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The environmental cost implication of hub-hub versus hub bypass flight networks

Peter Morrell [a] , *Cherie Lu* [b,1]

[a] *Director of Research, Department of Air Transport, Cranfield University, Cranfield, Bedford,MK43 0AL, UK*

[b] *Assistant Professor, Department of Aviation & Maritime Management, Chang Jung Christian University, Tainan 711, Taiwan*

Abstract

The increasing congestion at major hubs and the advantage to passengers of non-stop flights and faster journey times has intensified the debate on patterns of air service. At the same time the economics of highly focused networks has been challenged by the availability of very economic smaller capacity long-haul aircraft. The purpose of this research is to value the environmental costs of these two patterns of service: hub-to-hub and hub bypass. Five long-haul markets were evaluated both on a hub to hub and hub by-pass basis. These involved both transatlantic and Europe/Asia flights. It was found that the noise and emissions social cost impact of the hub by-pass networks was significantly lower than the hub to hub in all cases. The difference in environmental costs per passenger ranged between 25% and 73%, depending on the concentration of population around the airports and the degree to which the hub routing involved extra mileage. The difference increased to a range of 56% to 113%, if a stimulation factor of 25% was applied to the non-stop market. The environmental cost saving for the non-stop flight amounted to just under 20% of the total aircraft operating costs of one of the cases considered.

[1] Corresponding author.

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1. Introduction

The network model of scheduled air service has been a key feature of increasingly liberalised air transport markets. Nero (1999) stated that 'the hub-and-spoke structure is likely to flourish around the world as a consequence of airline liberalisation …'. In the US, airlines made greater use of hubs and feeder flights following de-regulation in 1978. US industry departures from the top 3% of points rose from 23.8% in 1977 to 38.6% in 1984 (McShan and Windle, 2004). In Europe, the share of transfer traffic at the hub airports of the major network carriers, Air France-KLM, British Airways and Lufthansa rose significantly with the liberalisation of the 1990s.

However, the theoretical advantages of these networks were not all realised or declined over time: in particular the lower unit costs of hub and spoke operations compared to point-to-point operation were challenged by:

- Increasing congestion at major hub airports
- Larger aircraft operating costs did not turn out to be as low as expected compared to smaller aircraft (Wei and Hansen, 2003)
- Expensive aircraft and crew resources could not be utilised as intensively

Furthermore, network carriers often need to offer discounts on both leisure and business class fares to attract traffic to their high capacity hub-to-hub flights. Non-stop flights at adequate frequencies can command a premium, but for many city-pairs, there is insufficient higher yielding traffic available for profitable services with existing aircraft

E-mail address: cherie@mail.cjcu.edu.tw (C. Lu).

such as the B767/A330.[2]

Two developments may result in a challenge to the long-haul hub-to-hub routes. First, the introduction of two smaller long-haul aircraft, the Boeing 787 and the Airbus A350. These promise significantly improved unit costs for long-haul aircraft of 200-250 seat capacity compared to existing types in this category. This presents opportunities for a considerable number of profitable non-stop hub bypass flights at adequate frequency. Second, the internalisation of external environmental costs (both noise and emissions) might lead to a shift in the pattern of air services towards hub bypass and more direct flights. At the local level airport expansion plans are increasingly subjected to environmental impact assessment, especially on noise and NOx. Internationally, there is pressure to address the growing climate change impact of aviation emissions. This paper explores the cost implications of this second possibility, which looks increasingly likely to be realised through caps or mandatory limits, charges and taxes. However, the extent to which airlines might adapt their route structures will not be explored.

2. The approach

2.1. Alternative networks

Origin/destination (O/D) passenger markets can be carried on non-stop flights, or routed via intermediate points. At these points, they either stay on the same aircraft and continue to their destination after a stopover (transiting), or transfer from one aircraft to another. The latter is the more common way that hub carriers use to combine a number of O/D markets across their network. This gives considerable potential for scale economies

[2] For example, Delta Airlines has offered and then discontinued a non-stop service between Hamburg and Atlanta twice over the past ten years.

both on the feeder flights (spokes) and on the hub-hub flights.

Network carriers use this hub-and spoke network structure to build up traffic volumes. Low Cost Carriers (LCCs), on the other hand, offer point-to-point flights without any consideration for transiting or transferring passengers between their own flights, or from their own to those of other airlines.[3] They build volume by offering very low fares. So far they have largely restricted their flights to short/medium haul sectors. Long-haul passenger markets are still predominately served by network carriers, with some point-to-point charters to selected high volume leisure destinations.

Most long-haul markets are low volume, and thus the network model is still the most appropriate one to provide adequate frequency and economic sized aircraft. Economic traffic volumes, however, can only be achieved by routing the passenger via one, or more often two major hub airports. This means at least one and sometimes two intermediate stops. This paper explores the environmental implications of serving long-haul markets on a non-stop basis involving at most one hub airport, or hub by-pass routes.

The type of airline operating on this basis would still be a network carrier. It would be more likely to be one basing aircraft at either one of its major or secondary hubs in its own country, and operating to a non-hub destination in another country. An example of this would be Japan Airlines operating Tokyo/Hamburg (hub by-pass) instead of on an interline basis via Frankfurt or Munich.[4]

The economic rational for a change in the global network structure away from hub-to-hub operations to hub by-pass is growing congestion at the hubs, and improved

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[3] For a more detailed description of the differences between the various airline business models see O'Connell & Williams, 2005.

[4] If Japan Airlines were members of a strategic alliance they might choose an intermediate point that was the hub airport of one of their European partners.

economics for hub by-pass. The latter could come from a new long-haul aircraft type (eg the B787) or from the application of LCC techniques to these sectors. Another driver could be the internalisation of environmental costs, and it is the valuation of the likely future extent of this that is the aim of this paper.

The model is designed to evaluate the environmental implications of carrying a given number of passengers between city-pair A/B, either via hub airport M or on a non-stop routing: hubbing scenario (a) or hub by-pass scenario (b). Fig. 1 illustrates the structure of the network.

Insert Fig. 1.

Scenario (a) is most likely to be accommodated by moving to a large aircraft type for both feeder and hub-to-hub sectors. This is because slots are likely to be scarce at many major hubs, especially at times when the feeder flights arrive and depart to connect with long-haul flights. Scenario (b) is dependent on an economic and smaller seat capacity aircraft, as well as a sufficiently good mix of high and low yield traffic. Any stimulation of demand from the reduced trip time will not be considered at this stage of the modelling process, since it is the per passenger impact that will be estimated for the two scenarios.

2.2. Environmental model

2.2.1. Noise social cost model

The hedonic price method (HPM) is the most commonly used technique for estimating noise damage costs (Lu and Morrell, 2006). This method extracts the implicit prices of certain characteristics that determine property values, such as location, attributes of the neighbourhood and environmental quality. By applying the HPM, the annual total noise social cost C_n could be derived from the following formula:

$$C_n = \sum_i I_{NDI} P_v (N_{ai} - N_0) H_i \tag{1}$$

Where I_{NDI} is the noise depreciation index expressed as a percentage; P_v is the annual average house rent in the vicinity of the airport; and therefore, $I_{NDI} P_v$ is the annual noise social cost per residence per dB(A).[5] The noise level above the ambient level is $(N_{ai} - N_0)$, where N_{ai} is the average noise for the ith section of the noise contour; N_0 is the background noise or the ambient noise. This is finally multiplied by H_i, the number of residences within the ith zone of the noise contour.

The annual house rent P_v could be converted from the average house value in the vicinity of the airport, P, by the following capital recovery equation, where r is the mortgage interest rate, and n is the average house lifetime (Levinson et al., 1998):

$$P_v = P \left(\frac{r(1+r)^n}{(1+r)^n - 1} \right) \tag{2}$$

After calculating the aggregate noise social cost, it is necessary to decide how to allocate this total external cost to individual flights. The principle of this process should be based on the real impact of noise nuisance generated dynamically from each specific flight. The factors influencing the noise impact include aircraft types, engine types, time of a day, flight paths as well as LTO procedures.

According to the availability of the data during the research period, a simplified approach to deriving the marginal noise nuisance, expressed as L_k, caused by each specific aircraft/engine combination flight is developed for the purpose of this research.

[5] dBA: the A-weighted decibel units, adjusted to conform with the frequency response of the human ear.

By reducing one LTO operation for the kth aircraft/engine combination per day, the reduced amount of noise could be considered as the marginal noise nuisance caused by this flight. The difference between the original average noise level, N_a, and the new lower average noise level, N_{ak}, could be expressed as ΔN_k in equation (3):

$$\Delta N_k = N_a - N_{ak} \tag{3}$$

If the noise reduction for the selected aircraft/engine combination, ΔN_{ks}, is indexed on 1 (the selected aircraft type could be the least noisy one), the noise index for the kth aircraft/engine combination, L_k, could be subsequently derived from equation (4).

$$L_k = \frac{\Delta N_k}{\Delta N_{ks}} \tag{4}$$

As the dynamic noise related data for specific flight is impossible to obtain, the later empirical analysis for the calculation of equations (3) and (4) will be based on the average of three noise certificated levels by the US Federal Aviation Administration (FAA), namely the Effective Perceived Noise Level (EPNdB) for take-off, sideline and approach, for different aircraft types.

Finally, the marginal noise social cost for the kth aircraft/engine combination, denoted as T_{nk}, including the impacts both from take-off and landing stages, could be expressed as the following general form:

$$T_{nk} = \frac{C_n}{\sum_k L_k D_k} L_k \tag{5}$$

Where D_k is the total number of the annual aircraft landings for the kth aircraft/engine combination.

2.2.2. Engine emissions social cost model

Differences in aircraft operations, engine types, emission rates and airport congestion are considered as important parameters influencing the damage level of pollutants. Air pollution at ground level resulting from the landing and take-off (LTO) phase of flights is distinguished from the cruise level impact, and therefore analysed separately in this research, as the damage pattern and magnitude is different between these two phases of flights. The climate change impact from the cruise phase of flight is complex and only the cost of CO_2 emissions has been included here.

The estimation of social cost is described in Table 1 which lists the wide range of social costs for each pollutant from a literature review. The average of those estimates is used in the empirical analysis for each of the pollutants, as the estimates are uncertain. It would be better to adjust the unit social cost for specific airports but it is impossible to achieve this with the scientific results that have been published to date.

Insert Table 1

The social costs for individual aircraft movements with specific engine types and standard flight modes can be derived, applying the average unit social cost for each pollutant listed in Table 1 to fuel flow and emissions date for the various phases of flight (ICAO, 1995).

F_{ij}, the amount (kilograms) of the jth pollutant emitted during the ith flight mode, can be derived from the following formula:

$$F_{ij} = t_i f_i e_{ij} \quad (6)$$

Where t_i is the time spent during the ith mode (hours); f_i the fuel flow during the ith mode (kg/hr); e_{ij} the emission indices of the jth pollutant during the ith mode (kg pollutant/kg fuel). Equation (7) shows the calculation of C_{ek}, the social cost per flight for the kth aircraft/engine combination ($/flight):

$$C_{ek} = \sum_{j=1}^{6}\sum_{i=1}^{5}\alpha_i F_{ij} U_j \quad (7)$$

Where α_i is the weight for each mode, depending on the damage multiplier factor. For this research, 1 is used for the CO_2 emissions during both cruise and the other phases of flight and ground movement, which means the pollutant causes the same damage when emitted during cruise. U_j is the unit social cost for the jth pollutant ($/kg). Five operational modes are calculated separately, which are take-off, climb-out, approach, taxi/idle and cruise. Six exhaust pollutants listed in Table 1 are considered.

2.2.3. Environmental impact model

Following the airline alternative network discussion in Section 2.1, the environmental impact model is to assess the net effect of each of the two scenarios, comparing against the current situation. Fig. 1 shows the network and the parameters used for both scenarios

(a) Airline hubbing scenario

The increased passenger demand from city A to city B, D_{AB}, would result in an increase of two sectors of flight; the first sector from airport A to hub M, the second from hub M to airport B; vice versa for the return flight. Therefore, the additional social costs of aircraft noise and engine emissions could be expressed in equation (8),

$$E_{AMB} = E_A + E_M + E_B = \alpha(T_{iA} + T_{iM}) - \alpha(T_{gA} + T_{gM}) + \beta(T_{kM} + T_{kB}) - \beta(T_{jM} + T_{jB}) \quad (8)$$

Where:

- E_{AMB} (\$/day) is the addition social costs for the route from A to B via hub M;
- E_A, E_M and E_B (\$/day) are the marginal social costs at airports A, M and B respectively;
- T_{iA} and T_{iM} (\$/flight) are the marginal social costs caused by one new flight i at airports A and M respectively;
- T_{gA} and T_{gM} (\$/flight) are the marginal social costs caused by one original flight g at airports A and M respectively;
- T_{kM} and T_{kB} (\$/flight) are the marginal social costs caused by one new flight k at airports M and B respectively;
- T_{jM} and T_{jB} (\$/flight) are the marginal social costs caused by one original flight j at airports M and B respectively;
- α (flights/day) is the number of additional flights departing from airport A and the number of original flights replaced at airport A;
- β (flights/day) is the number of additional flights departing from hub M and B, and the number of original flights replaced at airports M and B.

(b) Hub bypass scenario

In this scenario, there will be an increase of direct flights from airport A to airport B, and vice versa. Equation (9) then presents the additional social cost.

$$E_{AMB} = E_A + E_B = \lambda(T_{hA} + T_{hB}) \quad (9)$$

Where,

- T_{hA} and T_{hB} (\$/flight) are the marginal social costs caused by one new flight h at airports A and B respectively;

- λ (flights/day) is the number of additional flights departing from airports A and B.

3. Model inputs and results

3.1. Data and assumptions

Two UK airports (London-Heathrow and Glasgow Abbotsinch airports), two German airports (Frankfurt and Hamburg airports), three US airports (Chicago O'Hare, San Diego and Dallas airports) and one Japanese airports (Tokyo Narita Airport) are taken as the case studies for the empirical analysis. These include airports in the three major air transport regions, as well as a mix of major hubs and cities that are not hubs but have potential for their own long-haul scheduled air services. Based on the aircraft size and noise certificated levels, all aircraft types at these airports are categorised into eight categories, with a representative aircraft type being selected for each of the categories, as shown in Table 2. The various aircraft types for different noise categories (similar to that used at Heathrow Airport) are listed in Appendix A. The noise index in Table 2 is derived by applying the noise levels of the representative aircraft types to equations (3) and (4), with the noise reduction of the B737-700 indexed on 1.

Insert Table 2

Table 3 presents the aircraft movements by category in 2004 at these eight airports. Chicago O'Hare has the highest number of aircraft movements, followed by Heathrow, Dallas and Frankfurt etc. Narita has the highest percentage of larger aircraft.

Insert Table 3

The number of residences within the noise contour in 2004 is listed in Table 4. These were obtained from the selected airports and from environmental studies of these airports. Different noise measurements are used in different countries, even within countries. Equivalent Continuous Sound Level (Leq) is used both at the British and German airports.[6] Weighted Equivalent Continuous Perceived Noise Level (WECPNL) is used at Japanese airports. At Chicago O'Hare, Ldn is used;[7] however, Community Noise Equivalent Level (CNEL) is used at San Diego Airport. By using different noise measures, the absolute number of noise level is different; however, the ranges of these measures are similar. Therefore, the same NDI value of 0.6% per dBA is applied for all the airports concerned.

Insert Table 4

The absolute values of noise at each airport are compared to the background or ambient noise level. This ensures the similar treatment of noise at each airport. For the UK airports, 52 Leq is used as the background noise level for the calculation in the next section. For each contour, the average noise level between the contour and the next one is then compared with the background level. It should be noted that the number of residences within the noise contour 57 to 52 Leq is unknown. The inclusion of these would lead to higher noise social costs. This would also apply to all the airports in equal measure since the difference between the first contour (eg 57 Leq or 65 Ldn) and the background noise level are very similar for all airports in the sample.

The average house prices at the airport area are listed in Table 5. Ideally, the average

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[6] Leq: Equivalent sound level, defined as the level of equivalent steady sound that, over the measurement period, contains the same weighted sound energy as the observed varying sound.

[7] Ldn: Day/night average sound levels, a descriptor of noise level based on equivalent noise level (Leq) over the whole day with a penalty of 10 dB(A) for night time noise (22.00-7.00 hrs).

house price should be obtained for the houses situated between each noise contour. Airports do not generally have this data, which needs to be estimated from national statistical sources or local real estate agents. As far as possible, an average single-family dwelling value has been selected for the local authority or authorities within which the airport is located. For example, Chicago O'Hare is situated in Cook County, while Glasgow Airport is close to both Paisley and Johnstone administrative districts.

Insert Table 5

Generally, values have been averaged from actual sale price data, and where estimates from previous years have been converted to 2004 prices using the most appropriate house price index.

3.2. Empirical results

3.2.1. Noise social costs

The noise social costs by aircraft category at different airports are listed in Table 6. The noise social costs for different aircraft categories at Heathrow vary from €2 per landing for the Jetstream to €2,778 for the B747-100/200/300, with the weighted average of €523 per landing and take-off (or €262 per movement). Heathrow has the largest number of houses within the critical contour, as well as having the highest average house price (after San Diego). The average noise social cost at Chicago O'Hare, in contrast, is very low, due to few dwellings within the noisier contours, relatively low house prices, and a favourable aircraft mix. Chicago has many more small regional jet movements and few movements in the heavier, noisier categories, especially compared to both Heathrow and Narita.

Insert Table 6

These figures are based on the certificated noise levels for each aircraft type, rather than the actual measured noise. This means that more favourable operating procedures at some airports might reduce the figures shown.

3.2.2. Engine emissions social costs

The social cost of engine emissions for different aircraft has been calculated on the basis of different engine types and emission rates. Substituting the related parameters and data in equations (6) and (7), the average social costs during LTO and cruise stages for jet aircraft categories are shown in Table 7. As the impacts of engine emissions are less airport-specific (or at least little is known on their subsequent dispersion around the airport), the social costs for individual aircraft types are assumed the same for all eight airports.

Insert Table 7

One drawback with using certificated emission levels is the variation in power settings on take-off, depending on engine rating, length of haul and other operational parameters. This means that many take-offs are at less than full power which would reduced the certificated NOx values used in this study.

The data in Table 7 include not only the social cost at the ground level resulting from the standard LTO procedures, including take-off, climb-out, approach and taxi-idle modes, but also the costs of the emissions from 30 minutes' cruise either prior to landing or following take-off. The engine emissions social costs range from €140 to €1,996 depending on aircraft types for LTO and cruise stages. For the cruise stages, only the environmental cost of CO_2 emissions has been included in the table.

3.2.3. Environmental costs for airline network scenarios

The environmental costs here are defined as the aggregation of both noise and engine emissions social costs.

Five cases have been included for the evaluation of these costs for the two scenarios, (a) and (b), described above. The first case examines the impact of passengers that wish to travel between Glasgow and Chicago, either on a non-stop flight or via the hub, Heathrow. In practice, Heathrow based airline, British Airways would be more likely to favour the one-stop routing, while the non-stop route might be attractive to a US based airline, especially one competing with British Airways. Case 1 includes two hubs for scenario (a) and only one hub airport for scenario (b).

The second case has two airports in the US and only one in the UK. Passengers wishing to travel between London and San Diego are routed non-stop or via the Chicago hub. With Case 2, the non-stop scenario is more likely to appeal to British Airways than a US based airline.

Table 8 shows the operating assumptions for the five cases. Cruising altitude is important for fuel consumption, since it varies significantly depending on flight level selected. There is also a trade-off between speed and fuel burn. The flight levels have been selected as being typical for these sectors, as have average speeds and thus sector time. The UK airline, bmi, cruises at around 39,000 ft on transatlantic routes, but takes some time to reach this altitude as fuel is burnt off and payload reduced.

Insert Table 8

Table 9 shows the Case 1 results. The non-stop flight from Glasgow to Chicago and back shows a marked advantage over the routing via Heathrow in terms of noise. This is because of the use of noisier aircraft (especially the B747-400), as well as the location of housing around Heathrow. The non-stop flight also incurs less LTO emissions costs, although the difference is less. The indirect flight via Heathrow incurs a distance penalty of just over 1,000 km and so has a greater CO_2 environmental cost of € 2,866 per day. Together the incremental environmental impact of the non-stop flight is only €59 versus €101 for the multi-sector routing (which is thus 71% higher).

Insert Table 9

The full incremental environmental costs for the indirect routing have been attributed to the additional 150 passengers. Without these extra passengers, the existing market could be carried on the smaller aircraft at the same frequency. Conversely, the additional environmental costs could have been avoided by carrying the 150 passengers on the non-stop service.

However, it could be argued that a part of the 150 passengers might not have travelled at all without the non-stop flight, which has stimulated this origin/destination market. Assuming a stimulation factor of 25%, 120 passengers would travel on the hub routing, and 30 new passengers would be carried on the non-stop flight plus the 120 existing traffic. This would raise the indirect incremental costs from €101 to €127 per passenger, with the non-stop impact unchanged at €59. Thus the difference would rise from 71% to 115%.

Case 2 is shown in Table 10. Here the noise impact still favours the non-stop route, although by a smaller margin. The emissions advantage is similar to Case 1. On climate change, however, there is little to choose between the two routings. This is because

Chicago happens to lie close to the great circle routing between London Heathrow and San Diego, and only an extra 318 km are needed for the intermediate stop. The indirect hub routing is estimated to incur an incremental cost of €105 compared to €84 for the non-stop, a difference of 25%.

Insert Table 10

Both Case 1 and Case 2 assume the same time allowances for the various phases of the LTO cycle at both the secondary points and the hubs. In actual practice, the taxi out times would be expected to be higher at hubs such as Chicago and Heathrow, compared with, say, Glasgow and San Diego. The hubs may also impose some stacking on approach, since their declared runway capacity may assume some level of average delay, even before additional delays from the random nature of arrivals and sequencing of aircraft.

Case 3 for a Europe/Asia route is shown in Table 11. Here the noise impact also favours the non-stop route. The emissions advantage is similar to the previous cases, but the more direct routing gives the non-stop route a significant cruise emissions gain. The indirect hub routing is estimated to incur an incremental cost of €124 compared to €82 for the non-stop, a difference of 51%.

Insert Table 11

Case 4 for Glasgow to/from another US point is shown in Table 12. As for the previous route involving Heathrow, there is a marked gain from by-passing this hub. There is also a useful emissions advantage from the shorter point-to-point mileage. The indirect hub routing is estimated to incur an incremental cost of €113 compared to €69 for the non-stop, a difference of 64%.

Insert Table 12

The final Case 5 links Hamburg with a major US city, and is shown in Table 13. The indirect hub routing is estimated to incur an incremental cost of €112 compared to €75 for the non-stop, a difference of 49%.

Insert Table 13

4. Sensitivity analysis

Case 1 (Glasgow to/from Chicago) is used as the base case for the following sensitivity tests:

- Substituting the B787-8 for the B767-300 (in similar three-class layouts) on the non-stop, hub by-pass sector; frequency unchanged
- Substituting an A380-800 for the B747-400 (in similar three-class layouts) on the Heathrow/Chicago sector, and the B747-400 for the B777-200; frequency changes remain the same
- Testing the impact of a change in the Noise Depreciation Index from 0.6% to 0.4% and 0.8%
- Doubling the idle (taxi-in and taxi-out) time at the intermediate hub airports
- Assuming the engine with the worst environmental performance for the by-pass flight and the best for the route via the hub
- Substituting an B747-8 for the B747-400 (with a similar three-class configuration) on the Heathrow/Chicago sector, and the B777-300 for the B777-200; frequency changes remain the same

The results of these tests are shown in Table 14, as percentage changes from the base case. It can be seen in all cases the by-pass flights had a lower environmental impact than the flights via the hub, on a per passenger basis.

Insert Table 14

The noise value of B787-8 is estimated as the level of Category 4 aircraft (Hawk, 2005), and thus is lower than the original aircraft (B767-300) used in Case 1. The fuel burn is assumed to be around 20% lower than the B767-300. Although there are more seats available in B787-8, with the same additional demand of 150 passengers, the average environmental cost is then €48 per passenger, 18.6% lower than the original case.

The impact of the A380-800 replacing the B747-400 on the hub to hub Case 1 was also explored, comparing it with the use of the B787-8 on the hub by-pass sector. The A380-800 is expected to be quieter than the B747-400 and thus reduces noise costs substantially for the case that involved Heathrow. However, with the B787s fuel efficiency, it still retains a 17% advantage over the multi-sector alternative. For the cases that did not involve Heathrow, the B787-8 by-pass flights had greater advantage over the A380 combination on the hub/hub route.

The other sensitivities do not result in the by-pass advantage being eroded, but it does decline, especially when using the new B747-8 on the hub-hub sector, although this was compared to the older technology B767-300.

The above tests did not include a likely stimulation of the new non-stop flights for the non-stop market. A realistic estimate of this would be a 25% increase in the non-stop market relative to the one-stop alternative. While there would be other one-stop options not evaluated here, most of them involve a congested hub and significant transfer times. The difference between the incremental environmental costs per passenger for the non-stop versus one-stop flights increase to between 56% to 115%, if stimulation is taken into account.

5. Conclusions and recommendations

Based on the networks analysed, each of the hub by-pass routes generates considerable saving in both noise and engine emissions costs. The networks analysed have incorporated realistic assumptions on likely future airline operations, with the hub by-pass routes more likely to be operated by airlines in the country that is not the location for the hubs considered. It should be noted that the end-point of the long-haul flight was also a hub airport, and that this airport would also have had the potential to collect from and distribute to other cities in that region. The key characteristic, however, is that the long-haul sector includes at least one non-hub city (eg Glasgow and Hamburg). Further analysis could be done on routes where both cities are non-hubs, but it would then be less likely that the route would have sufficient traffic potential.

The difference in environmental costs ranged between 25% and 71%, depending on the concentration of population around the airports and the degree to which the hub routing involved extra mileage. The difference increased to a range of 56% to 115%, if a stimulation factor of 25% was applied to the non-stop market.

The analysis could be further refined by conducting more sensitivity tests, for example on variations in cruise altitude, engine types, populations and house prices. The network might also be expanded, after research into the overall viability of long-haul direct flights.

References

Dings, J.M.W., Wit, R.C.N., Leurs, B.A., Davidson, M.D., 2003. External costs of aviation. Environmental research of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, Research Report 299 96 106, UBA-FB 000411.

Hawk, J., 2005. The Boeing 787 dreamliner: more than an airplane. Presented at the Aircraft Noise and Emissions Reduction Conference in Monterey, California on 25 May.

ICAO, 1995. ICAO engine exhaust emissions data bank. First edition, Doc 9646-AN/943, International Civil Aviation Organisation, Montreal. Updated to Issue 14, 2005

Levinson, D.M., Gillen, D., Kanafani, A., 1998. The social costs of intercity transportation: a review and comparison of air and highway. Transport Reviews 18, 215-240.

Lu, C., Morrell, P., 2006. Determination and applications of environmental costs at different sized airports – aircraft noise and engine emissions. Transportation 33, 45-61.

McMillen, D.P., 2004. House prices and the proposed expansion of Chicago's O'Hare Airport. Economic Perspectives 3Q, 28-39.

McShan, S., Windle, R., 2004. The implications of hub and spoke routing for airline costs and competitveness. Logistics & Transportation Review 25, 209-300.

Nero, G., 1999. A Note on the competitive advantage of large hub-and-spoke networks. Transportation Research Part E 35, 225-239.

O'Connell, John F., Williams, George, 2005. Passengers' perceptions of low cost airlines and full service carriers: A case study involving Ryanair, Aer Lingus, Air Asia and Malaysia Airlines. Journal of Air Transport Management 11(4), 259-272.

OECD, 2005. Economic outlook, 77.

Pearce, B., Pearce, D., 2000. Setting environmental taxes for aircraft: a case study of the UK. CSERGE working paper GEC 2000-26.

UK Civil Aviation Authority, 2005. Noise Exposure Contours for Heathrow Airport 2004. ERCD Report 0501.

Upmystreet, 2005. www.upmystreet.com.

US Federal Aviation Administration, 2001. Noise Levels for U.S. Certificated and Foreign Aircraft. Advisory Circular, 36-1H.

Wei, W., Hansen, M., 2003. Cost economics of aircraft size. Journal of Transport Economics and Policy 37.

Appendix A. Aircraft categories

Category	1	2	3	4
Aircraft type	Small props Large props Helicopter	A318 BAe146 Business jet CRJ EMB 135/145 F100	A319/320 B737-300/400/500 B737-600/700/800 MD90	A321 B757 MD80 B787-8

Category	5	6	7	8
Aircraft type	A300 A310 A330 B767 B777	A340 B747-400 B747SR/SP MD11	B747-100/200/300 DC10 Tristar	B707 B717Q B727Q B737-200Q DC8/9

				A380-800 B747-8

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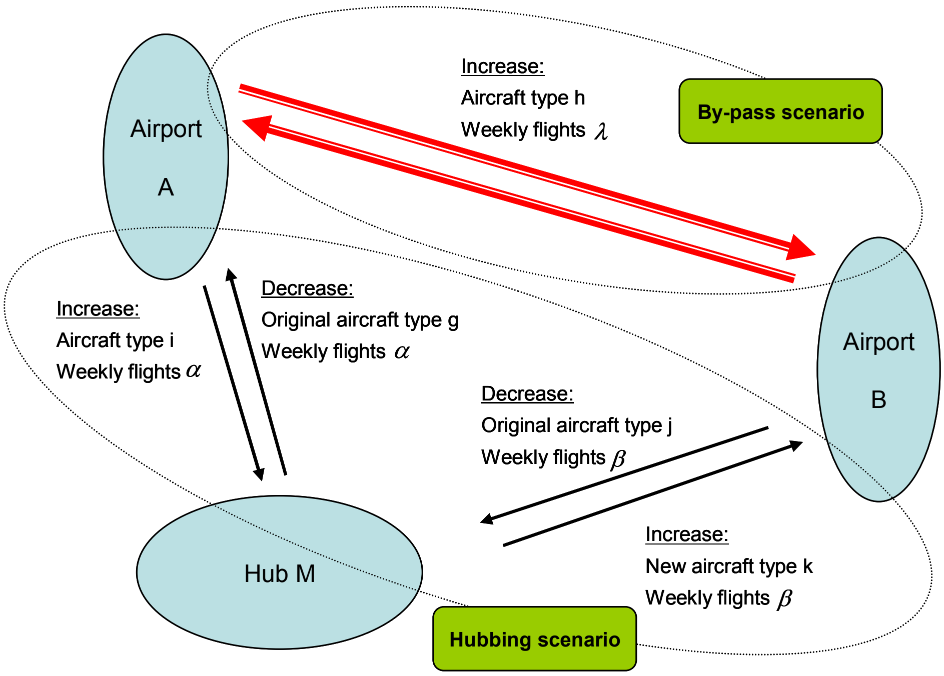

Fig. 1. Airline network: hubbing vs. by-pass scenarios

Table 1 Social costs of each exhaust pollutant

Pollutant	Average (2004 euros/kg)*	Rural	urban
HC	4.47	2.7-5.0	2.7-8.9
CO	0.08	0.01-0.19	
NO_X	10.05	4-13	7-25
PM	167.57	18-200	85-2,000
SO2	6.70	3.0-8.5	3.0-50.0
CO_2	0.03**	0.01-0.04	

Source: Pearce and Pearce (2000); UK DfT (2003); Dings et al. (2003); Lu and Morrell (2006).

Note: * The figures are inflated to 2004 values by applying the euro area inflation rates (OECD, 2005).

** The figure of 0.03351, used in the calculation, has been rounded to two decimal places.

Table 2 Aircraft categorisation

Category	Aircraft	Representative aircraft	Average noise (EPNdB)*	Noise index
1	Propeller aircraft	Jetstream 31	72.8	0.01
2	Regional jets	CRJ	86.2	0.32
3	Chapter 3 jets: short haul, network small	B737-700	91.2	1.00
4	Chapter 3 jets: short haul, network large	A321	92.7	1.41
5	Chapter 3 jets: wide-body twins	B767/B777	95.2	2.51
6	Large chapter 3 jets: 2nd generation wide-body multi-engines	B747-400	99.7	7.08
7	Large chapter 3 jets: 1st generation wide-body	B747-100/200/300	101.8	11.48
8	Hush kitted jets: 1st/2nd generation narrow body	B727Q	97.4	4.17

Source: Derived from US Federal Aviation Administration (2001).

Note: * The average of take-off, sideline and approach noise levels, taking from FAA noise levels for US certificated and foreign aircraft, averaging through all the possible engine types for each representative aircraft.

Table 3 Aircraft movements by category in 2004

Aircraft category	Chicago O'Hare	Dallas	Frankfurt	London Heathrow	Tokyo Narita	San Diego	Hamburg	Glasgow
1	8.6%	7.1%	5.26%	0.8%	0.6%	13.8%	11.5%	24.8%
2	37.3%	32.9%	66.53%	3.6%	7.1%	8.6%	37.7%	18.3%
3	10.2%	10.8%	13.61%	45.6%	1.6%	55.2%	40.9%	41.5%
4	19.0%	42.2%	12.87%	18.3%	0.0%	18.4%	5.8%	10.8%
5	4.2%	3.4%	1.36%	18.3%	38.9%	1.9%	3.2%	4.5%
6	2.2%	1.0%	0.06%	12.8%	33.6%	0.0%	0.8%	0.0%
7	0.3%	0.2%	0.11%	0.6%	18.3%	0.6%	0.1%	0.1%
8	18.2%	2.6%	0.15%	0.0%	0.0%	1.5%	0.0%	0.0%
Total movements	**992,427**	**816,058**	**477,475**	**469,560**	**186,309**	**185,828**	**151,434**	**92,836**

Source: UK CAA (2005); airport websites and contacts.

Note: Ranked by total movements.

Table 4 Residences within noise contour in 2004

Airport	Noise unit	Minimum measuring level	Residences within noise contour	Background noise level
London Heathrow	L_{eq}	57	104,217	52
Frankfurt	L_{den}	60	23,155	55
Chicago O'Hare	L_{dn}	65	13,167	60
Glasgow	L_{eq}	57	12,600	52
San Diego	CNEL	65	11,291	60
Tokyo Narita	WECPNL	75	5,421	70
Hamburg	L_{eq}	62	5,120	52
Dallas	L_{dn}	65	2,663	60

Source: UK CAA (2005); contacts with individual airports.

*Notes: Above table r*anked by residences within noise contour.

L_{den}: Day-evening-night level, a descriptor of noise level based on energy equivalent noise level (Leq) over a whole day with a penalty of 10 dB(A) for night time noise (22.00-7.00) and an additional penalty of 5 dB(A) for evening noise (19.00-23.00).

Table 5 House prices in 2004

Airport	House price (€/residence)
San Diego	335,428
London Heathrow	304,582
Frankfurt	275,000
Chicago O'Hare	253,676
Hamburg	250,000
Tokyo Narita	217,153
Glasgow	149,394
Dallas	60,000

Source: Upmystreet (2005) for UK airports; McMillen (2004) for Chicago; San Diego Housing Commission, Housing Statistics, www.sdhc.net (2005)

Note:

1. Exchange rates in 2004: £=€1.475; $=€0.805, ¥=€134; Monthly averages over year from OANDA.Com
2. An average house life of 30 years is applied to all cases. A mortgage interest rate of 6% is applied to all, except 4% for Tokyo Narita, reflecting lower interest rates in Japan.
3. Ranked by house price.

Table 6 Noise social cost by aircraft category (2004 €/LTO)

Category	Aircraft type	London Heathrow	Glasgow	San Diego	Hamburg	Frankfurt	Tokyo Narita	Chicago O'hare	Dallas
1	Jetstream 31	2	2	1	1	2	0	0	0
2	CRJ	77	70	44	46	49	3	8	1
3	B737-300	242	219	139	145	153	11	24	2
4	A321	341	309	196	205	215	15	33	3
5	B767/B777	607	550	349	365	383	27	60	5
6	B747-400	1,713	1,552	984	1,028	1,081	77	168	15
7	B747-100/200/300	2,778	2,516	1,595	1,667	1,753	124	273	25
E	B727Q	1,009	914	579	606	637	45	99	9
Weighted average		**523**	**165**	**142**	**111**	**89**	**59**	**37**	**2**

Note: Ranked by weighted average noise social cost.

Table 7 Engine emissions social cost by jet aircraft category (2004 €/flight)

Jet aircraft category	Aircraft type	LTO	30 minute Cruise	LTO+cruise	Fuel burn during cruise (kg)
2	CRJ	79	61	140	576
3	B737-700	224	130	354	1,230
4	A321	323	160	483	1,518
5	B767-300	620	263	883	2,493
5	B777-300	838	335	1,173	3,174
6	B747-400	1,283	503	1,785	4,764
7	B747-100/300	1,455	541	1,996	5,121
8	B727Q	220	234	454	2,220

Note: Mid-point between the worst and best engine/aircraft combination for each aircraft type.

Table 8 Cruise characteristics of flight sectors

		Distance (km)	Altitude (ft)	Cruise (hours)
Case 1				
Hubbing	GLA-LHR	555	31,000	0.7
	LHR-CHI	6,347	37,000	7.2
By-pass	GLA-CHI	5,896	37,000	6.7
Case 2				
Hubbing	LHR-CHI	6,347	37,000	7.2
	CHI-SAN	2,783	37,000	3.1
By-pass	LHR-SAN	8,812	37,000	9.9
Case 3				
Hubbing	HAM-FRA	410	31,000	0.5
	FRA-NRT	9,338	37,000	10.5
By-pass	HAM-NRT	8,965	37,000	10.1
Case 4				
Hubbing	GLA-LHR	555	31,000	0.7
	LHR-DFW	7,633	37,000	8.6
By-pass	GLA-DFW	7,183	37,000	8.1
Case 5				
Hubbing	HAM-FRA	410	31,000	0.5
	FRA-DFW	8,247	37,000	9.3
By-pass	HAM-DFW	8,116	37,000	9.2

Note: The corresponding cruise speed for altitude 31,000 ft and 37,000 ft are 842 and 886 kms/hour respectively.

Table 9 Environmental costs - Case 1: Glasgow to/from Chicago

	Seats per flight	Total seats	Noise cost (€/day) A	LTO Emissions cost (€/day) B	Sector cruise CO_2 emissions cost (€/day) C	Environmental cost (€/day) A+B+C	Environmental cost (€/passenger)
A. Hubbing scenario*							
Glasgow to/from Heathrow							
Add three daily flights with larger aircraft to accommodate 150 GLA/CHI pax:							
(+) A321-200	195	585	+1,951	+1,936	+1,282	+5,169	
Less three daily flights with smaller aircraft:							
(-) B737-700	126	378	-1,384	-1,345	-1,039	-3,767	
Net increase in seats**		207					
Heathrow to/from Chicago							
Add two daily flights with larger aircraft to accommodate 150 GLA/CHI pax:							
(+) B747-400	392	784	+3,763	+5,130	+28,831	+37,725	
Less two daily flights with smaller aircraft:							
(-) B777-200	300	600	-1,334	-3,351	-19,209	-23,894	
Net increase in seats***		184					
Total net change in environmental costs			**2,996**	**2,370**	**9,866**	**15,232**	**101**
B. By-pass scenario							
Glasgow to/from Chicago (non-stop)							
(+) B767-300	210	210	**610**	**1,240**	**7,000**	**8,850**	**59**
Net increase in seats**		210					

Note: * Assuming new demand of 150 passengers per day from Glasgow to Chicago via Heathrow.
** Resulting in additional passengers carried at 72% seat factor.
*** Resulting in 150 additional passengers carried at 82% seat factor.

Table 10 Environmental costs - Case 2: Heathrow to/from San Diego

	Seats per flight	Total seats	Noise cost (€/day) A	LTO Emissions cost (€/day) B	Sector cruise CO_2emissions cost (€/day) C	Environmental cost (€/day) A+B+C	Environmental cost (€/passenger)
A. Hubbing scenario*							
Heathrow to/from Chicago							
Add two daily flights with larger aircraft to accommodate 150 GLA/SAN pax:							
(+) B747-400	392	784	+3763,	+5,130	+28,831	+37,725	
Less two daily flights with smaller aircraft:							
(-) B777-200	300	600	-1,334	-3,351	-19,209	-23,894	
Net increase in seats***		184					
Chicago to/from San Diego							
Add three daily flights with larger aircraft to accommodate 150 GLA/SAN pax:							
(+) A321-200	195	585	+688	+1,936	+6,025	+8,649	
Less two daily flights with smaller aircraft:							
(-) B737-700	126	378	-488	-1,345	-4,882	-6,715	
Net increase in seats**		207					
Total net change in environmental costs			**2,629**	**2,370**	**10,766**	**15,765**	**105**
B. By-pass scenario							
Heathrow to/from San Diego							
(+) B767-300	210	210	**956**	**1,240**	**10,456**	**12,653**	**84**
Net increase in seats**		210					

Note: * Assuming new demand of 150 passengers per day from Glasgow to San Diego via Heathrow.
** Resulting in additional passengers carried at 72% seat factor.
*** Resulting in 150 additional passengers carried at 82% seat factor.

Table 11 Environmental costs - Case 3: Hamburg to/from Tokyo Narita

	Seats per flight	Total seats	Noise cost (€/day) A	LTO Emissions cost (€/day) B	Sector cruise CO_2 emissions cost (€/day) C	Environmental cost (€/day) A+B+C	Environmental cost (€/passenger)
A. Hubbing scenario*							
Hamburg to/from Frankfurt							
Add three daily flights with larger aircraft to accommodate 150 HAM/TYO pax:							
(+) A321-200	195	585	+1,260	+1,936	+936	+4,133	
Less three daily flights with smaller aircraft:							
(-) B737-700	126	378	-894	-1,345	-759	-2,998	
Net increase in seats**		207					
Frankfurt to/from Tokyo Narita							
Add two daily flights with larger aircraft to accommodate 150 HAM/TYO pax:							
(+) B747-400	392	784	+2,316	+5,130	+42,400	+49,846	
Less two daily flights with smaller aircraft:							
(-) B777-200	300	600	-821	-3,351	-28,249	-32,421	
Net increase in seats***		184					
Total net change in environmental costs			**1,861**	**2,370**	**14,329**	**18,560**	**124**
B. By-pass scenario							
Hamburg to/from Tokyo Narita							
(+) B767-300	210	210	**392**	**1,240**	**10,651**	**12,283**	**82**
Net increase in seats**		210					

Note: * Assuming new demand of 150 passengers per day from Hamburg to Tokyo via Frankfurt.
** Resulting in additional passengers carried at 72% seat factor.
*** Resulting in 150 additional passengers carried at 82% seat factor.

Table 12 Environmental costs - Case 4: Glasgow to/from Dallas

	Seats per flight	Total seats	Noise cost (€/day) A	LTO Emissions cost (€/day) B	Sector cruise CO_2emissions cost (€/day) C	Environmental cost (€/day) A+B+C	Environmental cost (€/passenger)
A. Hubbing scenario*							
Glasgow to/from Heathrow							
Add three daily flights with larger aircraft to accommodate 150 GLA/DFW pax:							
(+) A321-200	195	585	+1,951	+1,936	+1,268	+5,155	
Less three daily flights with smaller aircraft:							
(-) B737-700	126	387	-1,384	-1,345	-1,027	-3,756	
Net increase in seats**		207					
Heathrow to/from Dallas							
Add two daily flights with larger aircraft to accommodate 150 GLA/DFW pax:							
(+) B747-400	392	784	+3,457	+5,130	+34,658	+43,246	
Less two daily flights with smaller aircraft:							
(-) B777-200	300	600	-1,226	-3,351	-23,091	-27,668	
Net increase in seats***		184					
Total net change in environmental costs			**2,799**	**2,370**	**11,808**	**16,977**	**113**
B. By-pass scenario							
Glasgow to/from Dallas							
(+) B767-300	210	(+) 1	**556**	**1,240**	**8,534**	**10,330**	**69**
Net increase in seats**							

Note: * Assuming new demand of 150 passengers per day from Glasgow to Dallas via Heathrow.
** Resulting in additional passengers carried at 72% seat factor.
*** Resulting in 150 additional passengers carried at 82% seat factor.

Table 13 Environmental costs - Case 5: Hamburg to/from Dallas

	Seats per flight	Total seats	Noise cost (€/day) A	LTO Emissions cost (€/day) B	Sector cruise CO_2emissions cost (€/day) C	Environmental cost (€/day) A+B+C	Environmental cost (€/passenger)
A. Hubbing scenario*							
Hamburg to/from Frankfurt							
Add three daily flights with larger aircraft to accommodate 150 HAM/DFW pax:							
(+) A321-200	195	585	+1,260	+1,936	+936	+4,133	
Less three daily flights with smaller aircraft:							
(-) B737-700	126	387	-894	-1,345	-759	-2,998	
Net increase in seats**		208					
Frankfurt to/from Dallas							
Add two daily flights with larger aircraft to accommodate 150 HAM/DFW pax:							
(+) B747-400	392	784	+2,193	+5,130	+37,446	+44,770	
Less two daily flights with smaller aircraft:							
(-) B777-200	300	600	-777	-3,351	-24,948	-29,077	
Net increase in seats***		184					
Total net change in environmental costs			**1,782**	**2,370**	**12,676**	**16,827**	**112**
B. By-pass scenario							
Hamburg to/from Dallas							
(+) B767-300	210	210	**370**	**1,240**	**9,642**	**11,253**	**75**
Net increase in seats**		210					

Note: * Assuming new demand of 150 passengers per day from Hamburg to Dallas via Frankfurt.
** Resulting in additional passengers carried at 72% seat factor.
*** Resulting in 150 additional passengers carried at 82% seat factor.

Table 14 Sensitivity analysis for Glasgow to/from Chicago (Case 1)

	Hubbing	By-pass	Hubbing	By-pass
	Environmental cost (€/passenger)		% change from base case	
Base case	**101**	**59**		
Using B787-8 for by-pass operations	101	48	--	-18.6%
Using B787 for by-pass operations, and the A380-800 on the LHR/CHI sector	58	48	-43.1%	- 18.6%
NDI = 0.4%	95	58	-5.9%	-1.7%
NDI = 0.8%	108	60	6.9%	1.7%
Double of the idle time at hubs	106	59	5.0%	--
Worst engine for bypass, best for hubbing	99	61	-2.0%	3.4%
Using the B747-8 as a replacement for the B747-400 on the LHR/CHI sector	76	59	-24.8%	--