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Choice of aircraft size – explanations and implications

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Abstract

To keep load factors high while offering high frequency service, airlines tend to reduce the size of the aircraft they use. At many of the world's largest airports there are fewer than 100 passengers per air transport movement, although congestion and delays are growing. Furthermore, demand for air transport is predicted to continue growing but aircraft size is not. This paper aims to investigate and explain this phenomenon, the choice of relatively small aircraft. It seems that this choice is associated mainly with the benefits of high frequency service, the competitive environment in which airlines operate and the way airport capacity is allocated and priced. Regression analysis of over 500 routes in the US, Europe and Asia provides empirical evidence that the choice of aircraft size is mainly influenced by route characteristics (e.g. distance, level of demand and level of competition) and almost not at all by airport characteristics (e.g. number of runways and whether the airport is a hub or slot coordinated). We discuss the implications of this choice of aircraft size and suggest that some market imperfections exist in the airline industry leading airlines to offer excessive frequency on some routes and too low frequency on others.

1. Introduction

It is expected that as traffic volumes increase transport services will be provided by larger capacity vehicles. In other words, vehicle capacity is expected to be positively correlated with demand. This does not seem to hold true in the operation of air transport services. The leading aircraft manufacturers predict that demand for air transport services will continue to rise in the next 20 years but they also predict that the average size of the world's aircraft fleet will not change much (Airbus, 2004; Boeing, 2005). This result on average aircraft size depends on the balance between two forces: the increase in demand on existing routes – probably leading to the use of larger aircraft - and the opening of new routes – probably implying the introduction of below average aircraft sizes. In the present paper we will investigate the first aspect: the choice of aircraft size in established markets.

To meet growing demand, airlines can increase service frequency, aircraft size and/or the load factor. High load factors are considered as prerequisite for profitable operation and airlines try to maximize this at any time, they do so relatively well with an industry average of around 75%[1]. This implies that when demand increases, airlines are left with two tools to meet it: service frequency and aircraft size.

Mohring (1976) demonstrated that in public transport under inelastic demand, when demand increases with 1% both frequency and vehicle size will increase with 0.5% - the well known square root rule. An obvious difference between the two contexts is that Mohring had in mind a public firm. The square root rule follows from minimizing the sum of the cost of operations (proportional to frequency) and the scheduling costs at the side of the travelers (inversely

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[1] 76% for January-August 2006 (www.iata.org).

proportional to frequency). In the context of aviation in deregulated markets there are two obvious differences. First, the transport companies would no longer minimize social costs, but rather minimize operator costs (or maximize profit in the case of elastic demand). Under inelastic demand, the minimization of operator costs would lead to the use of relatively large aircraft since the benefits of high frequencies would be ignored. The second difference is that in many submarkets aviation is characterized by a certain degree of competition. It is in this context that frequency is an important competitive tool and this will have a dampening effect on the aircraft size chosen by airline companies. Models for one or two stage competition in transport markets lead to the conclusion that also in this context the square root law applies; equilibrium responds to demand increases with an elasticity of 0.5 (see for example Schipper, 1999, based on monopolistic competition approaches similar to Salop, 1979). Schipper also shows that in the more general context where total demand is elastic this simple square root law no longer applies. The elasticity may well be higher. For example, Schipper et al. (2002) arrive at a frequency elasticity of about 0.75. Under the assumption of a constant load factor, this would imply that aircraft size responds to demand with an elasticity of about 0.25.

The main rational for increasing service frequency in a competitive environment is reducing passengers' schedule delay. Schedule delay in air transport is defined as the difference between the passenger’s preferred time of departure and the nearest *available* service (Wei and Hansen, 2005). Therefore, in addition to higher frequency, increasing aircraft size also reduces schedule delay since it increases the probability of seat availability. Yet, by adding services (increasing capacity through frequency and not aircraft size) airlines target both elements of schedule delay. Following the reasoning given above, the larger the competitive forces the smaller the aircraft size one may expect given the importance of service frequency.

Considering the forecast for increased demand for air transport services and the prediction that aircraft size will not change significantly in the future, despite already high levels of congestion and delays (see for example Reynolds-Feighan and Button, 1999; Johnson and Savage, 2006; CODA 1998-2005), this paper aims to investigate airlines’ choice of aircraft size. In most cases, research on air transport includes aircraft size as one of many explanatory variables in the context of airlines or airport operation, here explaining aircraft size is the focus. In addition, most of the research which considers aircraft size is based on the US domestic market (e.g. Gosling and Hansen, 2001; Wei and Hansen, 2005), here we consider also the European and Asian markets. The remainder of the paper is structured as follows. In Section 2 we examine the choice of aircraft size at the world’s largest airports. In Section 3 we provide possible explanations for this choice based on a literature review and in Section 4 we find empirical evidence to explain it. High frequency service (and the small aircraft size implied by it) also has some potential adverse effects, like congestion and higher operating and environmental costs, and we briefly consider and discuss these in Section 5. Section 6 concludes.

Aircraft (measured in seats per service) can be divided into two groups: the single-aisle and the twin-aisle aircraft, also known as narrow-body and wide-body aircraft respectively. Other than larger seat capacity, the wide body aircraft can typically also fly further, probably the result of technological constraints but also market demand. The narrow-body aircraft typically have maximum range of about 6000 km (e.g. B737-700: 6230 km, A320: 5700) while wide-body aircraft typically can fly more than 10000 km (e.g. B777-300: 11029 km, A330-200: 12500).

Table 1 provides a list of aircraft in each category and their respective seat capacities. Another group of aircraft size, a subgroup of narrow-body aircraft, is the regional jet, with seat capacity of fewer than 100 seats.

Table 1: Seat capacity of various aircraft

Narrow-body models	Seat capacity		Wide-body models	Seat capacity	
	Nominal	2-class		Nominal	2-class
A318	117	107	B767-200	238	163
B737-600	122	110	B767-300	280	200
B737-700	140	126	B767-400	315	229
A319	138	126	A330-200	355	233
A320	160	150	A330-300	379	268
B737-800	175	162	B777-200	415	308
B737-900	189	177	B777-300	510	385
A321	202	183	B747-400	553	429
B757-200	217	200			
B757-300	258	243			

Source: Swan and Adler, 2006.

2. Airlines' choice of aircraft size

Runway capacity is a key determinant of airports' capacity and it is measured by the number of aircraft that can safely be handled during a specific period of time (Reynolds-Feighan and Button, 1999). Airport capacity, however, is usually measured by both the number of air transport movements (atm) and the terminal capacity which is measured in the number of passengers (when passenger transport is of concern). When an airport is bounded by runway capacity limitations, it can nevertheless increase its number of passengers when larger aircraft are used, as long as this is allowed by sufficient terminal capacity.

In different airports a different mix of aircraft is used depending on the nature of routes served from the airport. Usually, the higher the average distance of routes served from an airport the larger, on average, the fleet used at this airport since on long haul routes only large aircraft are used. The average size of the fleet used at each airport will also increase with the average level of demand on routes it serves. This implies that at large airports average aircraft size will tend to be larger compared to smaller airports. Furthermore, these airports usually experience airside congestion, at least at some parts of the day - another reason to expect airlines to use larger aircraft at these airports.

Table 2 shows the average number of passengers per atm at the world's largest airports in 2003 (or average size of aircraft assuming an average load factor of 75%). With the exception of Tokyo Haneda airport (and considering Table 1), the aircraft fleet at the world's biggest airports is, on average, in the narrow-body range. Rearranging Table 2 by the number of passengers per atm, the first 11 airports are all in the US, the next 7 are in Europe (with the exception of JFK) and the last two are in Asia. In the US airports, the average number of passengers per atm is 77 (with a load factor of 75% this equals the size of a regional jet), in Europe it is 110 and in Asia 180. The case of Haneda, Tokyo's domestic airport, illustrates that an airport can support an aircraft fleet which is, on average, in the wide-body range. Airports ranked 50 to 65 in the world in 2003, had an average of 93 passengers per atm. Hence, based on this illustrative example, at larger airports actually smaller aircraft fleet is used despite higher average demand on routes and probably more congestion[2].

Table 2: Runway utilization at the world's major airports (ranked by passenger capacity, 2003)

Rank (pax)	Airport (code)	Pax (million)	atm[1]	Rwy	pax/atm	atm/rwy	pax/rwy (million)
1	Atlanta (ATL)	79.09	910398	4	**87**	227600	19.77
2	Chicago (ORD)	69.51	928691	7	**75**	132670	9.93
3	London (LHR)	64.26	460748	2	**139**	230374	32.13
4	Tokyo (HND)[2]	59.41	285000	3	**208**	95000	19.80
5	Los Angeles (LAX)	55.31	637120	4	**87**	159280	13.83
6	Dallas (DFW)	52.46	759288	7	**69**	108470	7.49
7	Frankfurt (FRA)	48.36	458865	3	**105**	152955	16.12
8	Paris (CDG)	48.12	515025	4	**93**	128756	12.03
9	Amsterdam (AMS)	39.96	392997	5	**102**	78599	7.99
10	Denver (DEN)	37.51	508930	6	**74**	84822	6.25
11	Phoenix (PHX)	36.61	544572	3	**67**	181524	12.20
12	Madrid (MAD)	35.37	382857	3	**92**	127619	11.79
13	Las Vegas (LAS)	35.34	475420	4	**74**	118855	8.83
14	Houston (IAH)	33.41	458347	5	**73**	91669	6.68
15	Minneapolis (MSP)	33.20	508813	3	**65**	169604	11.07
16	Detroit (DTW)	32.66	487762	6	**67**	81294	5.44
17	New York (JFK)	31.74	280302	4	**113**	70076	7.93
18	London (LGW)	30.06	234248	1	**128**	234248	30.06
19	Bangkok (BKK)	29.68	195530	2	**152**	97765	14.84
20	Miami (MIA)	29.53	381248	4	**77**	95312	7.38

Note: Pax - passenger, Rwy – runway

[1] Cargo atms are included. This is not considered to considerably affect the results. In 2003, 7.2%, 4.5% and 3.7% of the atms at CDG, FRA and AMS were cargo movements. At LHR it was only 0.7%.

[2] For Tokyo Haneda the stated runway capacity and not the actual atms are used, but at this airport they are considered to be similar.

Source: ATRS, 2005.

It is clear from Table 2 that there is no simple relationship between airport size (measured in total number of atms or passengers) and the average number of passengers per atm and between airport size and the number of runways. With only one runway Gatwick was 18th biggest in the world in 2003. At JFK only 70076 atms per runway were handled in 2003, 30% of the utilization of Gatwick's single runway. Furthermore, there is no apparent correlation between the number of runways and atm capacity. Atlanta and JFK both have four runways but Atlanta has much bigger atm volumes since it handles more atms per runway.

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[2] Smaller airports might serve on average longer distance routes

In the context of this paper, the number of passengers per runway is a useful indicator for runway utilization. Heathrow, with 32.13 million passengers per runway, achieves the highest degree of utilization followed by Gatwick (30.06 million). Detroit airport, with six runways, served only 5.44 million passengers on each of its runways, and it had almost twice the atm capacity of Gatwick. Prevailing weather conditions have an immediate affect on airport atm capacity, but since Detroit airport had double the atm capacity of Gatwick (487,762 compared with 234,248) it means that worse weather conditions do not explain the difference in the number of passengers per runway, the differences are due to differences in the average size of aircraft used. The situation at the US airports seems to be stable over time, despite growth in demand, aircraft size on domestic services from Los Angeles airport between 1988 and 1999 remained virtually the same (Gosling and Hansen, 2001).

Demand for air transport services is expected to continue growing, Boeing forecasts that traffic will grow at an annual rate of 4.8% between 2004 and 2024. For the North America region Boeing predicts an annual growth rate of 3.5% and for Europe 3.4% over the same period (Boeing, 2005). Airbus forecasts a 5.3% annual global growth rate for the period 2004-2023, 3.2% for domestic traffic in the US and 5% for Western Europe domestic traffic (Airbus, 2004). Most of this growth, according to Boeing, will be met by an increase in frequency while only a small part will be accommodated through the use of larger aircraft, thus no notable change in aircraft size is expected. The Airbus prediction is somewhat different, it agrees with Boeing that future demand will be met mainly through an increase of frequency but it also forecasts that the average number of seats per aircraft will increase by 20% from 181 to 215 in 20 years[3].

The scope for changing aircraft size is limited on long haul routes, since, as mentioned above, at these distances only larger aircraft can be used. Thus, the choice of aircraft size is more relevant at the shorter distances[4].

To illustrate the potential to increase aircraft size two routes are considered. In July 2006, 55 and 51 daily one-way services were scheduled between London and Amsterdam (370 km) and between Tokyo and Sapporo (820 km) respectively (AirWise, 2006). The average aircraft size on these routes was 125 and 395 seats respectively[5]. With the exception of one service, all services from London were by narrow-body aircraft and all services from Tokyo (except for three services) were operated by wide-body aircraft, including 16 services by B747 (according to Boeing, typical seating capacity of the B747-400 in 2-class configuration is 524, JAL provides 546 seats and ANA 569 seats on domestic services). With 55 daily services (first flight at 06:10 and the last at 20:25) and considering the journey time from origin to destination (including access to and egress from the airport) higher level of service on the London-Amsterdam route will probably not result in significant benefits to passengers, even business passengers with a

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[3] The differences between the manufacturers led Airbus to develop the A380, a 555 seats aircraft designed to operate between the world's congested hubs (the consolidation scenario) and Boeing to develop the B787, expected capacity of 250 to 300 seats, designed mainly to serve long distance point-to-point routes (by-passing the hubs, the fragmentation scenario).

[4] For the purpose of the paper, the exact definition of short vs. long haul service is not of importance.

[5] Excluding services to Amsterdam from London City airport (due to the short runway only 50 seats aircraft are used on services to Amsterdam) result in 143 seats per flight and excluding services from Tokyo Narita airport to Sapporo (only 3 daily services compared to 48 from Haneda) result in 410 seats per flight on this market.

high value of time. Similarly, lowering frequency will probably not disbenefit passengers significantly in this market.

A final remark on Table 2 is that airports are not the most appropriate level to analyse the choice of aircraft size. The average aircraft size will depend, as noted, on the features of the routes served (like distance and demand). To correct for this, an analysis at the level of routes will make more sense. Such an analysis is carried out in section 4.

3. Theoretical explanations for the choice of aircraft size - literature review

The choice of aircraft size depends on a variety of factors related to market conditions, including competitive conditions related to regulation of markets, airport policies and cost parameters. In section 2 we already mentioned the dependence on market size and variations on the square root principle. In the present section we will discuss some of the other dimensions.

Following the deregulation of air transport markets, service frequency became an important element in the competition between airlines (Peeters et al., 2005), due to the ability to attract more passengers by reducing schedule delay and charging higher fares for that. The increase in service frequency also relates to the formation of Hub and Spoke (H&S) networks. The economies of density created by H&S operations lead to higher frequency of service. A model of airline scheduling shows that in a H&S network an airline "provides excessive flight frequency relative to the social optimum" (Brueckner and Zhang, 2001: 217).[6] Increasing flight frequency results in reducing the average schedule delay, which in turn allows the (monopolistic) airline to charge higher fares. Reducing schedule delay by increasing frequency also attracts more passengers which lead to economies of density. These effects are larger in a H&S network since each flight serves the origin market and also the transfer market. Thus, demand and the benefits of higher frequency are larger in a H&S network leading to excessive frequency. Almost all the airports in Table 2 are hub airports in a H&S network of an airline.

H&S operation is also closely associated with the use of regional jets, the smallest capacity commercial jet aircraft. Regional jets replace smaller capacity turoboprops aircraft, larger capacity jet aircraft (allowing airlines to reduce aircraft size without losing the benefits of operating jet aircraft which are preferred by passengers), and they are often used to increase the number of (short-haul) spokes in a hub. Hence, the effect of introducing regional jets on the average size of aircraft at airports is not clear (see Dresner et al., 2002a and Savage and Scott, 2004 for empirical evidence).

High frequency service is also associated with market power: an increase in frequency above a certain level can result in a more than proportional increase in market share, the S-curve phenomenon. Button and Drexler (2005) found very weak evidence for the existence of the S-curve phenomenon in the US. They argue that in the S-curve model, an airline that increases its frequency (to achieve a higher market share) assumes that the other airlines will not do the same, but in practice it is expected that airlines will react with their own increase in frequency, to

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[6] In a related paper Brueckner (2004) arrives at the opposite result in a similar model. He indicates that the question whether or not frequencies set by monopolists are below or above the optimal levels depends on the way demand is specified in the model.

protect their market share. This will result in a similar market share for each airline but at a higher level of frequency (and lower load factor if airlines do not reduce aircraft size). In contrast, Wei and Hansen (2005) did find evidence for the S-curve phenomenon in US duopoly markets and conclude that airlines have an economic incentive to use smaller aircraft since for the same capacity provided in the market an increase of frequency can attract more passengers. The evidence for the S-curve phenomenon suggests that smaller airlines (those who offer lower frequency on the route) cannot always react with an increase of frequency, due to airport capacity constraints (see below).

Demand for air travel is not uniformly spread across the day and therefore scheduling (when flights are offered) is more important than just how many flights are offered. For this reason, services are much more concentrated around the peak demand periods. At Chicago O’Hare, “in the morning there are periods of congestion because aircraft all seem to wish to depart at the same time at about the top of each hour" (Johnson and Savage, 2006: 186).

Scheduling competition is often analogue to spatial competition, and reference to Hotelling's work is made (see discussion in Rietveld and Rouwendal, 1997). In the temporal version of Hotelling's model, if passenger demand for a flight is uniform across the day and two airlines compete on the market and offer one (similar in all aspects) service then both services will be offered in the middle of the day one after the other. Hotelling competition thus leads to a high frequency of service. If currently there are no services between 12:00 and 16:00 there is an incentive for an airline to offer one at 14:00. Once an airline does this, other airlines will probably follow (offering a flight just before or after) to protect their market share. In the case of a non-uniform distribution of demand across the day the theory implies that equilibrium may not exist (Rietveld and Rouwendal, 1997). This implies that in practice time tables may change from year to year as airlines try to improve their scheduling with respect to competitors, yet other constraints (such as slot shortages) might restrict airlines' scheduling flexibility. Based on the Hotelling competition approach, there is an incentive for an airline to schedule a service close to a competitor's service (but not before the start of the day or after the end of the day) – this would lead to a higher frequency in a competitive market.

“On a route with a given number of daily flights, departure times are less differentiated if the route is served by competing airlines than if it is served by a single firm” (Borenstein and Netz, 1999: 638). Similar evidence was found in Norway’s domestic market after it was deregulated (Salvanes et al., 2005). On the London-Amsterdam route, most of BA and KLM flights from Heathrow are on the same time or 15 minutes apart and clustering is more apparent when including bmi services. In Japan, JAL and ANA scheduled 11 daily flights each from Haneda to Sapporo on *the same* departure time. In contrast, no clustering of flight departure time is evident at Gatwick where a low cost carrier (EasyJet) and a full service carrier (BA) offer services to Amsterdam. These airlines are considered to provide different products, differentiated by price.

The way runway capacity at the major airports is allocated and priced may also contribute to the use of relatively small aircraft. The system adopted in most airports for the allocation of (scarce) runway capacity is still the “grandfather-right" rule. Therefore airlines have an incentive to use any runway capacity they currently hold, even if it is not entirely justified by demand, to keep reserves for meeting future demand. Furthermore, any runway capacity that an airline will not use may go directly to a competitor. In 2004, United Airlines and American Airlines, which controlled 48.8% and 40.5% of the slots at O'Hare respectively, agreed to move 37 flights out of the peak hours, in order to relieve congestion (Johnson and Savage, 2006). The grandfather-right rule might explain why the airlines did not simply remove these services and instead used larger aircraft during the peak on the remaining services; removing them might have resulted in losing the slots.

In the US, Dresner et al. (2002b) found that slot controls, gate constraints (due to exclusive leasing arrangements between airlines and airports), and gate utilization during peak periods all contributed to airlines' yields. This underlines, indirectly, the importance of preventing available (slot and gate) capacity from competitors. For example, they find that increasing gate utilization during peak periods from 53% to 95% reduces the probability of a new airline entering the route from 20.8% to 5.7%, and introducing slot control reduces the probability of a new airline entering the route from 20.8% to 15.2%, an important incentive to use any available airport capacity.

Also the current pricing practices of runway capacity by means of landing charges does not always provide an incentive to use large aircraft and lower frequency. First, in many airports the charges relate to the weight of the aircraft which means that smaller aircraft pay less. For example, at CDG the landing charges accounts for the aircraft weight and per seat the landing charges for an A320 (150 seats) are €2.69 and for the larger B747 (421 seats) €6.55 (Givoni, 2005). Second, and also at airports where the landing charges do not include a weight element, the cost of using the runway compared to the total operating cost of a flight is relatively low. On a flight from Heathrow to CDG the landing charges (average of the two airports) represent about 10% of the flight operating costs (Givoni, 2005).

Finally, operating costs benefits are considered to be an important implication of using larger aircraft, due to economies of scale in aircraft operation (see discussion below), however there is a countervailing tendency related to pilots' remuneration agreements. Pilots get higher salaries for flying larger aircraft, leading airlines to prefer in some cases the use of smaller aircraft on short-haul, high density markets (Wei and Hansen, 2003). This would imply that the cost benefits for large aircraft are (partly) absorbed by pilots, reducing the incentive to use large aircraft.

4. Factors influencing the choice of aircraft size

Following the above discussion of factors influencing the choice of aircraft size and frequency a regression analysis will be performed. Domestic and international routes from the world’s 100 biggest airports were selected for analysis. To exclude long haul routes (where airlines already use relatively large aircraft and where the frequency of service is usually low), route distance was limited to up to 3500 km (as the crow flies). 549 routes between 74 airports (26 in Europe, 21 in North-America and 30 in Asia of which 8 in Japan) were included in the database. The specification of the model is as follows:

$$\begin{aligned}\ln \text{Seat/Flight} = {} & \beta_0 + \beta_1 \ln \text{Market size} + \beta_2 \ln \text{Dist} + \beta_3 \ln \text{HH} + \beta_4 \text{LCC} + \beta_5 \text{Europe} + \\ & \beta_6 \text{N. America} + \beta_7 \ln \text{Rwy1} + \beta_8 \ln \text{Rwy2} + \beta_9 \text{Hub1} + \beta_{10} \text{Hub2} + \beta_{11} \\ & \text{Slot1} + \beta_{12} \text{Slot2}\end{aligned}$$

Descriptive statistics of the variables used and their definitions are given in Table 3.

Table 3: Characteristics of the routes and airports (data for 2003)

Variable	Definition	Avg./%	Min.	Max.
Seat/flight	Average number of seats per flight	155	30	447
Market size	Route density, no. of weekly seats (two-way)	16894	200	240448
Dist	Great circle distance (km)	1408	129	3499
HH	Herfindahl-Hirschman index – the sum of square of airlines' market share on the route	0.62	0.16	1.00
LCC	Dummy, at least one Low Cost Carrier operates on the route	21%		
Europe	Dummy, route is within Europe	46%		
N. America	Dummy, route is within North-America	32%		
Rwy1	No. of runways (larger airport on the route)	3.55	1	7
Rwy2	No. of runways (smaller airport on the route)	2.38	1	7
Hub 1	Dummy, one of the route airports is a hub (transfer passengers > 15%)	38%		
Hub 2	Dummy, two of the route airports are hubs (transfer passengers > 15%)	47%		
Slot1	Dummy, one of the route airports is slot coordinated (level 3)	16%		
Slot2	Dummy, two of the route airports are slot coordinated (level 3)	54%		

Source: based on OAG data and ATRS (2005).

The regression analysis results are summarized in Table 4 applying OLS and 2SLS methods to estimate the coefficients in a log-linear model (only continuous variables are logged). The 2SLS method was used due to possible endogenity of the market size variable (we add the number of passengers at both of the airports on the route as instrumental variables). The results are rather similar for the two methods and in both cases over 60% of airlines' choice of aircraft size can be explained.

The explanatory variables can be divided into two groups: route characteristics and airport characteristics. It appears that route characteristics provide most of the explanation for the choice of aircraft size while airport characteristics play a secondary and only limited role.

As expected, market size and route distance have a positive effect on aircraft size. A similar result is found for market concentration (measured through the Herfindahl-Hirschman index). Assuming a constant load factor, the elasticity of aircraft size with respect to demand is 0.35 in the 2SLS outcome. This implies a frequency elasticity of 0.65, somewhere in between the value of 0.75 found by Schipper et al. (2002) for Europe and 0.50 as would follow from the square root rule. Note that ignoring the possible endogeneity of market size would lead to a higher frequency elasticity of about 0.78. Of particular importance is the result on market concentration. We find that airlines are relatively responsive to changes in competition; aircraft size elasticity with respect to the market concentration index is 0.37. Consider for example the entry of a carrier in a market where initially there was only one supplier, and where after entry both suppliers have equal market shares. The – ceteris paribus - effect on aircraft size is a decrease of 23%.

Table 4: Regression analysis results of average size of aircraft in number of seats (Log-linear model, N=549)

	Model 1: OLS		Model 2: 2SLS	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	1.398	6.86	-0.365	-0.09
Market size	0.219	16.28	0.347	10.08
Dist	0.298	16.40	0.349	15.02
HH	0.173	4.66	0.370	5.90
LCC	0.145	5.01	0.141	4.49
Europe	-0.440	-11.06	-0.403	-9.16
N. America	-0.822	-13.25	-0.735	-10.47
Rwy1	0.040	0.98	-0.019	-0.41
Rwy2	0.092	2.57	0.076	1.95
Hub 1	-0.066	-1.87	-0.081	-2.11
Hub 2	-0.104	-2.58	-0.144	-3.24
Slot1	-0.049	-1.16	0.064	1.20
Slot2	-0.127	-2.36	-0.008	-0.12
R^2	0.679		0.612	

On routes where low cost airlines are present, aircraft size is 14% higher than elsewhere. This captures several aspects. First low cost airlines use a one-class (economy) configuration, allowing them to put more seats on each aircraft compared to other airlines. Further, they are more focussed on price competition than on frequency competition, and therefore one may expect that they use larger aircraft to exploit economies of density. Note also that this figure does not say that LCC carriers have aircraft that is 14% larger than aircraft of other companies, since the figure relates to the average aircraft size used by both LCC and other airlines on the routes we analysed.

The regional dummy variables are harder to interpret; but the results are what was expected based on Table 2, i.e. aircraft size is largest in Asia, smaller in Europe and smallest in the US. After controlling for demand, competition and LCC operation it is less clear why aircraft size in Europe and much more in North-America will be smaller than aircraft size in Asia (the reference group). Here we suggest some possible explanations. A first explanation concerns, at least for the US, the incorporation of aircraft size in flight crew pay scales. This remuneration practice leads airlines to use smaller than the cost minimizing aircraft size (Wei and Hansen, 2003). If air crew unions are weaker in Europe and more so in Asia this may contribute to the explanation of the differences. Another possible explanation relates to the demand side; scheduling costs, being related to the value of time, may be valued differently relative to other costs in the various continents: high in North-America, medium in Europe and low in Asia. This would imply that in America and to a lesser extent in Europe, competition would lead to high frequency and small aircraft size compared with Asia. Another possible explanation one might think of would be competition by high speed rail, being present in parts of Europe. This might stimulate airlines to enter frequency competition and hence reduce aircraft size. However, this does not explain the case for America, neither that of Japan. Model variants where we accounted for high speed rail competition in the model[7] did not lead to significant results and in some cases showed (the wrong) positive effect on size. Finally, the practice by Japanese airlines to put more seats on wide-body aircraft used on domestic routes (as noted in Section 2) probably leads to higher aircraft size for Asia.

The airport variables are harder to interpret and the results vary. In both the OLS and 2SLS models the number of runways found to have virtually no effect on aircraft size (for unexplained reason the result for the smaller airport on the route was significant but not for the larger airport). A possible explanation for this result is that the number of runways may be a poor indicator for the capacity of an airport, since in some airports the effective use of runways is restricted by weather conditions and/or noise regulation.

At hub airports, as expected, airlines use on average smaller aircraft (ceteris paribus)[8]. The hub effect is stronger when both of the airports on the route are hubs; in this case aircraft size will be 14% lower. It is important to note that the literature on aircraft size at hub airports usually relates to the hub airline only. Yet, on routes between hubs these airlines probably dominate the market.

Slot coordination is an indication for congestion at an airport[9], and thus the variables involved test the effect of congestion on aircraft size. The results differ between the two models (in direction of effect, magnitude, and level of significance) but in both cases there is no evidence that airside congestion results in the use of larger aircraft. This is an indication that present ways of dealing with slot control do not lead to efficient use of congested airport capacity. Differentiated pricing of airport slots during congested periods would not only shift demand towards the off-peak period, but it would also stimulate the use of larger aircraft.

Including the level of landing charges in the model was not possible due to lack of data.

5. Implications of current choice of aircraft size

Airlines' choice of aircraft size has a direct effect on congestion at airports that operate close to capacity. At Chicago O'Hare congestion prevails during long periods of the day. In 2004, the cost of congestion imposed on a United Airline's flight departing at 15:00, when there were 28 aircraft queuing for take-off, was estimated at $10,035 and on a flight departing at 18:00, when there were 27 aircraft queuing for take-off, at $5,165 (Johnson and Savage, 2006). At the current situation, "even a relatively small change in the number of flights has the effect of reducing delays considerably" (Johnson and Savage, 2006: 188).

The choice of aircraft also has direct effects on operating costs. Empirical comparison of operating costs for large and small aircraft is difficult due to the fact that narrow-body aircraft

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[7] Dummy variable, high-speed train competition defined as railway services on the route of less than 3 hours.

[8] In general this can be explained by the importance of feeding services in a H&S operation (services on short haul low density routes), but our database consists of mainly high density routes (average of 109 two-way weekly services) thus feeding services are not the main explanation for the observed hub effect.

[9] A coordinated airport (Level 3) is one where congestion is at such a high level that: the demand for facilities exceeds availability during the relevant period; attempts to resolve problems through voluntary schedule changes have failed; and airlines must have been allocated slots before they can operate at that airport (IATA, 2005).

are designed and used on short haul routes and wide-body aircraft on long haul routes. Swan and Adler (2006) estimated an operating cost function of a flight given a certain seat capacity and route distance, but evaluated different functions for short haul and long haul designs. They note, however, that the cost function for narrow-body aircraft on routes between 1000 and 5000 km can provide some approximation for using wide-body aircraft on short haul routes if aircraft are purchased at lower gross weights and configured in short haul seating densities. Using this function, the operating costs per seat on a 1000 km route are $59.7 for B737-700 with 126 seats (2-class configuration), $55.6 when the aircraft has 149 seats (1-class, typically low cost airline), and only $39.0 if a B747-400 is used on the route with the capacity of 546 seats (JAL).

In more general terms, there is ample evidence in the literature for economies of scale in aircraft operation (see Wei and Hansen, 2003 for review). However, this is very much related to the bundling of size and range in aircraft development. For example, there are economies of scale in purchasing price of new aircraft, but after controlling for range there are diseconomies of scale in purchase price (Wei and Hansen, 2003). A detailed analysis of US airlines' direct operating costs shows that there are diseconomies of scale considering the landing and take off stages of a flight and economies of scale in the cruise stage of the flight. These effects together mean that the least cost aircraft size for short haul flight is smaller than the least cost size for long haul flight. Nevertheless, it was found that airlines in the US (routes up to about 4500 km) choose aircraft size which is smaller than the cost minimizing aircraft size, due for example to flight crew pay scales dependency on aircraft size. Thus, if pilot's salary would not relate to aircraft size, airlines in the US could reduce operating costs by upsizing their fleet (Wei and Hansen, 2003).

The third direct effect of the choice of aircraft size is on environmental pollution from aircraft operation. This is probably the most difficult effect to estimate. The literature suggests environmental benefits can be expected from increasing aircraft size, "large aircraft have lower environmental per passenger km costs than small aircraft" (Peeters et al., 2005: 141). Indeed, comparison of emissions during the landing and take-off cycle (LTO) of a B737-300 and a B747-400 based on EPA (1999) shows that the B747-400 has an advantage over the smaller B737-300 across most major pollutants of aircraft operation (HC, CO and SO_2). However, NOx emissions are an important exception. Since NOx is considered as the pollutant leading to most local air pollution from aircraft operations around airports (Givoni, 2007) it might be that larger aircraft contribute to more environmental pollution. Furthermore, considering a short haul route with a flight of 70 minutes, it appears that operating the A737-300 results in less emission per seat of CO_2 and NOx (the main green-house-gases emitted on such a flight) than operating the larger B747-400. Thus, also with respect to climate change impacts larger aircraft might contribute more to environmental impacts. Finally, the analysis by Pearce and Pearce (2000) suggests that larger aircraft cause more noise than smaller aircraft per seat. The above should be seen as an indication only, further analysis is required and such an analysis should also consider the environmental burden of congestion which is associated with choice of relatively small aircraft.

The forth effect of aircraft size choice is on the need to expand runway capacity. At Chicago O’Hare construction of a new (eighth) runway and reconfiguration of some existing runways is planned at a cost of $14.8 billion to deal with congestion (Johnson and Savage, 2006). Our analysis suggests that there are good reasons to look for other routes to solve the congestion problem at airports. For example, pricing measures would stimulate carriers to use larger aircraft[10], allowing the airport to serve more passengers with the same runway capacity.

6. Conclusions and discussion

Choice of aircraft size depends on market size with an elasticity of 0.35, indicating that in the airline industry carriers give priority to increases in frequency. Another result is that aircraft size increases with distance, a natural result of the trade-off between cost of loading/unloading, and cost of flying. Further, the presence of low cost carriers leads to somewhat larger aircraft. We identify two main market failures with respect to the determination of average aircraft size. One is related to lack of competition, the other one to congestion at airports. The two market failures appear to have opposite impacts. First, we find that market concentration on certain routes leads to the choice of relatively large aircraft: lack of competition allows carriers to reduce frequencies. Hence in a strongly concentrated market aircraft size tends to be larger than optimum. The second market failure concerns the allocation and pricing of runway capacity implying a suboptimal use of available runway capacity and higher levels of congestion. When there would only be one carrier on an airport owned by the carrier, the potential externality effects related to congestion do not occur, and the carrier would be stimulated to find the proper mix of airport capacity and aircraft size. When there are several users of aircraft on the airport, the externality problem does occur, implying a lack of incentive to consider the use of larger aircraft. Since congestion pricing has hardly been adopted on airports thus far, a tendency exists that aircraft size is set at below optimal levels. This is confirmed in our analysis in the sense that we do not observe a significant effect of slot control (being an indicator of airport congestion) on aircraft size.

At the two largest airports in the world, Atlanta and Chicago O'Hare, there were only 87 and 75 passenger respectively on each aircraft landing and taking-off in 2003. The atm capacity of these airports was almost double the capacity of the third biggest airport in the world (which had only two runways compared to the four at Atlanta and seven at O'Hare) but both opted to invest in an additional runway (at Atlanta airport, the fifth parallel runway was inaugurated in May 2006). Assuming that airlines make an optimal decision, under the current market conditions, on the choice of service frequency and aircraft size and considering current capacity at the above airports there seems to be evidence for the second market imperfection mentioned above. Current market conditions at Atlanta and O'Hare probably deter airlines from using larger aircraft to meet demand and preventing the airports from considering alternatives to solving the congestion problem through new runways.

To test whether such market imperfections exist, the benefits of high frequency service must be weighed against the congestion, operational, capital and environmental costs of providing it. The benefits from high frequency of service are undisputable, but it is expected that the marginal benefit of an additional service after a certain level of service has been achieved will be close to zero (while it will be large when level of service is relatively low). This paper suggests that such level has been reached on routes like the London-Amsterdam. In this case, "Hotelling

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[10] Note the correspondence with road pricing which would stimulate car-pooling, though at a limited extent. In the context of aviation and airport pricing much larger effects may be expected given the relatively straightforward option for carriers to increase aircraft size.

competition" seems to provide the best explanation why airlines might offer excessive frequency which leads to the use of relatively small aircraft. From the supply side, the relatively low landing charges, with respect to flight operating costs, do not deter airlines from offering high frequency service even at congested airports. Further, "grandfather" rules for allocating runway capacity encourage airlines to increase frequency to maintain their share of runway capacity.

If some market imperfections do exist in the airline industry then the remedy lies in changing the way runway capacity is allocated and priced (and in stimulating more competition by removing barriers to entry when these exist). Higher landing fees in general and especially some form of congestion charging for runway capacity could provide the driving force for airlines to consider using larger aircraft leading to increased utilization of existing runway capacity. This will reduce the need for new runways in congested airports.

In many airports, such as in Atlanta and O'Hare, building new runways seems to be considered as a solution to congestion, also by policy makers who must approve such decisions. However, such a strategy is not likely to solve congestion but rather increase it as it will further encourage increases in frequency and not aircraft size to meet demand. Providing more capacity in order to meet rising demand and reduce congestion (without using appropriate pricing policies) has failed in the road transport sector and this is an important lesson for the air transport industry. In addition, even if building more runways can solve congestion on the ground it may still increase congestion in the sky resulting in aircraft queuing on the ground waiting for a route to clear.

One of the reasons of considering new runways as the natural choice to meet future demand is that aircraft size does not play a role in the planning process of air transport infrastructure. In the UK and the Netherlands, the forecasts which serve as the base for shaping air transport policy (and for deciding if, how many and where new runways should be built) aircraft size is assumed to remain virtually the same in all scenarios tested, at just over 100 passengers per atm (DfT, 2003; CPB, 2006). In other words, aircraft size is considered an exogenous factor in the planning process of air transport infrastructure, the strategy of meeting future demand through larger aircraft and current runway capacity is ignored. We hope the present paper contributes to broaden considerations in planning the future of air transport.

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