Hub-based Network Analysis and Change in the US Air Transport System (ATS)

Hans Huber

W.P. No.2014-05-02
May 2014

INDIAN INSTITUTE OF MANAGEMENT
AHMEDABAD-380 015
INDIA

Hub-based Network Analysis and Change in the US Air Transport System (ATS)

Hans Huber
Associate Professor, Indian Institute of Management Ahmedabad
Email: hanshuber@iimahd.ernet.in

Abstract:

The US has been a pioneer w.r.t. the modern hub-and-spoke (HS) system which found near unequivocal support among aviation scholars over the last few decades. The author takes a more critical approach with regards to the central role that hub airports play within the ATS, particularly when assessing operational decisions that in effect may lead to highly skewed traffic distributions and increasing spatial concentration of air traffic. The behavior of airlines to organize traffic around central airports can be evaluated more meaningfully by differentiating for their constituent route-structures and comparing these ensembles for the largest airports in the entire system. A new understanding of behavior and evolution of the ATS as an aggregate of hub-driven networks can be obtained and alternative HS structures be compared. Our understanding of the scope of feasible hub strategies may expand beyond conventional strategies of 'consolidation' versus 'de-hubbing' and their impact on the overall ATS may plausibly be shown.

Hub-based Network Analysis and Change in the US Air Transport System (ATS)

Introduction

HS as the dominant form of airline network organization have received attention from scholars worldwide over the last two decades or so. Although the initial impetus for such attention may well have been a change in policies (‘deregulation’, ‘liberalization’), a true “free market regime” (Burghouwt 2005, p.137) mostly remained elusive. The other driving force for research into “market dynamics” of ATS was the fact that it was highly applied, a circumstance that made it interesting for all sorts of stakeholders, such as national carriers that were to be privatized, airports, consultants, lobbyist groups, etc. Without making a judgment about the risks/benefits of such practitioner-oriented research and the actual impact it would have on externalities (sustained economic development, for example), one needs to be aware of possible biases in research design, methodology or findings. With the benefit of hindsight and the aviation industry not escaping cycles of recession, it may be worthwhile re-assessing critical elements of mainstream research into HS and airline behavior w.r.t. to the development of airports and ATS as a whole[1].

Literature Review

There has been a long debate on airline/airport combinations and their relationship with spatial concentration or de-concentration of air traffic. A similar strand of research assessed the impact of selected airlines (both grouped and individual) on spatial (de-) concentration (see Reynolds-Feighan 2007).

For the US, Reynolds-Feighan (2000) concludes that US airline traffic has increasingly been concentrated on relatively few hub airports jointly with a reduction of small community airports and number of flights they served. Goetz & Sutton (1997) indicate that large hub airports in the US benefitted more from de-regulation compared to smaller airports. They show that although flight frequency has increased for all type of airports, seating capacity, the number of direct destinations and service quality have

---

[1] The author himself was able to draw extensively from this mainstream research in the past, while progressively shifting his paradigm to a more agent-based network perspective.

declined for small community airports. From Burghouwt (2001) we take this review: “On the other hand, flight frequencies from a large number of small community airports retaining service have increased considerably because of the use of smaller aircraft and because of the Essential Air Service program which encouraged more convenient departure and arrival times (Reynolds-Feighan, 1995). Moreover, in a lot of cases the connectivity of small airports increased because of higher frequencies to major hub airports. Having service to a hub is superior to service to a non-hub because of the much greater connecting opportunities (Graham, 1998, p.136).”

Reynolds-Feighan (2007) applies a long-term Gini decomposition analysis to evaluate changes in spatial distribution and industry shares of total US air traffic since industry deregulation. Her method also allowed decomposing this index for components of both individual airlines and airports. Results of this research (p.239) suggest “…very little change in the overall spatial distribution of traffic across the airports system despite the economic and industry events of the past 20 years” versus (p.248) “…in the decade following deregulation there was a significant and permanent adjustment in the air traffic distribution, with traffic becoming more concentrated at the busier airports and among the largest carriers. Since then there have been relatively small variations in combined spatial and industry concentration”.

One may conclude from the above that ‘hubbing’ – i.e. the spatial concentration of air traffic which also involved schedule coordination at the hub airport[2] – would show little (longer-term) structural changes after some initial adjustment processes in the 1980’s. The impact on smaller community airports needed not necessarily be negative, as added connectivity via hubs would more than compensate for lost direct connections, etc. From this dominant line of research one cannot help but infer that hubs were – and still are – an inherently competitive, efficient and proven center-piece of the US air traffic system.

More recent research looking at changes in air fares at and around airport hubs in the US draws a different picture. Scholars that helped shape our understanding of HS behavior now acknowledge that the competitive landscape has changed significantly for hub airports: “Legacy-carrier competition in an airport-pair market has a limited effect on fares, while legacy competition at adjacent airports has no measurable effect in most model specifications. In contrast LCC competition has dramatic fare impacts, whether it

---

[2] see Bourghouwt 2003, p. 377 for an overview of hub definitions

occurs in-market, at adjacent airports, or as potential competition. These findings confirm and extend previous results, while affirming a common view about the sources of competition in today's airline industry. Moreover, the paper finds a dramatically altered competitive picture from the one that prevailed as recently as 2000, when nonstop legacy competition (both in-market and from adjacent airports) had substantial effects." (Brueckner et al., 2013, p.15).

A Critique

There is consensus about the great importance that hub airports present for the ATS. The evaluation of traffic concentration that coincides with hub operations, though, remained rather formulaic with single, highly aggregate, values deemed valid to represent what essentially are structural aspects of a network. In spite of long-run and multi-scale analyses, results often remain static and difficult to interpret, i.e. little can be said about the mechanics of network formation or disaggregation. The use of (spatial) concentration as a welfare proxy (what other teleology could there be for a Gini index?), which often sees its multiple scales being transformed into a new factor, rarely sheds light on critical airline behaviors (mergers, outsourcing to regionals, location of an airline hub versus collusion of dominant airlines through dense routes to/from big airports, etc.). Moreover, it says little to nothing about the effectiveness of these most concentrated airports or 'hubs' for the ATS as a whole.

Identifying viable topologies for HS from a contingency perspective (implying varying possible distributions of traffic) and suggesting an evolutionary approach would add new insights. The author suspects legacy and other airlines to primarily seek profit through market-power (as compared to the canonical 'economies of density' literature that in effect provides arguments for super-dense routes at select airports). Also, both theory and practice emphasize the role of connectivity for welfare effects. However, the dimension of connectivity is different from those of frequency, airport size, transfer time for connecting flights, ticket prices, etc. – all of which eventually would contribute to welfare. As a consequence, longitudinal network analysis of the ATS in the US would gain if key variables could be kept separate in the process.

It is an uncontested fact that the distribution of air traffic across airports is highly skewed. One may argue whether this distribution is merely exponential or actually follows a power-law (see Guimera et al., 2005). Assessing changes in traffic concentration (incremental flows) within single regions (US, Europe, etc.) without critically addressing the structural issue of an extremely uneven allocation of capacity over space (the stock) may be considered a serious flaw. This is why Huber (2009) compared market structures, degrees of concentration and changes across continents (US versus Europe). For a single region's assessment, the very high unevenness of traffic distribution needs to be regarded as a potential problem in itself with increasing risks of failure or disruption over time (as compared to incremental accounting alone). Instead, some authors seem to propagate even bigger hubs (Bourghouwt, 2013), arguing that one hub with twice the capacity of smaller hubs would provide better connectivity, ergo be superior.

If HS operated by legacy carriers were experiencing great pressure on fares from LCCs, as Brueckner writes, important changes to route traffic at HS would be a logical consequence. One may expect increasing threats for the established HS from alternative network topologies, be them evolving forms of HS, increasing point-to-point or other network forms. The extent to which operators of bigger hubs may be in a better position to guarantee for better connectivity under such circumstances may be questioned.

Apart from the competitive "threat" of efficient LCCs, the instrumental role of regional airlines as well needs to be assessed in the context of structure and change in the ATS of the US.

The role of Regionals for spatial concentration

There is little literature on the specific role of Regional airlines and their interaction with 'majors' w.r.t. ATS. Januszewski et al. (2009, p.1833) look at their role as "subcontractors" for major US network carriers and empirically confirm a high degree of adaptation to the 'majors' operational preferences. In the logic of transaction cost economics, this adaptation of the Regionals was found to be dependent on their degree of integration with the 'majors', be it through ownership or code-sharing. Their results show (p.1840) that "city pairs with the major's hub at either endpoint are significantly more likely to be served by a regional that the major owns. Holding all variables at their means, the coefficient implies that having the major's hub at either endpoint increases the conditional probability of using an owned regional by 57.4 percentage points, compared to having no hub at either endpoint."

Another finding by the authors was with respect to changes in population size at the endpoints of the city-pairs (p.1843): "We find that increasing the population of the larger endpoint airport of a city pair increases the likelihood of using a regional, while increasing the population of the smaller endpoint decreases the likelihood of using a regional. These estimates suggest that city pairs connecting a large city with a small city are the ones that are most likely to be served by a regional." These findings are consistent with the notion of smaller cities funneling traffic into hubs that happen to serve a larger population in the metropolitan area: they also suggest a bias of Regionals to prefer these hubs as endpoints for their own traffic concentration. Januszewski et al. do not discuss Regionals' contribution to traffic between hubs or the possibility of Regionals to develop their own 'hubs'.

Research Objective

What is lacking is a heuristic approach that introduces classifications for the most concentrated airports (i.e. hubs) as the key agents in the ATS. For one, this will allow highlighting distinct network features and different combinations of route types to form coherent sub-structures in the ATS: if such sub-structures can be identified, their viabilities may be acknowledged and structural attributes be compared. Understanding these structural features may – by logical inference – even yield insights into the dominant evolutionary path the ATS has been taken during the observation period. The different roles for hub-driven sub-structures should become apparent. Moreover, the interpretation of the ATS as a combination of different hub-driven sub-structures should open a perspective for alternative, possibly welfare enhancing, paths of system development.

We seek to assess the dependency of the US domestic ATS on hubs, which are determined by route decisions of distinct airline groups, including regional airlines. The identification of relevant 'hub' airports requires an – embedded – classification of traffic distributions for airline groups. The major parts of our analysis consist of:

(1) A classification of US domestic airlines into groups following a mixed heuristic for the clustering of network attributes and qualitative assessment of carrier typology. This preliminary step will allow selecting airline's hubs for relevant airline groups according to network characteristics.

(2) Grouping of the 25 biggest airports in the US depending on hub service as operated by groups of legacy and regional carriers. The locational coincidence of traffic concentration and hub operations for groups of airlines opens the possibility for logical

inferences to be made regarding the evolution of hub presence within these top-25 airports in the ATS.

(3) A decomposition of the HS sub-structures along route types to discuss attributes of connectivity, density and adjacency as well as their changes over the period. This route-specific decomposition will enable us to compare attributes both with the HS sub-system for distinct route types as well as across HS for the same route structures.

A further decomposition of (3) for airline classes highlighting the influence of airline groups on attributes (connectivity, density, adjacency) on route types would be feasible and would deepen our understanding of airlines' roles w.r.t. the formation and changes within these sub-structures. However, due to restrictions in scope and space of the paper, this endeavor shall be postponed for separate analysis.

Data, measurement and heuristics

Data and Sample

T-100 (U.S. Carriers) Databases for Domestic and International markets from the US Bureau of Transportation Statistics (DoT) provide complete flight schedules of all domestic airlines. Flights to/from Alaska, Hawaii, Puerto Rico and Guam as well as airlines that were headquartered in these States were excluded from our population for reasons of geographic homogeneity and continental adjacency (i.e. flight distance, etc.). Airlines which predominantly operated cargo service were also excluded. Our sample period is the month of November each from 2006 through 2011. The level of observation was for directed origin-destination routes (OD) between airports and by each airline. The distinction for regional airlines was made through technology: T-100 data allowed to identify the type of aircraft used. If an airline's fleet was mostly made up of such regional aircraft (that in general offered less than 100 seats), the carrier was considered as a Regional. With these restrictions, we obtain the following total number of ODs: 12,215 (2006), 13,493 (2007), 12,232 (2008 and 2009 each), 12,986 (2010) and 13,665 (2011). For each OD that is differentiated by airline, we obtain the frequency of flights in November. With this semi-aggregated data to serve as base, more specific heuristics allow adapting it further during the multi-step analysis performed below.

Heuristics and skewness of data

The range of methods for classifying airports, airline clusters or the interaction between both types of agents by definition is endless. Although such groupings are purposedriven to answer specific (often policy-related, thus normative and qualitative) research questions, in practice they mostly remain formulaic and dependent on statistical technique alone. One observation characteristic for empirical statistics of ATS is that traffic distributions tend to follow a power-law (Huber 2010, Burghouwt 2005, p.137 refers to 'skewness'). "It is likely that there is more skewness than equality in the world, so that betting on skewness may turn out to be a better strategy (Gigerenzer 1999, p. 124)." However, these kinds of distributions put serious limits on the predominantly used forms of statistical analyses through multi-linear regression, etc.

One strategy for defending heuristics over purely statistical techniques would be that they need to be at least as accurate and more useful[3]. We maintain that classification and subsequent analyses remain a hybrid and interpretative process that cannot be solved by computation alone. In fact, good heuristics should include a mix of statistics and careful selection that the researcher iteratively develops and where his growing insight into the dataset proves complementary to the 'blind' application of formulas. Understanding the 'skewness' of distribution shall remain central to our multi-step analysis.

One consequence would be to emphasize the interpretation of meaningful summary results rather than mathematically more elegant formulae that (1) often are derived from far-fetched applications and (2) often are being transformed into more abstract 2nd order relations (e.g. elasticities) which pretend for scientific objectivity but in fact lack to acknowledge more fundamental structural properties of the data itself. Insightful and structurally robust summary descriptions arguably provide for better understanding while leaving space for critical questioning of system problems and alternative paths of network development.

Airline Groups

Grouping of airlines along multiple dimensions was a mixed process of clustering and selective re-classification following the author's heuristics. The selection of cluster criteria was the same as for previously published studies by the same author, i.e. it comprised airlines' variables for 'Number of airports served', 'Maximum Frequency at the most densely served airport' and 'Number of OD links'. After a first cluster-based analysis (Ward's method), steady membership of an airline to the same group over the entire observation period was sought – even if cluster results would suggest changes in

---

[3] This approach needs to be distinguished from the "fast and frugal heuristics" that Gigerenzer at al. (1999) focus on.

membership to other groups over time. In order to keep airline-agents within same groups, the ranges of the various scale dimensions had to be re-adjusted in a non-linear fashion. These manually modified ranges indeed allowed for distinct and robust allocations of airlines to separate groups that remained largely unchanged over time.

An important part of the heuristic was to screen the 80+ airlines before proceeding with preliminary clustering. For example, over 60 airlines could be classified as regional carriers, determined by the type of aircraft that its fleet consisted of. Clustering of this sub-sample yielded considerably more accurate results as compared to clustering them as part of the overall airline population. Initial cluster results showed the three biggest airlines to be AA, DL and WN and thus grouped them together. As we interpret the network features of WN to be distinctly different from those of AA and DL, we separated them into two top-airline clusters, while clustering the remaining non-regional airlines afresh. This iterative and increasingly selective clustering approach helped to better account for outliers while being left with fewer airlines for which the variable ranges could be altered without losing homogeneity within groups over time.

Airline groups that resulted from the outlined heuristic were (see ***Annex 1*** for summary of airlines' codes and classes):

Group 1 (1 airline): WN

Group 2 (2 airlines): DL, AA

Group 3 (6 airlines): CO, UA, US, NW (NW merged operations with DL after 2009), B6 and FL (in late 2010 FL was acquired by WN with code-sharing starting not before 2013).

Group 4 (5 airlines): G4, SLQ, SY, 09Q, U7.

Group 5 (4 airlines): HP, F9, NK, VX (HP merging with US and integrating operations in 2007, VX commencing service by 2007, F9 integrating defunct YX(1) in 2010).

Group 6 (8-10 airlines): mostly short-lived airlines, many of them entering and exiting the industry.

Group 7 (22 regional airlines): 16, 17, 9E, 9L, AX, C5, CP, EV, G7, MQ, OH, OO, OW, QX, RP, S5, XE, XJ, YV, YX, ZK, ZW.

Group 8 (13 airlines): 04Q, 0KQ, 3M, 9K, CH, FRA, KAH, LW, NEW, SEB, VI, WST, YR (Charter, air-taxi, etc. using smaller regional aircraft).

Group 9 (12 decreasing to 7): many short-lived operators (Charter, air-taxi, etc. with smaller regional aircraft).

The obtained classification showed airline groups with constant memberships between November 2006 and 2011 (except for the case of mergers or ceased operations). It can also be shown that groups' network attributes differed significantly (average values for multi-scale variables are available from the author upon request).

Table 1 lists all airline groups along with their domestic movements for the months of November. As shown, different types of carriers could be found within a same group. Values at the right-most columns present sampled frequencies as a percentage of all carriers' frequencies in each group population.

Table 1: Airline group samples versus population –

Domestic flight frequencies (Nov.'06-'11)

Group	FRE'06	FRE'11	Type	Sample'06	Sample'11	*06 in %*	*11 in %*
1	91.265	90.995	**LCC**	91.265	90.995	*100,0%*	*100,0%*
2	90.715	99.649	**Inc**	90.715	99.649	*100,0%*	*100,0%*
3	162.133	113.883	**Inc**	127.522	76.091	*78,7%*	*66,8%*
			LCC	34.611	37.792	*21,3%*	*33,2%*
4	3.909	5.268	**Charter**	236	358	*6,4%*	*7,1%*
			LCC	2.850	4.656	*77,0%*	*92,9%*
			Reg	206	254	*5,3%*	*4,8%*
5	30.924	15.705	**LCC**	25.547	15.602	*82,6%*	*99,3%*
6	2.005	1.100	**other**			*0,0%*	*0,0%*
7	321.293	290.908	**Reg**	321.293	290.908	*100,0%*	*100,0%*
8	17.202	17.529	**Reg**			*0,0%*	*0,0%*
9	19.940	4.077	**Reg**			*0,0%*	*0,0%*
Total	***739.386***	***639.114***		***694.245***	***616.305***	***93,9%***	***96,4%***

Airline groups that were deemed most relevant for the identification of hub operations were Groups 2&3 (for legacy carriers) and Group 7 (for larger Regional carriers). Hubs were identified by taking the top-2 airports operated by each legacy carrier (above a monthly frequency threshold of 10,000) and the biggest airport for Regional carriers (minimum threshold of 1,000). ***Annex 2*** shows the traffic distributions within these sampled groups (most other airline groups were not considered relevant as their traffic distributions remained well below our threshold figures). Low cost carriers in general operated on point-to-point and thus would not be hub dependent. Even if new forms of LCC operations emerged which would occasionally concentrate traffic on top-25 airports, such a trend was not pervasive throughout the ATS. ‘Hubs’ for LCCs therefore were not taken into account.

Classes of airline hubs and spatially concentrated airports

While the ATS was considered to be driven by hub airports, each hub – by convention – would be controlled by a single or very few airlines. This is not to forego an overview of traffic concentration among the top-25 airports in the US. The sample size of 25 for the largest airports (see ***Annex 3***) not only was chosen because of highly skewed traffic distributions within the ATS: its member airports, although changing in ranks within the observation period, all remained within the top-25 range. Our sample is slightly bigger than the one selected by Reynolds-Feighan (2007, p.253).

Some top airports may not figure as airline hubs, although they showed high levels of spatial concentration which would be obtained by lower ranked airline routes, or traffic concentration of non-legacy carriers, including Regionals’ (Group 7), with low market shares at the airport. We then classified these top-25 airports depending on the presence of hub operations (by legacy carriers) or changes in such hub presence during the observation period. As a result, four airport groups could be distinguished (with legacy hub operators following the same order as the listed airports):

(1) 11 airports (LAX, JFK, LAS, MCO, SEA, BOS, LGA, FLL, BWI, IAD, MDW) without any legacy carrier hubs between 2006 and 2011.

(2) 3 airports (MIA, SFO, PHX) where legacy carriers (AA, UA, US) established hubs in the period from 2006 to 2011.

(3) 7 airports (ATL, ORD, DFW, IAH, CLT, EWR, MSP) where hub presence was maintained by DL, UA, AA, CO, US, CO, NW/DL

(4) 4 airports (DEN, DTW, PHL, SLC) where legacy carriers (UA, NW, US, DL) had abandoned previously existing hub operations by 2011

Logics would suggest that hub presence in these four airport categories also followed a chronological order (with category 4 in turn possibly preceding category 1).

Attention was also paid to (group 7) Regionals’ which had concentrated their densest routes at these top-25 airports[4]: it was found that practically each one of the 22 larger

---

[4] Airlines’ traffic confirmed the rule of rapidly decreasing distributions for legacy carriers, but also regionals and low-cost (WN being the most notable exception).

regional airlines of Cluster 7 operated at least one of their two densest airports within the 25 biggest airports in the US. All airports in categories 3 and 4 showed unchanged presence of such Regional's 'hubs'. Among the 3 airports of category 2, i.e. those where legacy carriers had added a hub, PHX showed maintained 'hub' operations of Regionals, SFO had one set up by 2011 and MIA had no Regional hub operations. Category 1 consisted of 4 airports JFK, SEA, LGA, IAD where Regionals had set up 'hubs' and another 7 airports without such Regional 'hubs'. For the latter a new airport category "0" was assigned. Please note the evolutionary pattern: the presence of incumbent and regional hubs had to follow a logical sequence among these top-25 airports (no hub, start of hub operations, keeping the hub, de-hubbing – all with a parallel phasing in/out of regional flight concentration).

Table 2 shows a summary of airport averages within each category (0-4). The figures are yearly movements and passenger numbers (with 5-year changes). The last line is a summary of the total (not averages).

Table 2: Summary top-25 airports '06–'11 (averages)

Inc_Cat	No_AP	Description[5]	with Reg_hub	Move'11	Move_d%	Pax'11	Pax_d%
0	7	w/o Inc hub	0	387.398	-4,64%	16.191.392	3,20%
1	4	w/o Inc hub	4	354.442	-5,56%	15.667.391	3,42%
2	3	Inc hub new	2	420.042	-0,16%	22.925.491	9,92%
3	7	Inc hub kept	7	621.890	-6,48%	24.980.531	-1,59%
4	4	Inc hub lost	4	469.489	-7,74%	16.492.325	1,38%
Avg.	**5**	**n.a.**	**n.a.**	**450.652**	**-4,92%**	**19.251.426**	**3,27%**
Sum	**25**		**22+**	**11.620.861**	**-5,86%**	**485.618.801**	**1,74%**

It can be seen that airports of category 3 (with constant presence of legacy hubs) are indeed bigger than other airports, but remain comparable to the other groups (as opposed to the highly skewed traffic distribution for the ATS as a whole). Interestingly, big airports without a legacy's hub operations (cat. 0, 1) did not fare worse as compared to airports which already had them established in 2006 (cat. 3, 4): the former (no hubs) reduced flight frequency much less while their passenger numbers grew more by comparison. An exception were the 3 airports of category 2 where legacy carriers had established hub operations after 2006 and which performed much better over time.

---

[5] Inc refers to legacy carriers

Connecting airport groups with the ATS

Each airport in the ATS – and by extension the OD linkages between them – can then be classified into one of the following classes: (1) hub airports, following a category from 0 to 4, (2) airports that are directly linked with category 0 to 4 airports without being a hub themselves (spokes), (3) airports with no direct links into any of the designated top-25 airports (others). Domestic traffic shall be distinguished from international.

Departing traffic from the different categories (0-4) of hub airports can connect either with other T-25 airports (intra), with domestic (spoke) airports or depart to international (INT) destinations. Spokes can be connected with each other for domestic (Intra_spoke) or show international departures (INT_exT25). The remaining domestic airports (Others) are also part of our network, although their traffic characteristics remain marginal when compared to other groups or routes. ***Table 3*** replicates this structure when accounting for the different network classes and their sub-systems.

The first column of ***Table 3*** lists the number of airports, which from a network perspective could be described as ‘nodes’: there are 25 nodes for ‘intra’ traffic plus 315 nodes for spoke airports plus another 70 domestic airports outside this HS structure. 23 of the T-25 airports operate international flights plus 63 airports outside this category. Changes for the months of November between 2006 and 2011 are shown on the right hand side of each column.

Table 3: Summary for route attributes ’06-‘11

	11_No.AP	**Chg.'06-'11**	**11_OD/AP**	**Chg.'06-'11**	**11_SEAT (avg./AP)**	**Chg.'06-'11**	**11_Fre/OD**	**Chg.'06-'11**	**11_L.F.**	**Chg.'06-'11**	**11_AAS**	**Chg.'06-'11**	**11_DIST**	**Chg.'06-'11**
0 - intra	7	0,0%	23	-1,9%	855.840	-8,3%	267	-6,1%	83,4%	8,3%	133	1,0%	1.090	-1,2%
1 - intra	4	0,0%	21	-6,7%	696.558	-2,7%	256	3,1%	82,8%	6,5%	115	-7,1%	973	-2,7%
2 - intra	3	0,0%	23	4,5%	941.511	8,9%	272	3,6%	83,8%	7,1%	141	5,0%	1.256	8,2%
3 - intra	7	0,0%	23	-1,8%	1.061.673	-6,0%	339	-3,9%	82,9%	5,2%	111	-4,1%	860	-5,1%
4 - intra	4	0,0%	23	-3,2%	806.127	-9,2%	273	-2,6%	83,7%	10,0%	113	-6,9%	848	-10,1%
T25_Hub_dom	***25***	***0,0%***	***23***	***-2,1%***	***890.315***	***-5,1%***	***287***	***-2,6%***	***83,2%***	***7,1%***	***121***	***-2,3%***	***979***	***-2,4%***
0 - spoke	198	3,7%	2 / 67	1,7%	19.363	-9,8%	72	-18,9%	80,6%	10,5%	121	8,6%	906	2,6%
1 - spoke	131	0,0%	2 / 57	-3,0%	13.570	-16,7%	94	-16,9%	75,6%	4,7%	85	-4,7%	666	-5,2%
2 - spoke	112	3,7%	1 / 55	-1,8%	14.614	-9,0%	98	-8,1%	78,6%	7,3%	113	1,2%	860	-5,2%
3 - spoke	252	1,2%	3 / 107	-2,0%	30.974	-10,4%	123	-9,3%	79,0%	5,7%	83	-4,6%	577	-8,1%
4 - spoke	213	0,9%	2 / 92	-3,3%	13.406	-9,9%	102	-6,4%	79,6%	11,4%	79	-2,6%	578	-1,1%
Spoke_dom[6]	***315***	***0,6%***	***6 / 78***	***-0,8%***	***56.855***	***-11,3%***	***103***	***-11,4%***	***78,9%***	***7,6%***	***90***	***-1,6%***	***651***	***-4,5%***
Intra_spoke	315	0,6%	10	28,7%	23.026	-25,6%	25	-49,7%	75,5%	9,2%	101	8,6%	591	6,4%
exHS_other_AP	70	27,3%	2	20,3%	1.200	9,7%	53	-6,0%	55,5%	4,6%	19	-38,5%	132	-21,4%
ALL_dom	***410***	***4,3%***	***19***	***6,1%***	***159.545***	***-14,6%***	***84***	***-21,7%***	***79,3%***	***7,9%***	***98***	***-0,4%***	***720***	***-1,5%***
0 - INT	5	-28,6%	19	96,4%	73.387	9,6%	29	-33,5%	78,0%	2,9%	136	-5,5%	1.360	-13,5%
1 - INT	4	0,0%	28	19,4%	174.219	14,1%	42	-6,5%	76,2%	2,3%	124	-5,7%	1.776	-0,2%
2 - INT	3	0,0%	40	25,0%	277.233	9,7%	43	-12,7%	80,1%	5,0%	138	-5,4%	1.478	-4,0%
3 - INT	7	0,0%	51	17,6%	249.441	-0,5%	36	-13,5%	77,8%	4,4%	125	-6,4%	1.552	-16,1%
4 - INT	4	0,0%	20	26,6%	85.401	-7,1%	35	-20,5%	74,1%	0,6%	109	-6,7%	1.249	-9,1%
exT25_int	63	21,2%	2	-11,8%	1.381	-40,0%	6	-56,2%	68,8%	0,1%	131	11,1%	1.194	5,0%
ALL_int_out	***86***	***11,7%***	***11***	***6,9%***	***47.328***	***2,5%***	***32***	***-16,4%***	***77,5%***	***3,8%***	***140***	***2,6%***	***1.525***	***-9,6%***

---

[6] Values for domestic spoke routes are directed OD to/from top-25 airports. Total traffic on HS routes is double that indicated in variables SEAT/AP and Fre/OD.

Variables used to describe key attributes of these decomposed airport routes are the following (figures are for Nov.'11 with 5-year changes on the right side of each column):

- The proxy for 'Connectivity' is 'OD/AP'. It shows the average number of origin-destination links per airport within each HS and route category. E.g., each airport which belongs to the T-25 category '0' (i.e. without an airline or regional hub), on average shows 23 departing links to the remaining top-25 airports and 67 to 'spoke' airports. The 5 airports in category '0' which offered international departures show 19 such links each, on average. Each spoke airport which receives traffic from the same category '0' in turn shows 2 routes – on average – which depart to T-25 airports (only changes for spoke airports are shown for this spoke-to-hub traffic). In addition, each spoke airport on average shows 10 more ODs to other spokes ('Intra-spoke' traffic).
- A proxy for supply per airport-route is 'SEAT'. This variable is commonly being used by industry and economists as a key unit of analysis (referred to as 'Available Seats'). It was also a unit of measure for spatial concentration discussed in the literature before. Due to HS network specifics, available seats between hubs and spokes in fact are twice the indicated volume (as OD traffic by definition is one-directional).
- Variables that describe density economics for different route types and airport categories are 'Number of monthly departures per OD' (Fre/OD), 'aircraft load factors' (L.F.) and 'Average aircraft size' (AAS). Each one of these proxies helps to assess different aspects of density[7]. The principal factor is reckoned to be 'Fre/OD' with the other two controlling for differences in aircraft operation and utilization.
- The 'territorial/geographical' attribute of 'adjacency' is stressed through 'average distance' (DIST) within the shown route types and airport categories. The values for average distances, including changes over the 5-years period, allow for comparisons within same route types as well as between hub-hub, hub-spoke, spoke-spoke or international (taking into account the T-25 airport category to which these routes are linked).

Interpretation of results

From a supply-side perspective (see 'SEAT' variable), capacity on HS networks was decomposed into the constituent route types and compared between airport classes. Available seat capacity on traffic between T-25 airports ('intra') was comparable, i.e. no highly skewed (such as exponential) differences existed between airport classes. Class 3 of T-25 showed a higher average for seat capacity per airport on such intra-routes, while class 2 had increased its capacity in this segment as the only one. For class 4 intra-traffic, available seats per airport fell to levels even lower

---

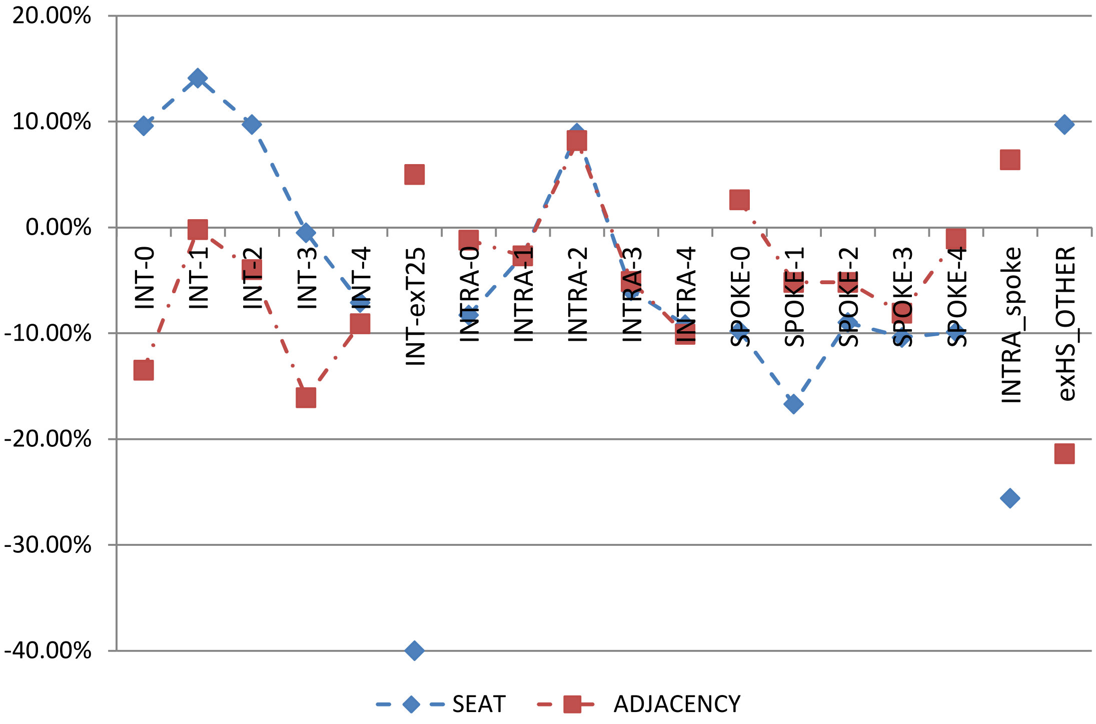
[7] Economies of density allow for diverse sets of networks or HS operations. It is not deterministic as to impose one single valid structure. However, structural inconsistencies and contradictions within existing structures w.r.t. 'density economies' can be shown.

than within class 0, showing the highest percentage decrease of all T-25 classes. Spoke traffic showed the highest value with category 3, surpassing the next highest (class 4) by 50%. The reduction in available seats was more pronounced on spoke routes as compared to intra (T-25), although for classes 0 & 4 changes between intra & spoke were quite similar. Seat availability (airport average) between spoke airports was in the same range as that for single T-25 spokes, although intra-spoke capacity had dropped by much more (25.6%). As for the availability of international seats, T-25 airports where legacy carriers operated 'hubs' during 2011 (classes 2 & 3) showed much higher capacities per airport (with the entry of a new hub in class 2 presenting high growth). Class 1, which only showed regional 'hub' activity, offered a multiple of international seats as compared to airports for classes 0 & 4 (where no legacy carrier operated a 'hub'). Available seats on international routes departing from spoke airports decreased by 40% during the period.

Geographical adjacency between the grouped route types remained distinct with average flight distance on international routes well exceeding that of intra (T-25), which on average exceeded distances for HS. In particular, one finds class 2 (added hub by legacy carrier) to be further spatially distanced w.r.t. other T-25 airports and also to present rather long spoke routes. Only class 0 (no legacy or regional 'hubs') shows a more far-reaching funneling into/from spoke airports (with distance even growing during the period), as well as above average distances for intra-traffic with other T-25 airports. The data for geographical adjacency suggests that longer lasting (class 3) hub operations tend to present shorter intra-routes (compare with class 2) as well as HS routes with shorter distances. These particularities intensified during the period - even more so for HS - and can be interpreted as a form of spatial & geographic reduction of catchment areas for class 3 hubs. Although intra-spoke distances had grown by 6.4%, they remained at the lower end of the range of HS routes.

Table 4 compares changes in seat capacity against average flight distances. In general, HS systems show more regular patterns of relationship than other T-25 or smaller airports: for intra-hub links, we observe near identical changes both in available seats and adjacency, with the setting-up of a new hub (intra-2) increasing both intra-hub capacity and their geographic reach. On international routes we see two parallel curves when hubs are involved: both flight distances and growth in available seats fall as hubs evolve from class 1 (Regional hubs only) via class 2 (legacy carrier establishes hub) to class 3 (hubs are maintained during the period). Also, the geographical adjacency of these routes (most of them covering the North American continent, see ***Table 3***) gets smaller as growth in available seats drops for HS. On spoke routes T-25 airports with regional hubs only (spoke-1) show much greater drops in capacity, whereas those showing no hub presence at all (spoke-0, spoke-4) could slightly grow or almost maintain their average flight distances. For all spoke routes, (negative) growth in capacity always remains below that of flight distance: with shorter spoke routes, available seats dropped even more. However, this effect was smaller for routes to/from airports where legacy carriers set up or kept their hub operation (spoke-2 and spoke-3). For other spoke routes, the difference in changes between capacity and adjacency was more important.

Table 4: Changes in seat capacity versus route lengths (averages, Nov.'07-'11)



Connectivity versus density

In terms of modes of connectivity, it is expected that T-25 airports showed domestic HS structures with international links: multiple domestic spokes would funnel their traffic into few central (T-25) airports with international linkages. However these T-25 airports being practically fully-connected among themselves, their seat capacity on intra-routes (T-25) was by far outweighing that of international seats. Such features clearly escape the definition of HS strictu sensu. Also, the structure of these HS for domestic connectivity was significantly altered for T-25 airports where legacy carriers already operated their 'hubs' during 2006 (classes 3 & 4): here, the number of spoke airports, on average, was significantly higher as compared to other classes of T-25. In contrast, international links were higher at T-25 for classes 2 & 3. In other words, when legacy carriers established new 'hubs', international connectivity would quite rapidly increase to high levels (class 2) while being brought back to much lower levels once it had ceased 'hub' operations (classes 4 & also 0). This increased international connectivity differed from the increased 'funneling' of domestic traffic through 'spokes' which only was observed with class 3 and somewhat persisted with class 4: connectivity through these domestic spoke routes appeared sticky as levels remained high even after the legacy carrier had abandoned its 'hub' (class 4), even though SEAT per route already had dropped to low levels. However, the bulk of domestic connectivity for the ATS was operated through 315 ‘spoke’ airports with each one offering an average of 10 OD links on intra-spoke (as compared to an average 6 links to T-25 airports). These intra-spoke connections showed 28.7% of growth, although SEAT had declined by 25.6%[8]. International connectivity strongly increased for all classes of T-25, which was markedly different from international connectivity of ‘spoke’ airports.

When analyzing the ATS for economies of density, our key proxy is ‘Frequency per OD’ with the variables load factor ‘L.F.’ and average aircraft size ‘AAS’ as control variables. These control variables are deemed necessary as both would be directly related to the efficient allocation of flight frequency (or possible excess frequency on routes): either inefficiently small aircraft could be used on otherwise dense routes or, for a given aircraft size, load factors would be lower at less dense routes (while frequency remained high). Both possibilities would contradict the argument for ‘economies of density’ through higher flight frequencies on existing routes.

A salient feature of route densities is the distribution of flight frequencies for different types of routes. While international routes from T-25 airports show an average of 1 to 1.5 daily flights per OD, density on HS routes was 2 to 3 times this number. Average load factors on both route types were comparable. International departures from class 1 & 2 airports showed the highest frequencies while class 2 showed higher load factors and used larger aircraft. However, frequencies on international routes had dropped considerably from previous levels, with international departures from outside T-25 airports falling by 56.2%. In spite of these reduced densities, the spatial concentration for international flights around ‘hubs’ therefore had continued, both for those operated by legacy and by regional carriers.

HS routes of classes 1, 3 & 4 mostly employed regional aircraft and saw their AAS decrease during the observation period. Classes 0 & 2 showed AAS which was larger than regional aircraft (and had increased in size) while also performing with higher load factors. Densities with class 3 ‘hubs’ were higher than with other networks, offering four daily connections on spoke routes. Spokes connecting to class 0 of T-25 only offered little more than two daily connections, a number that had dropped more than with other HS. Frequencies for classes 1 & 2 were about the same with three daily departures per spoke OD. Frequency per intra-spoke route was the lowest of all observed route types: it amounted to less than one daily, a number that had halved during the period.

A completely different order of magnitude for density existed for intra-routes connecting T-25 airports: nearly 10 daily (directed) flights per route on average, with even 11 daily flights for intra (T-25) departures from class 3 airports. Changes for these route types remain in the lower single digit range (both positive and negative), with average load factors well exceeding those of other routes.

---

[8] This was largely explained by a 44.7% drop in flight frequency (less density) per OD on intra-spoke.

Interestingly, class 0 airports (T-25 without 'hub' operations from legacy or regionals) decreased frequencies per intra-route more than others, a pattern that transcended into HS and international routes as well. For classes 3 & 4 of T-25 (where legacy 'hubs' had existed at the least during 2006), a similar translation of negative changes into other route types can be found, although these occurred from a higher base level each. On these intra-routes, average aircraft size was not particularly high although technological differences could be found: whereas classes 1, 3 & 4 operated regional aircraft on HS (and had been decreasing their size), on intra-routes the same classes – on average – employed aircraft that was only slightly bigger than Regional (AAS being reduced during the period). Classes 0 & 3 in turn used another technology mix of larger AAS on HS while on intra-routes yet bigger aircraft was employed: their daily frequency per OD on intra (T-25) averaged nine which was comparable to that of class 4.

Table 5: Changes in connectivity versus density (averages, Nov.'07-'11)

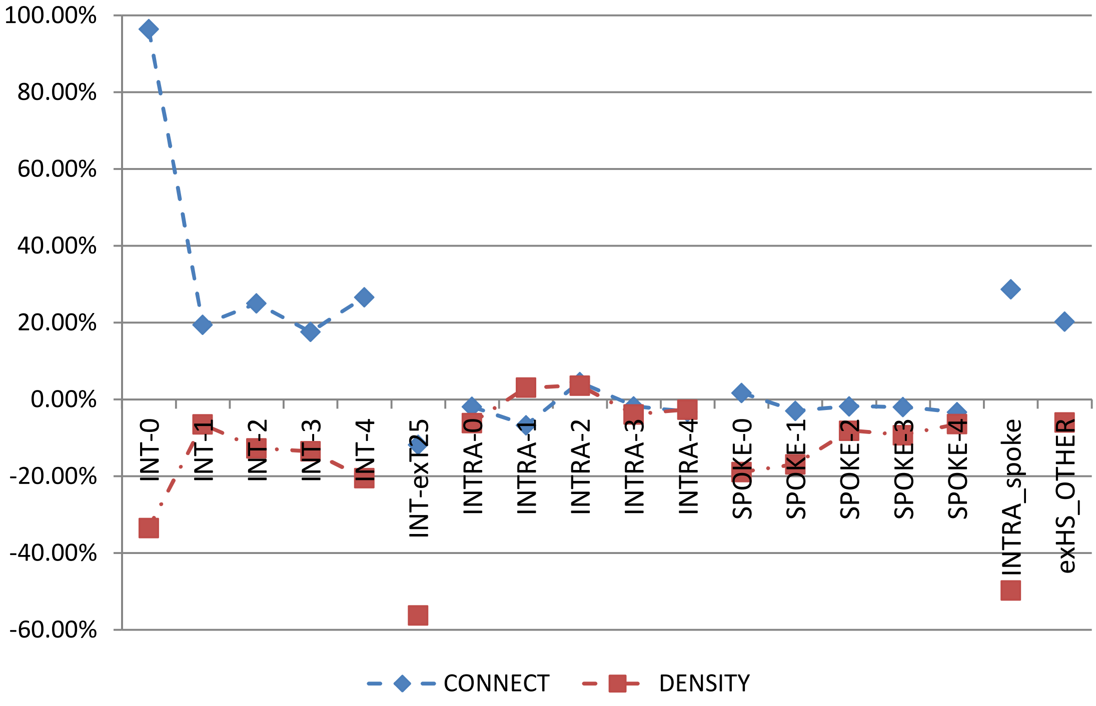


Table 5 compares changes in connectivity with that of density. One can find a few similar patterns of relationship as with ***Table 4***: very close overlap on intra-hub routes and greatest differences on international. However, the differences may be more telling: for one, the extent of changes (volatility) observed in ***Table 5*** is much greater than with ***Table 4***. Secondly, whereas it was shown that available seats increased for many T-25 airports, we can now see that this was much less significant than increases in international connectivity. Also, this was to the detriment of route densities which had fallen. The greatest fall on international densities could be observed for T-25 airports without any hub operations (INT-0, INT-4). On intra-hub routes, the near identical curves for connectivity and density are broken with intra-1

(only regional hubs present): these T-25 airports show improvements in density in spite of less connectivity. The third major difference to ***Table 4*** is the near unchanged degree of connectivity throughout all spoke routes: densities had dropped on all spoke routes, although this was much more significant for T-25 without a history of legacy hubs (spoke-0, spoke-1).

Conclusion

The results of this paper suggest that several assumptions that were fundamental for our understanding of network behavior and development of the ATS in the US can be challenged. For the observation period (2006 to 2011), increasing inequalities in traffic distributions appeared between airports that were part of an HS and those that were not. Within the HS, inequality also increased because of less frequent flights between the hub and the spokes: this traffic was thinning out and economies (of density) became ever more elusive in such a structure. Community airports that were said to profit from HS actually became more and more atomized; not only because they were not directly connected to an HS, but also because spoke routes were thinning out.

In stark contrast, the intra-routes connecting the most concentrated airports in the US showed (on average) three times as many frequencies per OD compared to spoke routes with the same hub airports. It is questionable if this unevenness in frequencies can actually facilitate transfer at the hubs. The symptom of super-frequent intra-routes was most pronounced for big airports where legacy carriers maintained their presence during the observation period. In total, intra-traffic between the 25 biggest airports in the US offered 62% as many seats as traffic to/from all 315 spokes (see ***Table 3***). The author continues to question the welfare impact of super-high frequency on intra-routes where no positive spill-over is apparent with regards to spoke frequencies. Everything suggests the contrary in times of economic stagnation.

Also, the process of spatial concentration of international routes around these hubs had continued: although average distances flown on international had dropped along with frequencies per OD, the degree of connectivity from these airports had increased. On the other side, international routes from outside these T-25 airports saw great losses in seat availability and even in connectivity: in the shorter to medium run, this situation is unlikely to be sustainable. Even if the new set-up of legacy hubs at big airports showed some positive effects on traffic figures and international links, it was not clear if this effect was due to the legacy’s own hub operations (likely for international routes) or due to sub-contracted operations to a regional carrier (which also could transfer on to international).

Clearly, economies of density were not found to strengthen the overall ATS. Such economies, if any, revealed itself as a privilege for those carriers operating super-high frequencies on intra-routes. Even in this atypical segment marginal benefits were likely to have surpassed their optimum level, i.e. the competitive benefit of such operations was unlikely to be found in such economies. On the other side, spokes were dependent on these intra-routes, as their own connectivity to T-25 airports was very low and direct traffic to other spokes offered few seats. The rationale of market power of legacy hubs over Regionals appears to be a more convincing argument than economies of density. As a result, the author questions if the current HS network topology of the ATS in the US is in fact sustainable.

Finally, the possible contribution of Regionals (and also LCCs) as more independent operators to make the ATS in the US more resilient and robust may be subject to continuing research and analysis.

References:

ACI (Airports Council International), 2013. *Airport Traffic Reports*. http://www.aci-na.org/content/airport-traffic-reports [date accessed 20/12/2013]

Brueckner, J.K., Lee, D, Singer, E.S., 2013. *Airline competition and domestic US airfares: A comprehensive reappraisal*. Economics of Transportation 2(1), March 2013, pp.1-17

Burghouwt, G., Hakfoort, J.R., 2001. *The European aviation network, 1990-1998*. Journal of Air Transport Management 7(5), pp.311-318

Bourghouwt, G., Hakfoort, J.R., Ritsema-van Eck, J.R., 2003. *The spatial configuration of airline networks in Europe*. Journal of Air Transport Management 9(5), pp.309-323

Burghouwt, G., 2005. *Airline network development in Europe and its implications for airport planning*. Doctoral thesis, Utrecht University, ISBN 9039339244

Bourghouwt G., 2013. *Airport capacity expansion strategies in the era of airline multi-hub networks*. Discussion paper 2013-5, International Transport Forum, OECD

Gigerenzer, G., Todd, P. M., ABC Research Group, 1999. *Simple Heuristics That Make Us Smart*. New York: Oxford University Press.

Goetz, A., Sutton, C., 1997. *The Geography of Deregulation in the U.S. Airline Industry*. Annals of the Association of American Geographers 87(2), pp.238–263

Graham, B., 1998. *Liberalization, regional economic development and the geography of demand for air transport in the European Union*, Journal of Transport Geography 7(4), pp.285-289

Guimera, R., Mossa, S., Turtschi, A., Amaral L. A. N., 2005. *The worldwide air transportation network: Anomalous centrality, community structure, and cities' global roles*. Proceedings of the National Academy of Sciences 102(22), pp.7794–7799

Huber, H., 2001. *Strategic behavior, barriers to entry and barriers to mobility: An investigation into the European airline industry from 1993 to 1997*, Doctoral thesis, Dept. SES, University of Geneva, Switzerland

Huber, H., 2009. *Spatial Structure and Network Behaviour of Strategic Airline Groups: a comparison between Europe and the United States*, Transport Policy 16(4), pp.151-162

Huber, H., 2010. *Planning for balanced growth in Chinese air traffic: A case for statistical mechanics*, Journal of Air Transport Management, 16(4), pp.178–184

Januszewski Forbes, S., Lederman, M., 2009. *Adaptation and Vertical Integration in the Airline Industry*, Amercian Economic Review 99(5), pp.1831-1849

Reynolds-Feighan, A., 1995. *European and American approaches to air transport liberalization: some implications for small communities*. Transportation Research A 19(6), pp.467-483

Reynolds-Feighan, A., 2000. *The US airport hierarchy and implications for small communities*. Urban Studies 37(3), pp.557-577

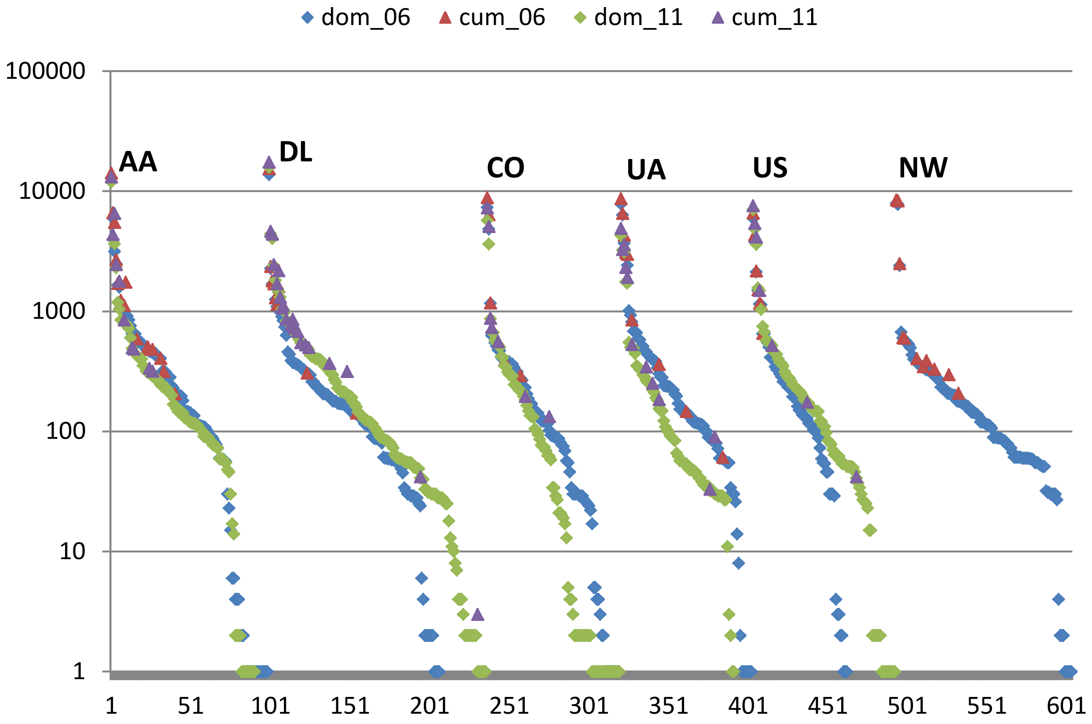
Reynolds-Feighan, A., 2007. *Long Run Distributional Effects of Industry and Carrier Changes in the US Air Transport Market.* In: Lee, D (eds). Advances in Airline Economics (2): The Economics of Airline Institutions, Operations and Marketing. Amsterdam: Elsevier Science

Annex 1: List of selected airlines (Clusters 1-5, 7)

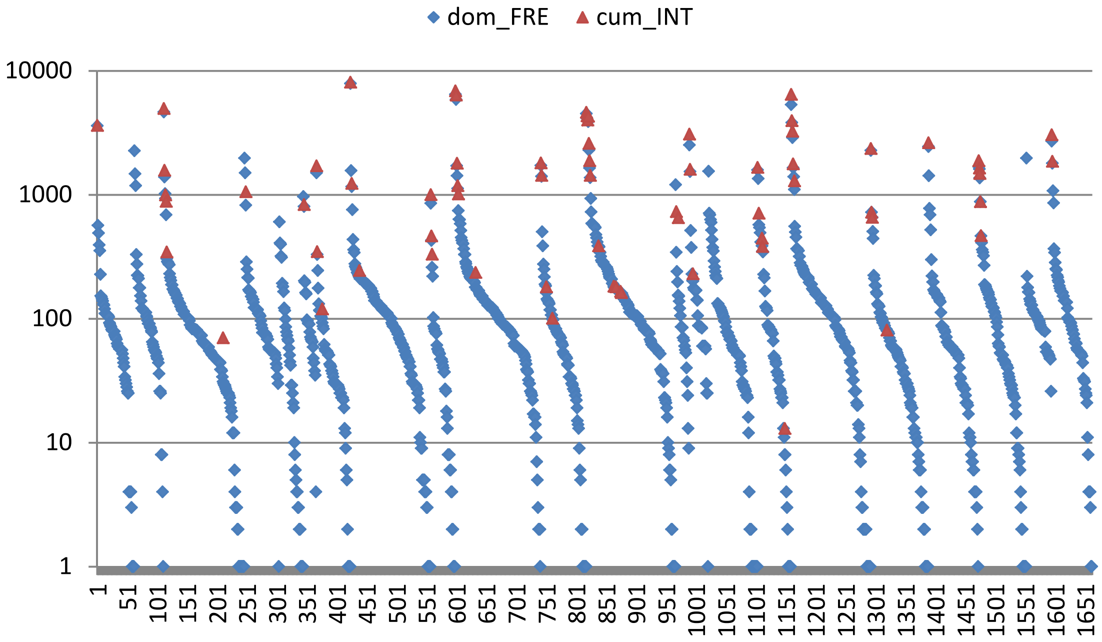
Code	Airline	Cluster	Type
WN	Southwest Airlines Co.	1	LCC
AA	American Airlines Inc.	2	Inc
DL	Delta Air Lines Inc.	2	Inc
CO	Continental Air Lines Inc.	3	Inc
NW	Northwest Airlines Inc.	3	Inc
UA	United Air Lines Inc.	3	Inc
US	US Airways Inc.	3	Inc
B6	JetBlue Airways	3	LCC
FL	AirTran Airways	3	LCC
SLQ	Sky King Inc.	4	Charter
G4	Allegiant Air	4	LCC
SY	Sun Country Airlines d/b/a	4	LCC
09Q	Swift Air, LLC	4	Reg
U7	USA Jet Airlines Inc.	4	Reg
F9	Frontier Airlines Inc.	5	LCC
HP	America West Airlines Inc.	5	LCC
NK	Spirit Air Lines	5	LCC
VX	Virgin America	5	LCC
16	PSA Airlines Inc.	7	Reg
17	Piedmont Airlines	7	Reg
9E	Pinnacle Airlines Inc.	7	Reg
9L	Colgan Air	7	Reg
AX	Trans States Airlines	7	Reg
C5	Commutair Aka Champlain	7	Reg
CP	Compass Airlines	7	Reg
EV	ExpressJet Airlines Inc.	7	Reg
G7	GoJet Airlines, LLC d/b/a United Express	7	Reg
MQ	American Eagle Airlines Inc.	7	Reg
OH	Comair Inc.	7	Reg
OO	SkyWest Airlines Inc.	7	Reg
OW	Executive Airlines	7	Reg
QX	Horizon Air	7	Reg
RP	Chautauqua Airlines Inc.	7	Reg
S5	Shuttle America Corp.	7	Reg
XE	ExpressJet Airlines Inc. (1)	7	Reg
XJ	Mesaba Airlines	7	Reg
YV	Mesa Airlines Inc.	7	Reg
YX	Republic Airlines	7	Reg
ZK	Great Lakes Airlines	7	Reg
ZW	Air Wisconsin Airlines Corp	7	Reg

Annex 2: Traffic distributions of selected airlines

a) Ranked distribution for legacy airlines (Nov.'06-'11), incl. international



b) Ranked distribution for Regionals airlines (Nov.'11), incl. international



Annex 3: Top25 airports

Full-year summary of Passengers and Movements (2011 – 2006)

Code	Pax_Rk'11	Chg_Pax	Dep_Pax'11	Pax_d%	M_Rk'11	Chg_M	Move'11	Move_d.%
ATL	1	=	44.414.121	7,40%	1	=	923.996	-5,37%
ORD	2	=	31.892.301	-13,40%	2	=	878.798	-8,33%
LAX	3	=	30.528.737	3,99%	3	+1	702.895	7,01%
MIA	4	+1	28.987.488	9,89%	16	+2	394.572	2,63%
DFW	5	-1	27.518.358	-3,88%	4	-1	646.803	-7,51%
DEN	6	+3	25.667.499	24,65%	5	+2	628.796	5,30%
JFK	7	+1	23.664.830	12,31%	14	+5	408.730	7,30%
SFO	8	+7	20.038.679	23,42%	15	+6	403.564	12,35%
LAS	9	-2	19.854.759	-9,87%	7	-2	531.538	-14,20%
PHX	10	=	19.750.306	-3,56%	9	-1	461.989	-15,47%
IAH	11	-5	19.306.660	-15,40%	8	-2	517.262	-14,17%
CLT	12	+5	19.022.535	27,24%	6	+4	539.842	5,94%
MCO	13	+1	17.250.415	2,63%	22	-5	309.884	-20,90%
EWR	14	-3	16.814.092	-5,56%	13	=	410.024	-7,80%
SEA	15	+3	15.971.676	8,62%	21	+1	314.947	-7,38%
MSP	16	-3	15.895.653	-7,54%	12	=	436.506	-8,10%
DTW	17	-5	15.716.865	-10,10%	11	=	443.028	-8,04%
PHL	18	-2	14.883.180	-3,30%	10	-1	448.129	-13,13%
BOS	19	=	14.171.476	4,63%	17	-2	368.987	-9,14%
LGA	20	=	11.989.227	-7,25%	18	-2	366.597	-8,42%
FLL	21	+3	11.332.466	11,05%	24	+1	267.119	15,74%
BWI	22	=	11.067.317	7,47%	23	+1	276.133	3,50%
IAD	23	-2	11.043.829	-0,01%	20	=	327.493	-13,72%
SLC	24	-1	9.701.756	-5,71%	19	-5	358.002	-15,10%
MDW	25	+3	9.134.576	2,46%	25	-2	255.227	-14,51%

Source: ACI, 2013