteen current hubs for series A and series B respectively. The types of effects are the same for both series, but the impact on the hubs is much more pronounced in series B, while the effect on the non-hubs is the same for networks 2a, 2b and 3. This means the reduction in local environmental impact of non-hubbing airports cannot be achieved by increasing hubbing: the number of departing passengers stays the same.

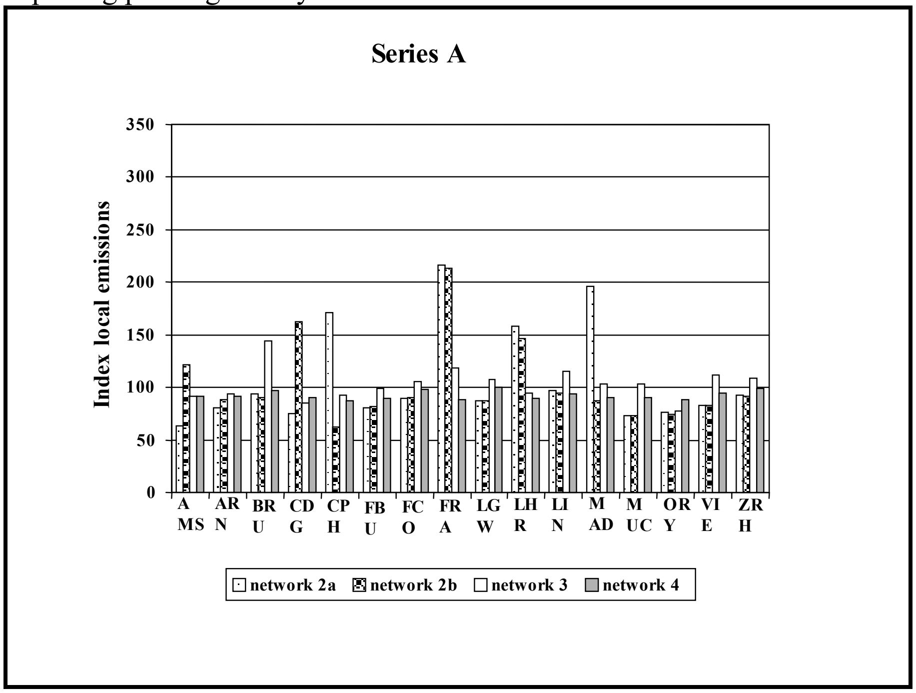

Figure 10: Local environmental impact for the hubs in series A (network 1 = index 100).

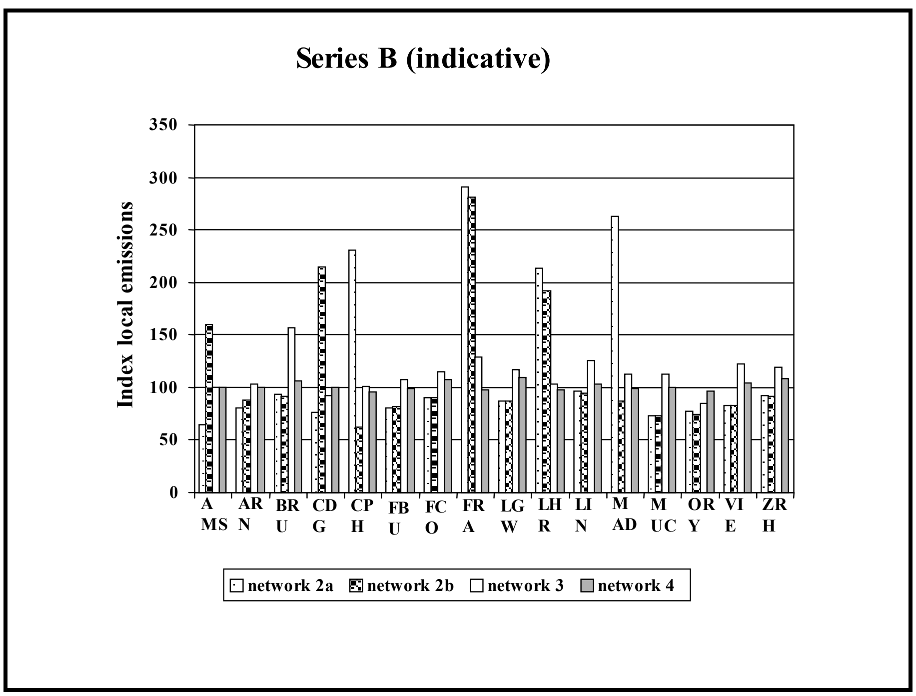

Figure 11: Local environmental impact for the hubs in series B (network 1 = index 100).

5. Policy implications.

According to our calculations the effects of various network structures on passenger kilometres are limited. Only when the airlines take rather drastic measures on terminating services on thin lines (series B) the number of passenger kilometres grows substantially. The effects on aircraft size are expected to be much smaller, however. Especially in the intra-European trips the effects on aircraft size are small. Given the technical parameters used, it appears that the point-to-point system has the best performance in terms of global environmental pressure. In terms of local environmental pressure the conclusion is that more focussed hub structures have quite large effects on the major hubs. Thus in terms of equity the point-to-point system performs well.

The conjecture that global environmental pressure can be reduced by introducing a super hub has not been confirmed in this study: the opposite seems to be the case. This result has important implications for national airport policies. Consider as an example the Dutch airport policy. The main background for proposals to shift the current Schiphol Airport to a new location off-shore is the inability of the airport management to keep the noise levels within the limits set by the Dutch national law. If the airport will continue to grow at the present rates during the coming ten years it will be impossible to stay within these limits. The problem with a new airport in the North Sea is that an investment of some 15-30 mld Euro would be required. To be cost effective a very large flow of passengers would be needed. For a small country such as the Netherlands this can only be achieved by creating a very large hub (a super-hub), and this would require increased ‘hubbing’ of the network. However, our analysis indicates that increased hubbing is not beneficial for the global environment. It will lead to an increase in the global environmental impact of aviation in terms of energy consumption and emissions of carbon dioxide (contributing to global warming) and nitrogen dioxides. Thus, the relocation of the activities of Schiphol to an artificial island in the North Sea will have a favourable effect on the local environment, but it cannot be defended for reasons related to the global environment. Since its economic merits are questionable given the high investment costs, it will be difficult to justify such a mega investment.

6. Conclusions.

Deregulation of aviation has impacts on prices, frequencies, and network structures. In the present study we have focussed on the latter aspect. Deregulation will most probably lead to more pronounced hub-and-spoke systems implying shifts in the international accessibility of metropolitan areas.
The main conclusions of this study are:
1. Point to point networks have the lowest global environmental impact, despite the larger aircraft size used in hub-and-spoke networks. Thus, the network structure effects of deregulation on the global environment are negative.
2. The local environmental impact depends mostly on the function of the airport: a hub has a significantly higher impact compared with a non-hub.
3. The influence of aircraft size on environmental impacts is not unambiguous: there is no clear evidence of environmental economies of scale in our data.
4. The number and geographical distribution of hubs both have a significant influence on the environmental impact of the total network. This means that optimising the

network for low environmental effects may give useful insights for global and regional aviation policies.
There is one particular point that deserves our attention when we interpret these outcomes. The absence of environmental economies of scale observed in sections 3 and 4 is based on data on the environmental performance of particular aircraft types. Technological developments in this area have not been uniform, however. During the past decades developments have been most intensive in the range of smaller to medium sized aircraft. It is not impossible therefore that the data are biased against large aircraft. If the aircraft manufacturers would give priority to the development of new models in the range of large aircraft it is not impossible that other results will be found. This observation makes clear that technological developments are of utmost importance for the assessments of the long-term consequences of network changes.

We have not analysed the environmental effects of deregulation: as shown by Schipper (1999), these are unfavourable. Furthermore, our analysis is partial since we do not consider other aspects of welfare, such as consumer benefits. Therefore, the overall welfare effects of deregulation cannot be quantified (see Schipper, 1999, for an analysis of price and frequency effects and an overall welfare analysis of European airline deregulation).

Deregulation of aviation has strong implications on the accessibility of metropolitan airports. The interesting implication is that a particular policy that is uniform in space will have quite differentiating spatial effects. Thus, public actors (EU, national governments) and private actors (airlines, airports) both play their role in spatial development, even when their policies are not explicitly spatial. The environmental consequences of the retreat of the public sector from the market regulation in aviation make clear that there remains a large scope for public intervention in other respects (for example, pricing and standard setting) in order to cope with these adverse environmental effects.

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