India's Air Traffic System: Network Topologies, Hierarchies and Evolution

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W.P. No. 2015-10-07
October 2015

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INDIA

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Abstract

The paper examines multi-dimensional patterns of network characteristics for scheduled Indian airlines between 2006 and 2014. The well-known skewed traffic distribution which concentrates traffic around relatively few hub airports serves as the starting point for decomposing the air traffic system (ATS) into its constituent route types. Operations of distinct airlines along these route classes allows for classifying carrier's network features as an embedded part of the system. Discussion of the carriers' role in the overall domestic ATS includes a spatial component. Inferences about development paths – past, present, future – of the Indian scheduled ATS can be made.

Keywords: **I**ndian aviation, network topology, spatial development, air traffic system

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Introduction

Questions on aviation networks in a market environment, their formation, development and competitive dynamics (or lack thereof) have been discussed before. For example, authors such as Reynolds-Feighan (2001), Alderighi et al. (2005), Martin and Voltes-Dorta (2009) and Huber (2009) aimed at assessing major impacts caused by liberalization and competition on air transportation networks by measuring market concentration. More recently, structural aspects of networks such as connectivity, etc. were examined in greater detail (Reynolds-Feighan 2010, see Shaw 2009, p.293 for references). In this same context, spatial aspects of network competition in aviation have become more relevant (Burghouwt et al. 2003, Graham et al. 2008, etc.).

These multi-dimensional approaches inter alia looked at structural aspects of air traffic flows and sought new insights by decomposing airline networks into their parts and examining – mainly through means of statistics and pattern recognition – salient features and properties (Huber, 2010). Derudder and Witlox (2009) defined frameworks through multi-ratio indices which described air transport networks as caught between dominance and connectivity. Normalisation of such computed ratios was to allow for longitudinal comparisons and to elaborate on changes in the overall spatiality, i.e. concentration or dispersal of the network (p.278).

After focusing on Western air traffic, which represented somewhat more mature market regimes, more recent attention was given to Asian development. This was e.g. the case with China. Jin et al. (2004) analysed geographic patterns of air passenger transport in China between 1980 and 1998. The authors interpreted market liberalization as distinct stages of reforms leading to sequential implementation of new policies: the period under investigation concerned the third stage which was called 'post-reform era' which led to industry consolidation around three big airline groups (Air China, China Eastern and China Southern) by October 2002 (p.473). In particular, the emergence and establishment of the hub-and-spoke (HS) transport system as a salient property of the evolved Chinese ATS (p.485) was found. Measures regarding changes in the Chinese ATS included rank orders for airports (in terms of passengers) across China's ATS (p.477). Structural change to the network over time was examined using dominant traffic flows, i.e. only the largest flow of passengers carried from/to each city was to be used. Hubs would usually be connected to large numbers of such 'priority links' (p.483).

Shaw et al. (2009) examined China's airline consolidation of 2002, which was considered to have been government-led, and its impact on domestic network structure and competition thereafter. This led the authors to identify a distinct (fourth) phase of reforms that had consolidated 11 smaller airlines into the 'Big Three' while another 6 smaller carriers could continue operations independently as of 2004 (p.296). The paper stressed that the Chinese Aviation Authority CAAC most likely had a pre-set goal of creating three roughly equal major airlines while trying to minimize direct competition among them. Changes in the ATS' network structure were accounted for by multiple, operations-related, variables such as numbers of airports served, non-stop routes, airport rankings within the airline network, but did not include any flow measures (such as passengers or frequencies).

Zhang (2010) compared fully-connected network systems with hubs-and-spokes in China. He employed a Cournot-based general equilibrium model to assess China's network optimality. According to Zhang, capacity at hub airports was socially inefficient requiring larger infrastructure investment to reduce congestion cost as compared to fully-connected airports which would otherwise provide the same capacity at lower cost and with greater social efficiency.

Huber (2015) compared air traffic patterns among China's scheduled airlines in January 2006 with those of January 2011, a period that was described as 'post-consolidation'. The author classified airlines and airports along network parameters. A heuristics approach central to the paper was to compare flow-related variables for distinct network parts taking into account the highly skewed traffic distributions within the system. Some key inferences regarding the fundamental structure and likely future patterns were made based on path dependency. Spatial growth of new traffic would still be driven by China's 'Big Three', however in an indirect and quite enabling manner for other carriers: concentrated traffic flows would be steered towards selected key airports from where other hub-based carriers could grow. Continued new entry of new types of carriers which avoided direct competition between the newly created hubs was found.

With regards to India's domestic ATS, there was little literature looking at the structural evolution of air traffic networks. This is remarkable as Indian aviation was about to enter a (presumably government-led) new phase of consolidation along with entry of new carriers around 2006. Industry growth which continued thereafter, though, was realised on a much smaller and more irregular scale as compared to China's.

Inspired by the heuristics used in the China papers, the author now seeks to highlight salient network characteristics of the Indian ATS and their changes between 2006 and 2014. Indian airlines would be considered as agent-firms whose strategic behaviour – at least in part - was influenced by Government policies. This behaviour would impact on network structures and development patterns. The ensemble of operations as depicted by origin-destination links between airports would constitute networks and the domestic ATS could be decomposed into its constituent parts for comparative analysis. Hierarchical ordering of route types is critical in this process. A matrix-computational approach was chosen as the dominant heuristic for representing structural features of Indian airline networks and their changes over time.

Mergers, entry & competition

For the Indian domestic context we need to justify our selection of (early) 2006 as the beginning of a period that can be described as industry consolidation. A first distinctive example was the takeover of Sahara by Jet Airways. This acquisition gave Jet access to Sahara's fleet of Boeing 737 and CRJ aircraft, and, more importantly, Sahara's parking slots in major Indian airports. Though the deal was announced in early 2006, Jet completed acquisition of Sahara in April 2007 and decided to run the airline as a value carrier subsidiary under the brand name JetLite. In mid-2007, Kingfisher acquired a controlling stake in Air Deccan. Kingfisher justified the acquisition based on synergies in aircraft maintenance, and spares since Air Deccan and Kingfisher both had fleets of the same types of aircraft (A -320 jets and ATR turboprop). Other shared services would include sales and marketing, ground handling, engineering services, customer service, and training. Over time, Kingfisher hoped to "mesh routes and frequencies through combined strengths of network reach, connections, frequencies, and infrastructure" (see references). A third major consolidation was the merger of the two national carriers Indian Airlines and Air India into a single national entity under the corporate name of National Aviation Company of India (NACIL) and the brand name of Air India. The move had first been mooted several years earlier, but was ultimately consummated only in 2007. Shortly before the official approval of the merger, the boards of Indian Airlines and Air India approved major fleet expansion plans that would result in a complete overhaul of their respective fleets (Rishikesha, 2008).

With both GoJet and Indigo having started operations in 2006, SpiceJet having started during 2005 (all of them being marketed as low-cost brands) new and more competitive industry dynamics could plausibly be expected. With such significant policy changes being made by Government of India (GoI) which might result in more competitive, possibly disruptive new industry dynamics, one could plausibly make a case for the beginning of a new phase in Indian Aviation reform during the year 2006. The period thereafter was affected by economic slow-downs and subsequent pick-up in economic activity. Also, major players had to leave the business while others more or less successfully pursued integration with the merged entities. Investigating the impact along structural criteria (as shown above) during this time was reckoned worthwhile. Both for reasons of cyclical changes and because of the rather long period between 2006 and 2014, it was decided to divide this period into two equally distanced parts: structural changes in the network shall be compared for a first 4-years period followed by a second one (longer-run). Assessing the impact of the new aviation policy on industry performance and salient changes after 2006 shall be discussed through analysis of the prevalent network structures which were expected to be organized in a hub-and-spokes system of airports.

Data

Data is taken from OAG's Historical Max Plus database. The OAG Historical Max Plus data represents the ex-post schedules of airlines, i.e. the actual capacity offered by carriers. Origin-destination (OD) data provides detailed information on carriers' operations inside India and was taken from OAG for the first quarters of 2006 through 2014. OD in this case refers to flight segments only, i.e. connecting flights or transfers between routes are not accounted for as such. The OAG database omits information about actual passenger demand. Although such additional data may be considered useful for further analysis, the author sees valid interest in a supply-sided structural analysis of the Indian ATS.

Our initial sampling procedure selected international (for summary information only) and domestic (core analysis) flights performed by Indian carriers. The exact time windows chosen were between 1st and 30th January for each of the years 2006, 2010 and 2014. After compiling the data into matrices of directed flight segments for each domestic operating carrier, a total 8,848 of such individualised segments could be listed for the respective months of January. This sample population was sufficiently comprehensive so as to allow for data aggregation within the format of our subsequent analysis of the Indian ATS.

Is a hub-and-spoke (HS) paradigm valid in the Indian context?

A well-established method of the empirical approaches quoted above has been to compare ideal hub-and-spoke structures with real network configurations (Derudder and Witlox, 2009, Alderighi et al., 2007).

The logic of funnelling traffic into highly connected airports to spatially concentrate traffic and increase flight densities is a fundamental property of HS (Brueckner and Spiller, 1994). In light of the pervasiveness of hub-and-spoke systems worldwide, including for domestic traffic, we would expect similar networks also to appear in India. Consolidation of the Indian ATS should support such HS structures: merged airlines would be expected to radially organise traffic around “their” hub airports, allowing for improved efficiency, facilitated coordination and connectivity advantages. Also, market entry by low cost competitors would be made more difficult, as airport slots at these hubs would be kept scarce and protected through ‘grandfather rights’ (Borenstein, 1989).

The basic mechanism that was often used to explain the comparatively faster growth of central hubs as compared to other airports was that of ‘preferential attachment’: new airports would have a natural higher propensity to link to already better connected airports vs. less well connected ones (Albert and Barabási, 2002). Ergo airline traffic would spatially concentrate around these hubs. Links between airport nodes are measured in terms of connectivity; this is different from traffic movements (‘Frequency’) at given airports. If one were to plot frequency distribution among airports on a diagram in decreasing ranked order, a highly skewed curve would appear. Its slope would be of a higher order: logarithmic or power law.

Figure 1 shows the distribution in domestic flight movements for rank-ordered Indian airports for each of the 1-month sample periods. A most significant change can be observed between 2006 and 2010. By comparison, the curve for 2014 only slightly exceeded values of that of 2010. For smaller airports (rank 55 onwards), the curve actually undercut that of 2010 – a symptom of spatial concentration from the ‘lower end’ of the Indian ATS. Upon closer inspection one distinguishes a steeper slope for the six biggest Indian airports (which all remained within the same top-6 group during the observation period), with the curve being kinked from rank 7 onwards. This suggests continued – disproportionate – spatial concentration at the top-end of the Indian ATS. A particular role in this regard is to be played by the two largest Indian airports at Mumbai (BOM) and New Delhi (DEL), as will be explored in more detail later.

Figure 1: Hub-and-spokes as highly skewed traffic distributions

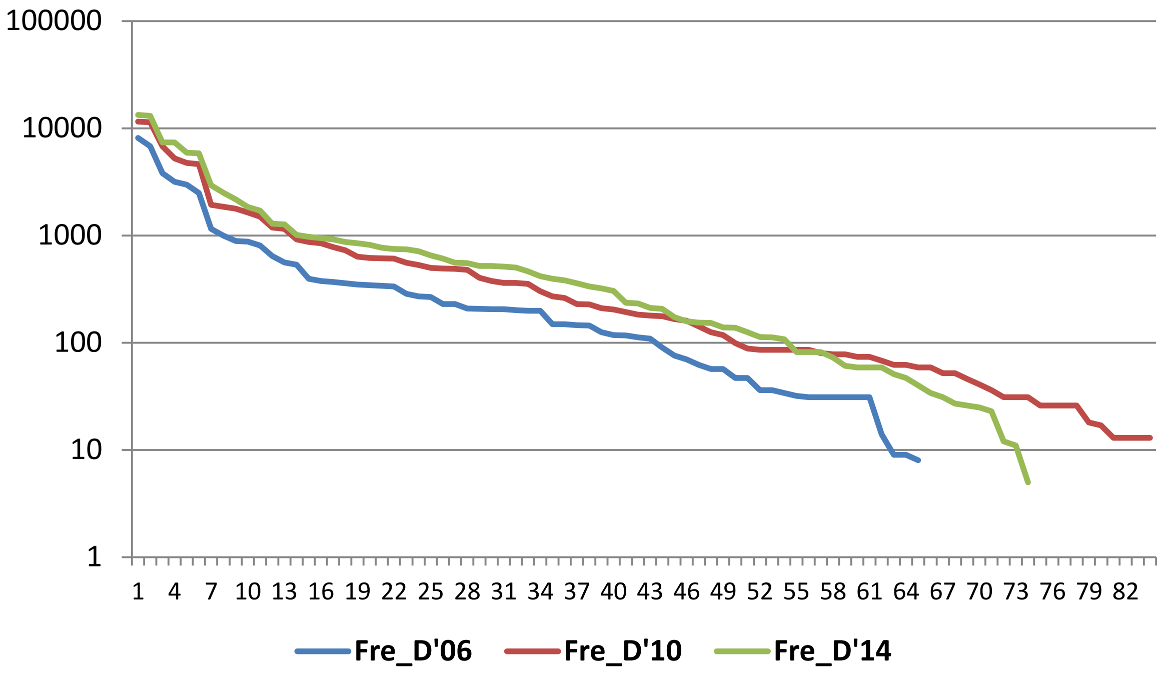


Table 1 shows sustained spatial concentration of traffic movements around India's largest airports, e.g. Mumbai and Delhi. However, shifts in traffic shares among the incumbents for these airports were significant: NACIL (Air India including merged entities) had recuperated from important cut-backs in 2010 and showed highest traffic at DEL followed by BOM by 2014. Spatial concentration of its domestic network around the top 3 airports stayed at very high levels suggesting dominant HS patterns for domestic traffic.

Table 1: Concentration of airlines' traffic: Incumbents with merged firms

AL	AL_name	AP'06	Fre'06	AP'10	Fre'10	AP'14	Fre'14
AI	Air India	**BOM**	513	**BOM**	240	**DEL**	3696
		DEL	127	**DEL**	110	**BOM**	3209
		BLR	84	COK	84	MAA	1082
		others	*34.1%*	*others*	*40.1%*	*others*	*53.3%*
IC	Indian	**BOM**	2551	**DEL**	1408		
		DEL	2361	**BOM**	1267		
		MAA	1152	CCU	556		
		others	*55.4%*	*others*	*58.9%*		
IX	AI Express	TRV	52	TRZ	177	**BOM**	178
		CCJ	34	**BOM**	161	MAA	131
		COK	18	CCJ	129	CCJ	120
		others	*0.0%*	*others*	*56.2%*	*others*	*45.4%*
9W	Jet Airways	**BOM**	3415	**BOM**	4079	**BOM**	2944
		DEL	2210	**DEL**	2520	MAA	2109
		BLR	1294	BLR	1864	**DEL**	1944
		others	*52.5%*	*others*	*53.8%*	*others*	*60.6%*
S2	Sahara	**DEL**	1205	**DEL**	1330	**BOM**	993
		HYD	943	**BOM**	1001	BLR	484
		BLR	624	CCU	719	**DEL**	478
		others	*52.6%*	*others*	*51.3%*	*others*	*50.9%*

IT	Kingfisher	BLR	621	**DEL**	3406		
		BOM	354	**BOM**	2347		
		DEL	236	BLR	2311		
		others	*46.0%*	*others*	*61.4%*		
DN	Deccan	**BOM**	276				
		BLR	248				
		HYD	186				
		others	*52.8%*				

The merged Jet Airways-Air Sahara entity clearly had cut back on its Delhi presence (post 2010) and concentrated most traffic at Mumbai (although at a lesser level than in 2010). Its emphasis on HS structures was slightly lower as compared to higher degrees of concentration of previous years. The Kingfisher-Deccan merged entity, which had ceased to exist by 2014, showed an abrupt and most significant traffic build-up around BOM and DEL by 2010. Nevertheless its traffic spread was somewhat more even across its domestic network as compared to the other merged entities, most of all NACIL.

Table 2: Spatial allocation of airlines' traffic: new entrants

AL	AL_name	AP'06	Fre'06	AP'10	Fre'10	AP'14	Fre'14
SG	SpiceJet	**DEL**	477	**DEL**	633	**DEL**	2428
		BOM	295	**BOM**	504	HYD	2017
		AMD	236	BLR	384	MAA	1990
		others	*45.3%*	*others*	*61.4%*	*others*	*62.8%*
6E	IndiGo	**DEL**	526	CCU	1472	**DEL**	3163
	(start in '07)	**BOM**	177	**DEL**	1405	**BOM**	2761
		CCU	177	**BOM**	1193	CCU	2199
		others	*57.1%*	*others*	*55.7%*	*others*	*63.6%*
G8	GoAir	**BOM**	436	**BOM**	613	**DEL**	1595
	(start in '07)	MAA	177	**DEL**	571	**BOM**	1562
		DEL	118	BLR	401	BLR	420
		others	*43.3%*	*others*	*34.0%*	*others*	*50.3%*

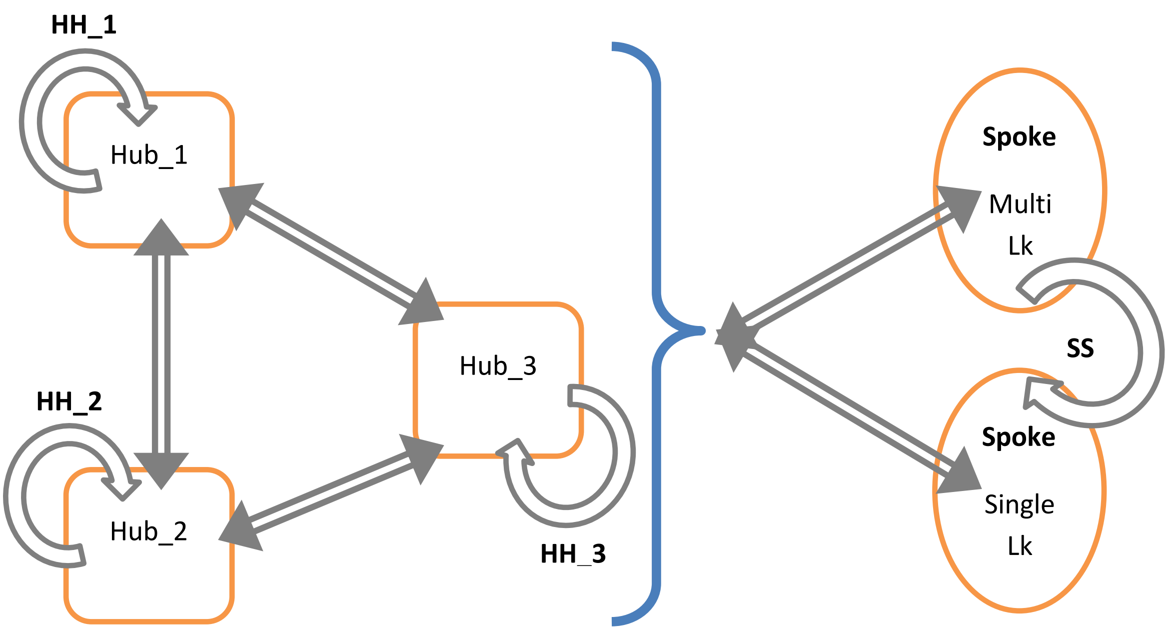
The three low cost carriers operating during the observation period (with IndiGo and GoAir having started operations by January 2007) do not contradict the pattern found with the industry incumbents before: they tended to concentrate their traffic around the same two airports BOM and DEL and ramped up capacity there at a very fast rate. Only SpiceJet operated similarly highly ranked traffic from HYD and MAA in 2014, whereas IndiGo had relegated its CCU airport to a lesser rank which now also showed significantly less frequencies to the next higher one (BOM). Furthermore the proxy for concentration rate (all other movements combined) seemed quite high for true low-cost business models which often claim to open new, underserved markets through point-to-point traffic.

Towards a route & airline dependent decomposition of the ATS

The Indian domestic ATS can be decomposed into constituent parts, while attributing different roles to the airports that make them up. Central to such a heuristic of system deconstruction is the identification of the different domestic airlines' most traffic-concentrated airports (which we refer to as 'hubs'). Airports that are directly connected to these hubs are treated as 'Spoke' airports. The preeminent role of both BOM and DEL for the Indian ATS has been shown before. We shall bundle their departing traffic under "Hub_1". With four other airports showing consistent and sustained rates of comparatively higher spatial concentration (MAA, CCU, BLR, HYD, see before), we shall evenly divide them and group them under "Hub_2"and "Hub_3"[1]. Traffic at this intra-hub level was to be designated as either "HH_1,2,3" for flights between the two airports within each hub-class or as "HH1_2,3", "HH2_1,3", "HH3_1,2" for traffic departing from one hub class to another one. This hub traffic which may be referred to as "horizontal" needs to be dealt with separately from "vertical" traffic, i.e. the one connecting the select number of most concentrated airports to lesser ones ("spokes"). A distinction between spokes connecting with different types of "Hub_1,2,3" shall not be made for the sake of simplicity and because several such spokes were likely to connect to multiple hub airports. These "multi-link" spoke airports were distinguished from "single-link" spokes, i.e. those that connected with one single hub airport only. The class of 'Spoke-Spoke' or 'SS' refers to connections between different or same kinds of spoke airports only. Figure 2 illustrates the schematic deconstruction of India's domestic ATS into its constituent route classes.

These routes classes were measured across the following variables: number of airports within a given class ('AP'), number of origin-destination (directed flight segments) departing from all airports within a given class ('OD') as well as their number of scheduled flight movements ('FRE') for 2014 as compared to 2006 (January each). The average number of frequencies per directed route is ('FRE/OD').

Figure 2: A template for analyzing the Indian ATS



[1] The reason for bundling HYD and BLR separately from MAA and CCU was finally made due to ongoing discussions about performance of private vs. public ownership. Although outside the immediate scope of this paper we found this criterion valid enough to serve as a controlling variable for group distinction.

Changes in India's domestic ATS: summary findings

The results present summary information about the Indian domestic ATS and the traffic contribution of each of its route classes for selected variables (see Table 3 in Annex). Depending on the airport classes for the city pairs involved, traffic flows are being considered either as "horizontal" or "vertical". For the sake of a more comprehensive perspective of the Indian ATS summary data regarding international traffic was included in Table 2.

Domestic traffic

With intra-hub 'horizontal' traffic linking a total of six airports to fully connected, no changes could be observed between the beginning and end of the observation period. The number of flight movements ('FRE_h') was very high and descending in magnitude from Hub_1 to Hub_2 and finally Hub_3. As a consequence the ratio of 'FRE/ODh' (avg. frequency per given route) was extremely high showing the same distributional order of magnitude. Horizontal traffic growth among these hubs had grown inversely faster with the smaller hub classes. This situation was different with vertical, i.e. spoke traffic from hubs: Hub_1 operated more such routes than Hub_2 and Hub_3 airports combined. Hub_3 showed much lower growth as compared to Hub_1 even percentage-wise and Hub_2 had added less in absolute numbers. The unevenness in traffic distribution between hub airports was much greater on these vertical routes: even though the smaller hubs added more movements as compared to Hub_1 airports in terms of percentage, this was greatly due to the much smaller base effect of these airports. The greater number of spoke routes from Hub_1 together with higher 'density' ('FRE/ODv') effectively compounded into more flight movements ('FRE_v') at BOM and DEL (35% more than from Hub_2 combined with Hub_3). As a result, market share in terms of total flight departures ('FRE_h' and 'FRE_v') for Hub_1 was the same as for Hub_2 plus Hub_3 airports combined. All flights departing from these six airports made up 61.9% of domestic traffic in India's ATS.

The remaining 64 spoke airports were divided into those which were connected to a single hub only (26) and the remaining showing multiple links with hubs (38). The number of such multi-link airports had grown by 40.7%, which could be considered a growth phenomenon of previously lesser well connected spokes. With a total of 56 spoke airports operating at the beginning of 2006, we can infer a clear trend towards multi-hub linkages over time. The bulk of traffic departing from spoke airports was performed by those with multi-hub connections: their market share for the domestic ATS stood at 34.1% (a 9.2% increase) as compared to the 4.0% (-3.5%) for spokes showing a single hub-link only.

In terms of connectivity we observe a relationship between horizontal and vertical links across these two classes of spokes: fewer single-link spoke airports coincided with even greater reductions of 'horizontal' spoke-to-spoke links from such airports. Rather, spoke-to-spoke links grew through multi-link airports and increases in 'vertical' routes of these airports also coincided with more 'horizontal' connectivity. However, spokes which were best connected to hub airports (with 5 or 6 links each) preferentially grew vertically as compared to horizontally between spokes. A slightly different pattern showed for the number of flight movements: spoke airports with only single links to hubs still showed increases for such vertical traffic in terms of frequency and density per route, although from modest levels. Spoke-to-spoke traffic from such single-link airports remained negligible. Those spokes with multi-hub links substantially grew their flight movements on vertical routes where they also showed important increases in density (per route). In fact their route density (‘FRE/ODv’) now exceeded the average of ‘vertical’ densities that departed from Hub_1. Spokes with five or six hub-links showed even greater vertical route densities (of an average of nine per day). By contrast, horizontal movements would only make up 19% as compared to vertical traffic for this spoke class (17% only for spokes with five or six hub links). Their average ‘horizontal’ density remained even below that of single-link spokes.

International traffic

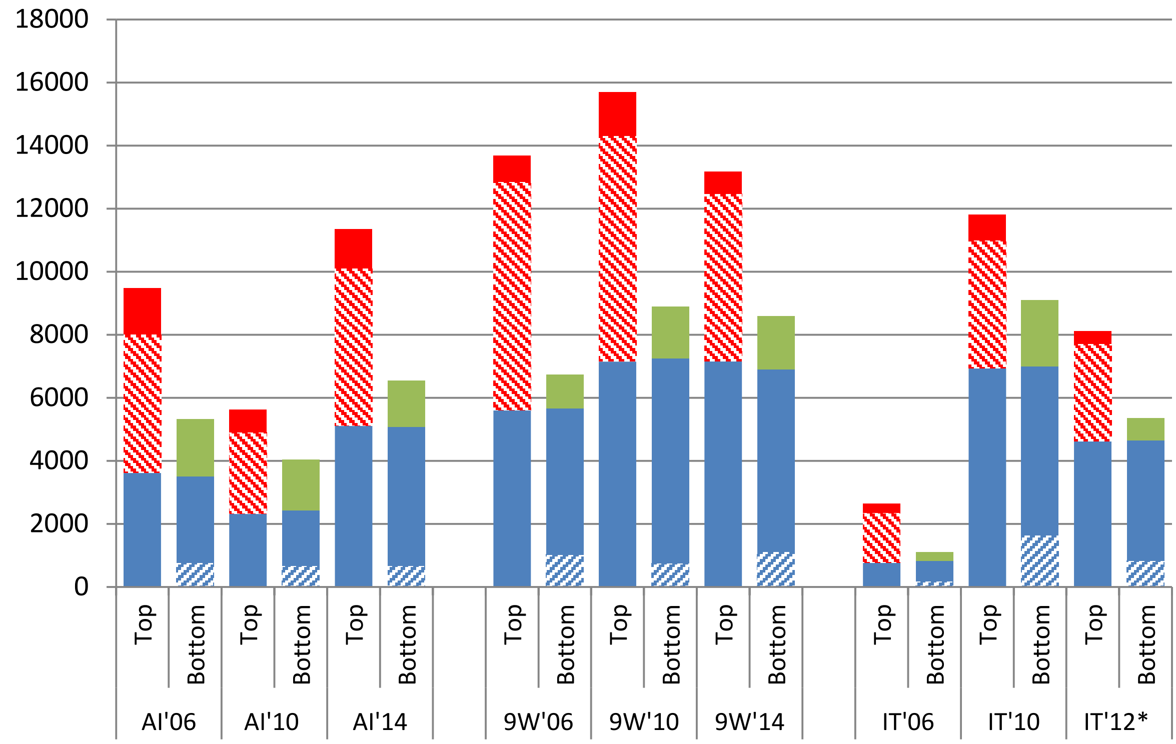
Nearly half of all international traffic departing from India (44.6%) left from either BOM or DEL. This number had stood even higher (54.5%) during January 2006. The respective share for all six hub airports stood at 71.1% (-11.1%). From Annex 1 we see that the number of their movements was significant for all hub classes, but much more so for Hub_1: FRE_INT nearly was at par with FRE_h. This ratio was much smaller for Hub_2 and Hub_3. Densities for international routes remained relatively low and evenly distributed among all three hub classes. For the group of spoke airports, those with single hub links only showed negligible international activity. Those with multiple hub connections had greatly increased their market share – mostly to the detriment of Hub_1 airports – to 26.9% in January 2014. These airports' overall international connectivity now was comparable to that of Hub_1 although their densities stood about a third lower which resulted in lower overall frequencies. This kind of international presence near evenly divided between those spoke airports with five or six (hub) links and those with less multiple links. By comparison their international movements were higher than ‘horizontal’ domestic ones.

An airline based comparison of traffic flows

We validated our assumption that the domestic ATS in India pervasively has been governed by a hub-and-spoke paradigm. If one were to group all directed air traffic of each operating airline into classes as shown before, one would need to consider not only routes which are departing from hub airports but also those arriving there. A full picture of the domestic ATS then needs to add ‘horizontal’ traffic at both sides of the hub-spoke network structure.

The depiction of outgoing versus incoming hub-spoke traffic side by side in the figures allows not only for comparing their growth over time but also for easily comparing ‘horizontal’ traffic between hubs on one side against ‘horizontal’ spoke-to-spoke on the other for the same time intervals. Hub-spoke traffic is shown at the bottom of each bar representation with hub traffic from single-link spokes highlighted through striped areas (right side bars only). ‘Horizontal’ traffic between hubs is shown in red diagonal stripes, with those for Hub_1 filled in solid red (left side bars only). The right side bars show spoke-to-spoke through a solid olive rectangle.

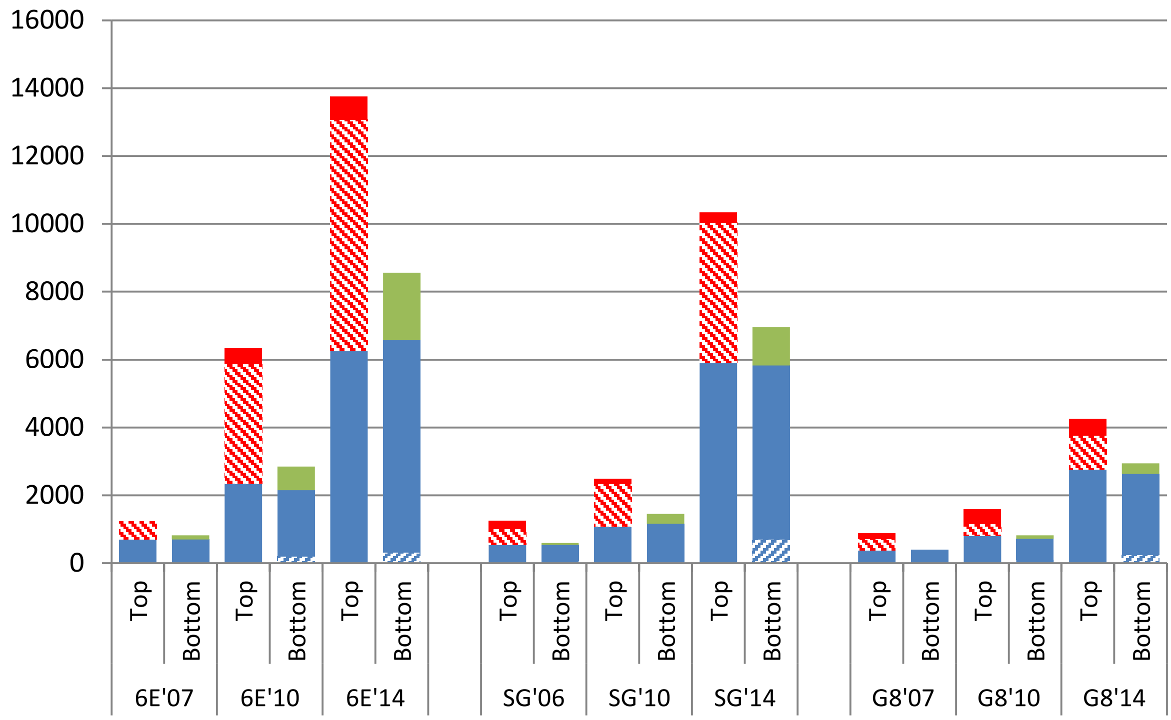
Figure 3: Departures for given routes of FSC incumbents



When comparing incumbents' traffic over time, fundamentally different patterns emerge. Air India (AI) significantly cut back on all routes during in (January) 2010 before steeply increasing capacity by 2014. With 'horizontal' spoke-spoke traffic remaining fairly constant over time, traffic between hub airports had dropped most of all classes by 2010 before surpassing spoke-spoke traffic by a higher ratio than before. The situation was different for Jet Airways (9W) which had grown mostly between 2006 and 2010. Its already high capacity on hub-spoke routes had increased to high levels which were kept at almost the same levels by 2014. Initially its hub-hub traffic was substantially higher than that of AI but by 2014 showed lower levels. The airline had increased its spoke-spoke capacity over time but by 2014 still stood at only a small fraction of its hub-hub traffic. Kingfisher (IT) aggressively had added capacity by 2010 with vertical capacity between hubs and spokes clearly surpassing that of 'horizontal' between hubs. By 2012 the business model of IT was compromised and it soon had to exit the industry.

New entrants which were trying to position themselves as 'Low-Cost' showed more consistent growth and seemingly less volatility in doing so. Several salient features appear: for one, capacity aggressively was added on 'horizontal' hub-hub routes, i.e. very dense routes which already were extremely well served and often congested. The entrants even operated sizeable traffic between BOM and DEL. During 2007 and 2010, capacity deployed by each 'new entrant' on hub-hub routes was higher as compared to 'vertical' capacity departing from these hubs to spoke airports. For Indigo (6E) this horizontal bias (hub-sided, not spoke-sided that is) even continued into 2014. Both SpiceJet (SG) and GoAir (G8) continued to grow on such routes during 2014. The most significant increases on 'vertical' capacity between hub and spoke airports were made after 2010 with each of the 'entrants' actually multiplying its previous stock of capacity for such routes. Unlike what one would expect from typical point-to-point low-cost markets, 'horizontal' spoke-spoke traffic remained low and did not exceed that of incumbents (although it had grown faster from very low levels).

Figure 4: Departures for given routes of low-cost entrants

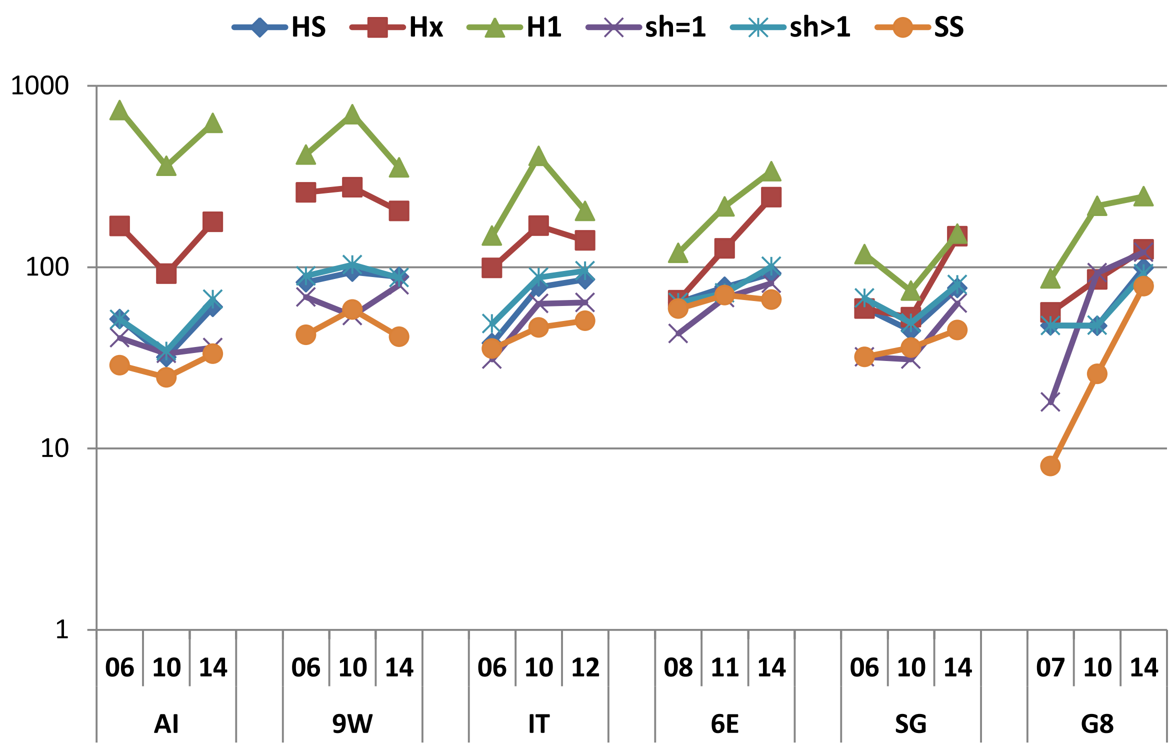


Frequency per route ('Density') can be compared across time and airlines for distinct segments of the ATS: traffic between DEL and BOM ('H1'), other intra-hub traffic ('Hx'), from hub to spoke ('HS'), from spokes to hubs for single-link ('sh=1'), multiple link airports ('sh>1') as well as spoke-to-spoke ('SS').

A first observation shows that the curves within the same groups are distanced from one another through a logarithmic curve. This shows a highly different value of density between the types of routes. Airlines which showed a smaller spread in route densities were Indigo (6E) and SpiceJet (SG). Kingfisher (IT) only showed more equal densities at the very end of its existence. All other carriers showed growth in density for most route types, except for Jet Airways (9W) which mostly regressed on intra-hub 'H1' and 'Hx'. In terms of density concentration, AI showed the highest unevenness not only between intra-hub 'Hx' and vertical hub traffic ('HS', 'sh>1'), but even within intra-hub ('H1' versus 'Hx'). In most cases, the difference in average densities for vertical traffic from single link-spokes ('sh=1') and horizontal spoke-spokes ('SS') is the smallest - given the logarithmic scale – and their growth remains comparatively incremental.

For the incumbent carriers, AI shows the greatest spatial concentration of density between DEL and BOM with traffic density structurally being much lower for the residual network parts. This is accompanied by high volatility regarding the respective routes' changes between 2006, 2010 and 2014. Densities with 9W for intra-hub traffic in 2014 dropped to levels below those of 2006 whereas densities on hub-spoke routes remained fairly constant. Also, 9W increased densities for vertical routes from airports with single hub links (sh=1). This may be interpreted as a (partial) compensation for lost intra-hub traffic.

Figure 5: Density on given routes

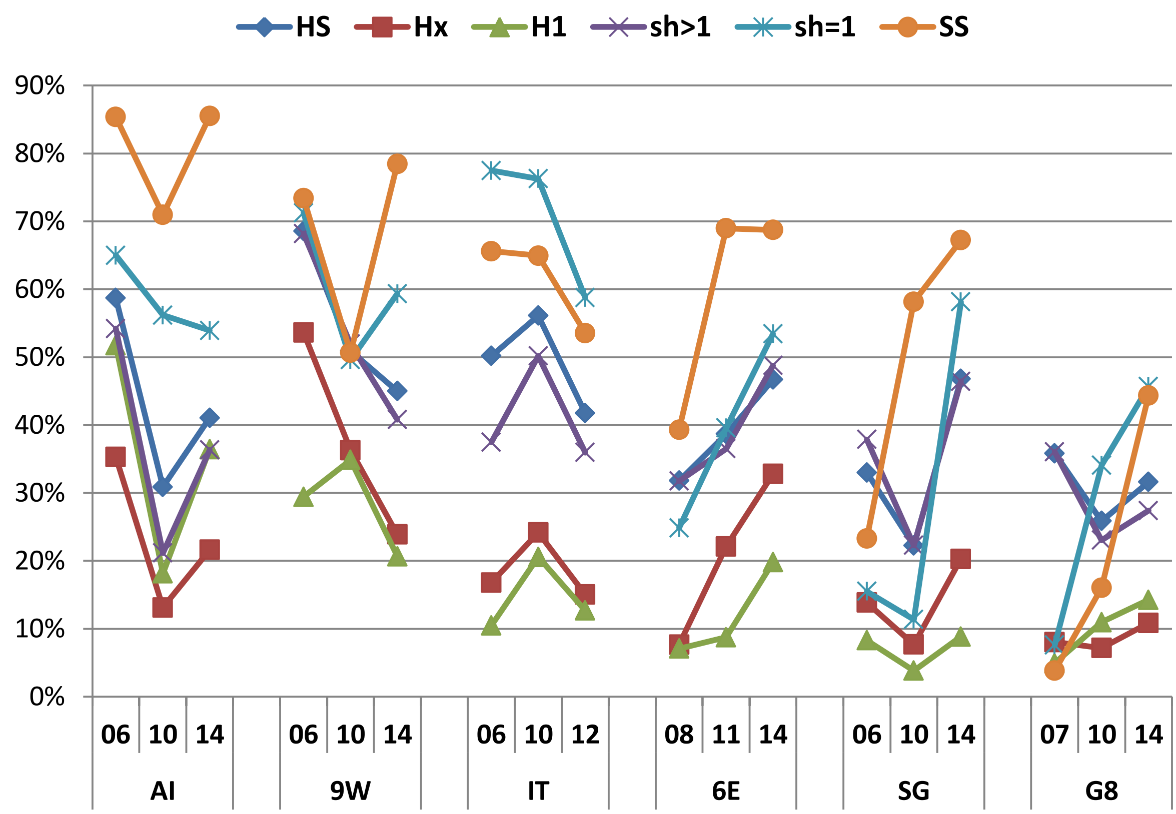


For the entrant carriers, 6E showed very high densities on intra-hub traffic following constant growth over time. Densities for H1 and Hx stood at nearly identical levels by 2014 (different from 2007). In absolute terms, only H1 density for AI stood significantly higher in 2014. The other routes for 6E remained fairly bundled together with average daily frequencies of 2 to 3 in 2014. In comparison, SG was clearly operating with lower densities on its routes. This can be well observed for intra-hub (at the high end) and spoke-spoke (on the low end) of its traffic. Vertical traffic figures for hub or multi-link airports ('HS', 'sh>1') showed average densities of almost 3 per day. Also, SG had to seriously curtail its volume on the denser routes by 2010. G8 operated the smallest network of all carriers shown and consistently had increased density throughout its network. It is interesting to see how the substantial gap in route densities has decreased over time with only H1 traffic between DEL and BOM maintaining a much higher (although somewhat flattened) density of over 8 per day for this carrier alone.

As a consequence of a lesser demand between smaller airports and less dense traffic, carriers are less likely to compete there. As shown before they tend to concentrate capacity at relatively few big airports. This is likely to result in lower local market shares if multiple airlines were to chose the same few airports as their hubs. From a perspective of optimizing hub-spoke operations of individual airlines and avoiding unnecessary competition, while growing the entire ATS, a spatial segmentation into distinctly operating HS networks would be conceivable. This would result in higher market shares for the individual airlines'routes over time.

This outcome, however, cannot be observed in our case of the Indian ATS. Instead, the routes known for airlines to concentrate their capacity on are, relatively speaking, the most contested and provide the lowest market shares for operating carriers: 'low-cost'entrants are preferentially present at intra-hub routes and could increase their market shares there, with 6E being the most impressive example of the same. After the demise of IT, we also observe market share for 9W decreasing quite dramatically on intra-hub ('H1'and 'Hx'). Although figures for AI now were lower here too (as compared to 2006), they had rebounded from lows during 2010 and still showed the highest market share in excess of 1/3 for traffic between DEL and BOM ('H1').

Figure 6: Changes in market share on routes



From the top-end it was understandable that less dense routes encountered less competition and that carriers could operate from smaller airports (typically lesser connected spokes) in a relatively uncontested way: in general, airlines' market shares for 'SS' and 'sh=1' would increase over time. However, such a trend was more evident with 'low-cost'entrants where market shares had increased the most for such less dense routes. As for the incuments, their respective share seemed more volatile experiencing important drops in 2010. By 2014 market shares on spoke-spoke routes ('SS') for carriers AI and 9W (at 85% and 80% respectively) stood above those of entrants. For 'sh=1' no significant differences could be observed across the airlines; in general they remained in a bandwidth between 50% to 60%.

An asymmetric pattern can be observed with regards to vertical links between hubs and multi-link spokes ('HS', 'sh>1'). For one, their curves mostly coincide for entrant airlines '6E', 'SG', 'G8' as well as '9W'. Only for 'AI' (and 'IT' before its demise) can we observe higher market shares for 'HS' as compared to 'sh>1' (upon closer inspection we may find that such 'spread' in market share also had occurred for 'G8' and '9W' by 2014). It is inferred that airlines affected by such 'spread' had likely been operating a comparatively higher proportion of single-link routes in their vertical traffic. The trend in market shares on these vertical routes is clearly positive for '6E' and 'SG', whereas '9W'lost most significantly on market share (from 70% in 2006 down to 40-45% in 2014). 'AI' experienced a very sharp drop by 2010 but improved its share to 36% ('sh>1') and 41% ('HS') by 2014.

The Indian ATS: past, present, future

The Indian domestic ATS was not immune to severe shocks as observed during 2010. By 2014 recuperation to levels of 2006 happened, but only for the top 55 or so airports. Smaller airports actually had to operate with less traffic compared to 2006. This is noteworthy as during the period three airlines which marketed themselves as 'low-cost' had entered the market. Operations of Kingfisher and its disappearance after 2012 had been a contributing factor to these structural changes in the Indian ATS.

All airlines (including IT) showed a clear and time-sustained pattern of spatial organisation around the same few airports, most notably DEL and BOM. This behaviour is even more remarkable for 'low-cost' entrants than incumbents. The structurally dominant role of both airports for Indian ATS was not truly altered during the period although its market share did come down moderately. Summary data for international connectivity from India mostly confirmed this finding. The Indian ATS from a more deconstructed viewpoint was found to operate distinctly and highly dense 'horizontal' traffic among the same top-6 airports. This suggested enhanced collective behaviour of the same (rather than competition) which would also translate into their respective 'vertical' relationships with spoke airports. Spoke airports would hasten to add links to more top airports over time. Horizontal spoke-to-spoke traffic remained relatively little and showed much lower frequencies as compared to the spokes' vertical traffic.

Clearly, capacity investment of Indian airlines was made at the top designed to trickle down and to expand in a hub-spoke fashion. The surprising fact is that over the period all of the carriers would focus on the same two airports together with very high densities to the other top airports ('horizontal' links) making competition prohibitively costly. As a consequence no real spatial segmentation for the airlines' networks could be observed during the observation period. These observations were reckoned to result in gravely sub-optimal allocation of capacity at both the top (oversupply around top airports) and at the lower end of the Indian ATS (too few spoke airports and relatively low market shares for airlines operating on thinner routes, including 'SS'). Given the mechanics of Indian ATS development, future traffic growth would be expected to happen at the already well served routes with smaller airports only benefitting from limited ‘trickle-down’ effects.

To conclude with the comparison made with China at the beginning of this paper: during the same period the country had permitted more entry and showed more airlines with better defined roles and less mimicry in their behaviour. This also translated into better segmented spaces of operation with major airlines creating their own hubs at separate airports. Other carriers (‘Low-cost’, Regional, etc.) had to adapt to a growing ecosystem of China’s ATS that was continuously created by China’s ‘Big Three’. Collective behaviour between the biggest carriers translated into enabling growth through the establishment of other carriers’ hub operations and by funnelling own high density traffic into these new hubs in a sequential manner.

References:

Albert R. and Barabási A.L.: Statistical mechanics of complex networks. Reviews of Modern Physics 74 (Jan.), 47-97 (2002)

Alderighi, M., Cento, A., Nijkamp, P., Rietveld, P.: Network competition – the coexistence of hub-and-spoke and point-to-point systems. Journal of Air Transport Management 11 (5), 328-334 (2005)

Alderighi, M., Cento, A., Nijkamp, P., Rietveld, P.: Assessment of new hub-and-spoke and point-to-point airline network configurations. Transport Reviews 275, 529-549 (2007)

Borenstein, S.: Hubs and High Fares: Dominance and Market Power in the U.S. airline industry. Rand Journal of Economics 20 (3), 344-365 (1989)

Brueckner J.K. and Spiller P.T.: Economies of Traffic Density in the Deregulated Airline Industry. Journal of Law and Economics, 37 (2), 379-415 (1994)

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

Derudder, B., Witlox, F.: Mapping world city networks through airline flows: context, relevance, and problems. Journal of Transport Geography 16 (5), 305-312 (2008)

Derudder, B., Witlox, F.: The impact of progressive liberalization on the spatiality of airline networks: a measurement framework based on the assessment of hierarchical differentiation. Journal of Transport Geography 17, 276-284 (2009)

Graham, B., Goetz, A.R.: Global air transport. In: Knowles, R., Shaw, J.,Docherty, J. (Eds.), Transport Geographies – Mobilities, Flows and Spaces. Blackwell, Oxford (2008)

Huber, H.: Comparing spatial concentration and assessing relative market structure in air traffic. Journal of Air Transport Management 15, 184-194 (2009)

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

Huber, H.: Network Structure, Capacity Growth and Route Hierarchies: The case of China's Air Traffic System revisited. Working paper, Indian Institute of Management- Ahmedabad, WP2015-04-03 (2015)

Jin F., Wang F. and Liu Y.: Geographic patterns of air passenger transport in China 1980-1998: Imprints of economic growth, regional inequality and network development. The Professional Geographer, 56 (4), 471-487 (2004)

Martin, J.C., Voltes-Dorta, A.: A Note on How to Measure Hubbing Practices in Airline Networks. Transportation Research E 45, 250-254 (2009)

Reynolds-Feighan, A.J.: Traffic distribution in low-cost and full-service carrier networks in the US air transportation market. Journal of Air Transport Management 7 (5), 265-275 (2001)

Reynolds-Feighan, A.J.: Airport competing terminals: recent developments at Dublin airport. In: Forsyth, P., Gillen, D., Müller, J., Niemeier, H.J. (Eds.), Airport Competition : The European Experience. Ashgate Publishing, Berlin (2010)

Reynolds-Feighan A.: Characteristics of airline networks: A North American and European Comparison. Journal of Air Transport Management 16, 121-126 (2010)

Rishikesha, T.K.: The Indian Airline Industry in 2008. Case study, Indian Institute of Management-Bangalore, http://www.iimb.ernet.in/~rishi/Indian%20Airline%20Industry%20in%202008%20v2.0.pdf (2008). Accessed 15 October 2015

Shaw, S., Lu, F., Chen, J., Zhou, C.: China's airline consolidation and its effects on domestic airline networks and competition. Journal of Transport Geography 17, 293-305 (2009)

Zhang, Y.: Network Structure and capacity requirement: The case of China. Transportation Research Part E, 46, 189-197 (2010)

Table 3: Decomposition of India's ATS & changes, summary (Jan.'06 vs. Jan.'14)

		AP	OD_h	OD_v	FRE_h	FRE_v	FRE/ODh	FRE/ODv	MS_dom*	OD_int	FRE_int	FRE/OD_in	MS_int*
Hub_1	Jan.'14	2	10	78	10,735	15,648	1,074	201	30.9%	101	9,310	92	44.6%
(BOM, DEL)	Chg.'06	0.0%	0.0%	41.8%	45.6%	108.5%	45.6%	47.0%	-6.0%	23.2%	74.6%	41.8%	-9.9%
Hub_2	Jan.'14	2	10	34	8,040	5,227	804	154	15.5%	29	2,016	70	9.7%
(BLR, HYD)	Chg.'06	0.0%	0.0%	78.9%	51.9%	252.5%	51.9%	97.0%	-1.2%	20.8%	129.4%	89.8%	0.7%
Hub_3	Jan.'14	2	10	36	6,878	6,336	688	176	15.5%	37	3,514	95	16.8%
(MAA, CCU)	Chg.'06	0.0%	0.0%	24.1%	77.6%	255.8%	77.6%	186.6%	1.5%	48.0%	92.5%	30.1%	-1.8%
Sub-Total_1	**Jan.'14**	**6**	**30**	**148**	**25,653**	**27,211**	**855**	**184**	**61.9%**	**167**	**14,840**	**89**	**71.1%**
Hub-spokes	**Chg.'06**	**0.0%**	**0.0%**	**43.7%**	**55.1%**	**152.7%**	**55.1%**	**75.8%**	**-5.7%**	**27.5%**	**84.7%**	**44.9%**	**-11.1%**
Sub-Total_2	**Jan.'14**	**26**	**11**	**26**	**849**	**2,599**	**77**	**100**	**4.0%**	**4**	**419**	**105**	**2.0%**
single Lk-Spoke	**Chg.'06**	**-10.3%**	**-26.7%**	**-10.3%**	**0.4%**	**19.0%**	**36.8%**	**32.7%**	**-3.5%**	**0.0%**	**222.3%**	**222.3%**	**0.7%**
Sub-Total_3 (*)	**Jan.'14**	**38**	**73**	**120**	**4,707**	**24,408**	**64**	**203**	**34.1%**	**97**	**5,621**	**58**	**26.9%**
multi Lk-Spokes	**Chg.'06**	**40.7%**	**97.3%**	**69.0%**	**223.1%**	**183.7%**	**63.7%**	**67.9%**	**9.2%**	**64.4%**	**247.8%**	**111.6%**	**10.4%**
of which spokes	Jan.'14	7	25	39	1,835	10,750	73	276	14.7%	43	2,561	60	12.3%
w. 5 or 6 links	Chg.'06	250.0%	150.0%	290.0%	447.8%	535.7%	119.1%	63.0%	12.4%	115.0%	282.2%	77.8%	9.1%
Total_1+2+3	***Jan.'14***	***70***	***114***	***294***	***31,209***	***54,218***	***274***	***184***	***100%***	***268***	***20,880***	***78***	***100%***
	Chg.'06	**12.9%**	**39.0%**	**44.8%**	**65.6%**	**151.5%**	**19.1%**	**73.7%**	**0.0%**	**38.1%**	**113.5%**	**54.5%**	**0.0%**

* Chg. MS in absolute value