Network Structure and Airline Scheduling with Asymmetric Travel Demand*

Wakako MANTANI**

Abstract

This paper provides an analysis of the impact of airlines' withdrawal from local service on scheduling, traffic, price and aircraft size. It considers the suspension of local route operation by a monopoly airline that changes the network structure from fully-connected to hub-and-spoke. The main finding is that hub-and-spoke networks are preferable from the standpoint of social welfare when travel demand of local routes is low, when flights are expensive to operate, and when passengers place a high value on flight frequencies. However, when the local travel demand is similar to that of urban routes, the fully-connected systems are chosen by a social planner.

Keywords: Network Structure, Airline Scheduling, Aviation Policy, Asymmetric Demand

JEL Classification Numbers: D42, L52, L93

* I would like to show my sincere acknowledgements to Junichiro Ishida, Noriaki Matsushima, Shigeharu Nomura, Eiichi Kido, Nobuo Akai and David Flath who read and commented on my draft.

** Student of Graduate School of Management, Kyoto University.

1. Introduction

After deregulation in the late 1980's, rivalry in the Japanese airline industry became fierce. Airlines radically improved their service patterns, introduced new pricing systems and expanded their aircraft fleets. Japanese airlines have continued to withdraw flights from unprofitable domestic routes, mainly service between local communities. This move toward abandoning unprofitable routes accelerated after the year of 2000, when the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) deregulated airfares and began to allow free entry and exit in the domestic market.

The question I address is how suspension of a local route by a monopoly airline affects scheduling, traffic, price and aircraft size in the asymmetric travel demand case, if it changes the network structure from fully-connected to hub-and-spoke network. While there is a large theoretical literature exploring the differences between fully-connected and hub-and-spoke networks, only a few theoretical papers, Berechman and Shy (1998), Brueckner and Zhang (2001), Wojahn (2001), Brueckner (2004) analyze scheduling decisions in the monopoly case.

My analysis is based on Brueckner (2004) but differs in its treatment of demand. In Brueckner's model, demand is identical in all markets under both the fully-connected and hub-and-spoke networks. To better reflect the realities of the Japanese market, the present analysis assumes less demand for local routes than for trunk routes, reflecting the fact that in Japan the population of rural areas is small and their demand much less compared to urban areas such as Haneda (Tokyo) airport and Itami (Osaka) airport. Moreover, in this analysis numerical exercise is presented aimed at comparing the effects of the exogenous parameters.

The main finding is that hub-and-spoke networks are preferable from the standpoint of social welfare when travel demand of local route is low, when flights are expensive to operate, and when passengers place a high value on flight frequencies but are not excessively inconvenienced by the extra travel time required for a connecting trip. This is mostly consistent with the analysis of Brueckner. However, we extend his analysis to case of asymmetric demand, and show that the fully-connected networks are socially preferable if fixed costs and variable costs are small and the local travel demand is close to that of the urban routes. The airline has a tendency to adopt a hub-and spoke system when the demand for urban and local routes is asymmetric, but consumers generally prefer the fully-connected networks. Only if the cost of layover time is moderately small, does the hub-and-spoke network attain greater consumer surplus.

Frequency, traffic volume, and price are highest on the urban route of hub-and-spoke network. Frequency and price move together because the passengers' willingness to pay for air travel rises with frequency. Airline chooses larger aircraft for the urban routes of the hub-and-spoke network and smaller aircraft for the local route under the fully-connected network. In addition, airlines face a trade-off in that a local route is more productive and stimulates greater flight frequency if it is part of a fully-connected network, but demand for it will be greater and the price higher if it is not part of a fully-connected network.

Moving to a hub-and-spoke system enables carriers to reduce operating cost by exploiting "economies of density". Such economies arise from networks that bundle small traffic flows onto routes that would otherwise require smaller aircraft with higher cost per seat-km. Caves, Chistensen, and Tretheway (1984) and Brueckner, Dyer, and Spiller (1992) provide empirical evidence of the economies of density in airline networks, and Hendricks, Piccione, and Tan (1995) show that economies of density can explain why the hub-and-spoke system is the optimal. When Hendricks *et alia* compare a fully-connected network and hub-and-spoke network, they find that the hub-and-spoke network is preferable if marginal costs are high, and demand is low. However, if there are substantial fixed costs and only modest variable costs, the fully-connected system is preferable.

As of the third quarter of 2009, Japan Airlines has suspended six unprofitable domestic routes and All Nippon Airways has suspended eleven. Residents of those regions will have to connect to their ultimate destinations via hub cities, or choose alternative modes of transportation. In compensation, for the inconvenience this will impose, airlines have begun to offer discount fares for connections that include soon-to-be suspended routes.[1)] These issues have been controversial since Japan Airlines, which is in the throes of a financial crisis and has filed for protection under the government's reconstruction with new management, has announced that it will terminate at least 29 more domestic routes by 2011 and the local governments that subsidize local airport facilities severely oppose such termination of operations, arguing that airlines should "serve the public". Policy implications are later discussed in chapter 6 from my findings to maximize the social welfare.

2. Model Setup

Let me first introduce the notation used below. Hereafter, superscript F refers to the fully-connected-network, while H refers to the hub-and-spoke network. The subscript u refers to the urban route (AH, BH), and subscript l refers to the local route (AB).

Consider a monopoly airline that serves three cities, A, B, and H, as shown in Figure 1. Demand for travel exists between each pair of cities, yielding three city pair markets, AH, BH, and AB. Suppose that the AH and BH routes are "urban", and the AB route is "local".

My analysis focuses on the demand for one-way travel in a single direction in each market. In a fully-connected network, the airline operates flights between each pair of cities, and nonstop travel occurs in the AB market. After the airline suspends operation along the local route AB, the network structure becomes hub-and-spoke. Direct flights are available only on the two urban routes, AH and BH, while AB (local) passengers must make a connecting trip via the hub city H.

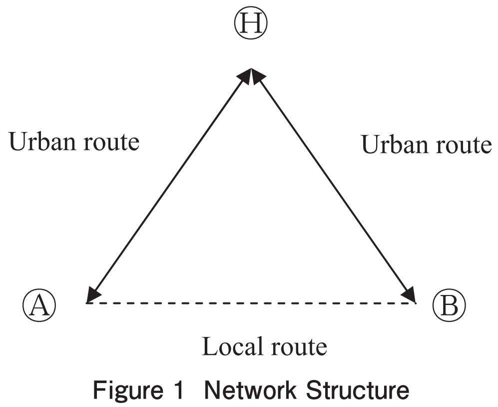

Figure 1 Network Structure

1) All Nippon Airways introduced new "Discount fare on select flights for connections" (or Noritugi Tokuwari) for the specific routes including local suspended routes in April 2008.

Travel demand is identical for the AH and BH city pair markets (urban routes), and the AB market (local route) has less demand, which is independent of AH and BH.

Consumer utility is given by

$$u = C + B - timecost, \tag{1}$$

where C is consumption, and B is travel benefit, which varies across consumers. Each consumer has a cost of actual travel time which equals to G for nonstop travel between any pair of cities. In addition, travelers incur costs of schedule delay caused by discrepancy between their preferred and actual departure times. Suppose that consumers' preferred departure times are uniformly distributed around the clock and that each hour of discrepancy generates a schedule-delay cost of δ. To derive the cost of schedule delay, suppose that airline flights are evenly spaced around clock, with T denoting the number of available hours. Letting f ($f>0$) denote the number of flights, the time interval between flights is T/f, the average time to the nearest flight is a quarter of this value, $T/4f$. Then, the average schedule-delay cost is $\delta T/4f$. The schedule delay cost is a decreasing function of f. Assuming this average value is relevant for each hour consumer, then utility equals

$$u = C + B - G - \delta T/4f\,. \tag{2}$$

The assumption is that consumers pay attention to *average* schedule delay and they know their preferred departure times when committing to travel as well as the frequency of available flights, but they may not know the exact departure times.

To derive the demand curve, let Y denote the common level of consumer income and p denote the airfare,

$$C = Y - p\,. \tag{3}$$

Assuming that no benefits are enjoyed when a consumer does not travel, and the utility from this option is Y. As a result, a consumer will undertake travel when

$$Y - p + B - G - \delta T/4f \geq Y\,, \tag{4}$$

or when travel benefit satisfies

$$B \geq p + G + \delta T/4f\,. \tag{5}$$

Then, suppose that B (which is consumer-specific) has a uniform distribution with support $[\underline{B}, \overline{B}]$ and density,

$$\eta_u = \frac{1}{(\overline{B} - \underline{B})}, \eta_l = \frac{\phi}{(\overline{B} - \underline{B})}, \qquad (1 > \phi) \tag{6}$$

implying that density of the local route is less than that of the urban route.[2] The number of consumers traveling equals

2) This set up is different from Brueckner (2004).

$$q_i^j = \int_k^{\overline{B}} \eta_i dB = (\overline{B} - p_i^j - G - \delta T/4 f_i^j)\eta_i, \quad i = u, l,\ j = F, H,\ k = p_i^j + G + \delta T/4 f_i^j,\ i \neq j \neq k. \tag{7}$$

The inverse demand curve, which comes from solving (2) for p, is given by

$$p_i^j = \alpha - \beta_i q_i^j - \gamma/f_i^j, \quad i = u, l,\ j = F, H,\ i \neq j. \tag{8}$$

where $\alpha = \overline{B} - G$, $\beta_i = 1/\eta_i$, $\gamma = \delta T/4$ and $\beta_l > \beta_u > 0$. From this setting, by reducing average schedule delay, an increase in flight frequency induces more consumers to travel, leading to an upward shift in the inverse demand function.

For local passengers in a hub-and-spoke network, an additional time cost G for connection as well as the cost of layover time are imposed. Denote the sum of these costs[3] by μ, and let the demand for travel for those consumers be $\alpha - \mu$ and not α. The layover portion of μ is taken to be independent of flight frequency f. The inverse demand curve for local passengers in a hub-and-spoke leads to

$$P_l^H = \alpha - \mu - \beta_l q_l^H - \gamma/f_u^H. \tag{9}$$

Let s (>0) denote the number of seats per flight, which is a choice variable for the airline. Then, the operating cost per flight is given by

$$c(s) \equiv \theta + \tau s, \tag{10}$$

where θ (>0) is the fixed cost[4] and τ (>0) is the marginal cost per seat.[5] Given (10), cost per seat equals $\theta/s + \tau$, a decreasing function of s. Although this cost formulation is not entirely realistic, it captures the economies from operating larger aircraft in the simplest possible fashion. I shall assume that the layover portion minus variable cost ($\mu - \tau$) is positive, $\mu - \tau > 0$.

Final assumption is that all aircraft seats are filled, with the load factor[6] equal to 100 percent. Under this assumption, f, q and s are related by the equation

$$s_i^j = q_i^j / f_i^j, \quad i = u, l,\ j = F, H,\ i \neq j. \tag{11}$$

In other words, on a given route, seats per flight must equal total passengers divided by the number of flights. The analysis would be unaffected if the load factor were fixed at a value realistically less than 100 percent.

3. Analysis of the Fully-Connected Network (The airline provides the local services, AB)

To analyze the effect of route suspensions, I develop the fully-connected solution as a benchmark case. The first step is to set up the assumptions on airline cost. Note that using (10) and (11), total

3) For connecting passengers, the following costs are imposed: extra hour in scheduled travel time, probability of missing connections or late arrival, and probability of baggage mishandling.
4) Fixed costs include aircraft, certain maintenance items, marketing and sales, as well as other costs of maintaining, operating an integrated network system, including a substantial ground side infrastructure.
5) Variable costs include fuel, labor and materials costs.
6) Load factor is the ratio of seat miles sold to seat miles actually flown.

cost per route is $fc(s)$, which in turn equals $f_i^j[\theta+\tau(q_i^j/f_i^j)]$.
Simplifying this, cost can be written

$$fc(s)=\theta f_i^j+\tau q_i^j\,,\ \ i=u,l\,,\ \ j=F,H\,,\ \ i\neq j \tag{12}$$

or fixed cost per flight (θ) times flight frequency (f_i^j) plus variable cost per passenger (τ) times total passengers (q_i^j). Denote urban traffic volume for routes AH and BH by q_u^F, and local traffic volume for route AB by q_l^F. Note that q_u^F and q_l^F will not be equal, $q_u^F>q_l^F$. Total airline cost is $\theta(2f_u^F+f_l^F)+\tau(2q_u^F+q_l^F)$.
The fare for the urban routes (AH, BH) is

$$p_u^F=\alpha-\beta_u q_u^F-\gamma/f_u^F\,. \tag{13}$$

The fare for the local route (AB) is

$$P_l^F=\alpha-\beta_l q_l^F-\gamma/f_l^F\,. \tag{14}$$

Using (11), aircraft size is

$$s_i^F=q_i^F/f_i^F\,,\ \ i=u,l\,. \tag{15}$$

Recalling that the airline operates three nonstop routes in the fully-connected case and using (12), (13), and (14), profit then equals

$$\pi^F=2q_u^F(\alpha-\beta_u q_u^F-\gamma/f_u^F)+q_l^F(\alpha-\beta_l q_l^F-\gamma/f_l^F)-2(\theta f_u^F-\tau q_u^F)-\theta f_l^F-\tau q_l^F\,. \tag{16}$$

Here f is treated as a continuous variable, an approach that only makes sense if the number of flights is large. The first-order conditions for choice of q_u^F and q_l^F lead to,

$$\alpha-2\beta_u q_u^F-\gamma/f_u^F-\tau=0\,, \tag{17}$$

$$\alpha-2\beta_l q_l^F-\gamma/f_l^F-\tau=0\,. \tag{18}$$

Also, the first-order conditions for choice of f_u^F and f_l^F lead to,

$$q_u^F\gamma/f_u^{F2}-\theta=0\,, \tag{19}$$

$$q_u^F\gamma/f_l^{F2}-\theta=0\,. \tag{20}$$

The first condition says that the number of passengers is set optimally when marginal revenue as a function of q_i^j equals the marginal cost of a seat, τ. The second condition says that flight frequency f is set optimally, holding total traffic fixed, when fixed cost per flight (θ) equals the revenue gain from an extra flight, which is given by passengers q_i^j times the fare increase per passenger ($q_u^F\gamma/f_u^{F2}$, $q_u^F\gamma/f_l^{F2}$) made possible by greater flight frequency. Note that, with q_i^j and f determined by (17), (18), (19) and (20), the optimal aircraft size (s_i^F) can be recovered from (15). Rewriting (17) and (18),

$$q_u^F = \alpha - \tau - \gamma / f_u^F / 2\beta_u , \quad q_u^F > q_l^F , \tag{21}$$

$$q_l^F = \alpha - \tau - \gamma / f_l^F / 2\beta_l . \tag{22}$$

Eliminating q_u^F and q_l^F in (19) and (20), using (21) and (22), and then rearranging, the following condition determining f emerges:

$$2\beta_u \theta f_u^{F3} / \gamma = (a - \tau) f_u^F - \gamma , \tag{23}$$

$$2\beta_l \theta f_l^{F3} / \gamma = (a - \tau) f_l^F - \gamma . \tag{24}$$

This condition is shown in Figure 2, where the S-shaped curve is the graph of the cubic expression on the left-hand side and the line represents the right-hand side. Note that since $\alpha - \tau$ must be positive for (23) and (24) to hold, the line is necessarily upward sloping. The figure shows the economically relevant case where (23) and (24) have three distinct solutions. Other possibilities include the case of no positive real solutions (where the line lies below the curve everywhere in the first quadrant), and the case of two repeated positive solutions (where the line is tangent to the curve in the first quadrant). Note that the latter case can be disrupted, yielding the second case, by a slight parameter change. The following result identifies the optimum:

Lemma. *The second positive solutions of the urban and local route under fully-connected network in Figure 2 represent the optimum. The second-order condition for the airline's optimization problem holds at these solutions, being violated at the first positive solutions.*

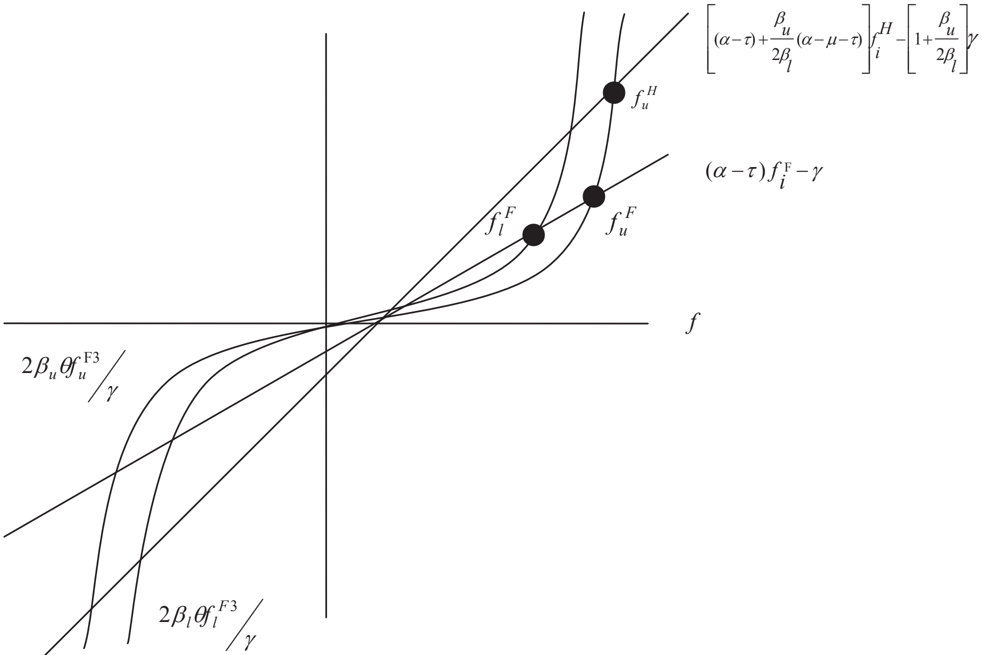

Figure 2 The f solutions

The Lemma, as well as all subsequent results, is proved in the appendix of Mantani (2010).

Most of the results can be derived by inspection of Figure 2, and a full statement of the comparative-static results is as follows:

Proposition1. *Flight frequency f rises when demand increases (when α rises or β falls), when fixed or variable cost falls (when θ or τ falls), and when the disutility from schedule delay rises (when γ rises). Traffic q moves in step with flight frequency, except that it responds ambiguously to an increase in γ.*

4. Analysis of the Hub-and-Spoke Network (Only urban routes are available and local route does not exist)

When the airline stops local operations between AB cities, as shown in Figure 1, the network structure changes from a fully-connected network to a hub-and-spoke network. In this case, a carrier combines passengers from city A and B onto the urban routes AH and BH, and thereby increases the average number of passengers on those routes, so revenue from the routes increases and operating cost per flight decreases.

Flight frequency on each of the urban routes is denoted f_u^H, urban traffic volume (AH, BH) is denoted q_u^H, and connecting traffic volume (AB) is denoted q_l^H. Note that q_u^H and q_l^H will not be equal from the assumption of demand.

Following previous studies, let us presume that pricing for connecting travel in hub-and-spoke networks is set independently of fares for existing routes, AH and BH, so that the fare for the connecting passengers (AB) is not simply the sum of the two routes, AH and BH. But because of arbitrage, the connecting air fare must be cheaper than two route tickets, which is written $p_l^H < 2p_u^H$. Under these assumptions, the urban fare in a hub-and-spoke network is given by,

$$p_u^H = \alpha - \beta_u q_u^H - \gamma / f_u^H \ . \tag{25}$$

The connecting fare (AB) is given by,

$$P_l^H = \alpha - \mu - \beta_l q_l^H - \gamma / f_u^H \ . \tag{26}$$

Since the connecting passenger must travel through the hub city H, passenger volume on each route (AH and BH) is $q_u^H + q_l^H$, and yielding aircraft size, $s_u^H = (q_u^H + q_l^H) / f_u^H$. Total airline costs are $2\theta f_u^H + \tau(2q_u^H + q_l^H)$. With the airline earning revenue from two markets and from the local route, hub-and-spoke (urban network) profit is

$$\pi^H = 2q_u^H\left(\alpha - \beta_u q_u^H - \gamma / f_u^H\right) + q_l^H\left(\alpha - \mu - \beta_l q_l^H - \gamma / f_u^H - \tau\right) - 2\tau q_u^H - 2\theta f_u^H \ . \tag{27}$$

The first-order conditions for choice of q_u^H, q_l^H, and f_u^H are

$$\alpha - 2\beta_u q_u^H - \gamma / f_u^H - \tau = 0 \, , \tag{28}$$

$$\alpha - \mu - 2\beta_l q_l^H - \gamma / f_u^H - \tau = 0, \tag{29}$$

$$\gamma(2q_u^H + q_l^H) / f_u^{H2} - 2\theta = 0. \tag{30}$$

To interpret (30), note that an increase in f_u^F on both routes costs 2θ while allowing a fare increase of γ / f_u^{H2} for $2q_u^H + q_l^H$ passengers, with the loss and gain equated at the optimum. Rewriting (28) and (29) to solve for q_u^H and q_l^H yields,

$$q_u^H = \frac{\alpha - \tau - \gamma / f_u^H}{2\beta_u}, \quad q_u^H > q_l^H, \tag{31}$$

$$q_l^H = \frac{\alpha - \mu - \tau - \gamma / f_u^H}{2\beta_l}. \tag{32}$$

Substituting (31) and (32) into (30) and rearranging yields the condition that determines f_u^H,

$$2\beta_u\beta_l\theta f_u^{H3}/\gamma = [\beta_l(\alpha - \tau) + 1/2\,\beta_u(\alpha - \mu - \tau)]f_u^H - [\beta_l + 1/2\,\beta_u]\gamma. \tag{33}$$

To compare (33) with (23), divide (33) by β_l,

$$2\beta_u\theta f_u^{H3}/\gamma = [(\alpha - \tau) + \beta_u/2\beta_l(\alpha - \mu - \tau)]f_u^H - [1 + \beta_u/2\beta_l]\gamma. \tag{34}$$

For the fully-connected case, this line has the same intercept and different slope, and cubic curve is different since $\beta_l > \beta_u$. The intercept of the hub-and-spoke line is more negative than in the fully-connected case ($\gamma < (1 + \beta_u/2\beta_l)\gamma$), and the relationship among the slopes is ambiguous. Although a comparison among f_u^F, f_l^F and f_u^H might look infeasible under these circumstances, the following result can be established.

Proposition 2. *The qualitative effects of the parameters $\alpha, \beta, \theta, \tau$ and γ on flight frequency and traffic levels in the hub-and-spoke network are the same as in the fully-connected case. In addition, f_u^H, q_u^H, and q_l^H all decline when travel time for connecting passengers rises (when μ increases).*

5. Comparing the Fully-Connected and Hub-and-Spoke Solutions

The primary focus in this analysis is on comparison of fully-connected and hub-and-spoke solutions for flight frequency, traffic volume, productivity, aircraft size and fares.

5.1 Comparison of Flight Frequency

Deregulation in the U.S. allowed better quality of service through increasing flight frequencies.[7] In fact, two thirds of the benefits to passengers from deregulation were from increased frequency of service made possible by the hub-and-spoke route structure.[8] In Japan, Yai, Hirata, and Yamada (2007) refer to the fact that airlines cannot increase flight frequency due to the limitation of slots, a situation without parallel in any other countries, and urge airlines to operate large aircraft such as Boeing 747 and 777 on Japanese domestic routes.

7) See Bailey et al. (1985), Caves et al. (1984), and Hendricks et al. (1995).
8) See Morrison and Winston (1986).

To compare flight frequency between the network types, recall (23), (24), and (33),

$$2\beta_u \theta f_u^{F3} / \gamma = (a-\tau) f_u^F - \gamma, \qquad \text{(fully-connected, urban)}$$

$$2\beta_l \theta f_l^{F3} / \gamma = (a-\tau) f_l^F - \gamma, \qquad \text{(fully-connected, local)}$$

$$2\beta_u \beta_l \theta f_u^{H3} / \gamma = [\beta_l(\alpha-\tau) + 1/2\,\beta_u(\alpha-\mu-\tau)] f_u^H - [\beta_l + 1/2\,\beta_u]\gamma. \qquad \text{(hub-and-spoke)}$$

Comparing (23), (24), and (33), it is clear that, while the intercept of the hub-and-spoke line is more negative than in the fully-connected case, the relationship of the slopes is ambiguous. Although a comparison among f_u^H, f_u^F, and f_l^F might look infeasible under these circumstances, the following result can be established.

***Proposition 3**. Flight frequency is the highest on the urban route of hub-and-spoke network, compared to those of the urban and local routes of the fully-connected network. Under the fully-connected network, flight frequency is higher in the urban route than in the local route, with $f_u^H > f_u^F > f_l^F$.*

5.2. Comparison of Traffic Volume

From the proof of Proposition3, it is clear that $f_u^H > f_u^F > f_l^F$ holds provided that $q_u^H + 1/2\,q_u^H > q_u^F > q_l^F$. To see the underlying intuition, observe that an increase in flight frequency on each route raises passengers' willingness to pay, allowing the fare to be increased. While the higher fare is paid by q_u^F and q_l^F passengers on each fully-connected route, the increase is effectively paid by $q_u^H + 1/2\,q_l^H$ passengers on each hub-and-spoke route (the higher fare is earned across two routes for connecting passengers, so that q_l^H passengers on hub-and-spoke route must be divided by two to put the gain on a per-route basis).

Under the assumption that more passengers are affected ($q_u^H + 1/2\,q_l^H > q_u^F > q_l^F$), the gain from the dollar (yen) fare increase is thus greater in the urban route for the hub-and-spoke case.

The comparison between q_l^F and q_l^H is ambiguous because the numerator term $a-\mu-\tau$ in (32) is less than the analogous term $\alpha-\tau$ in (22), offsetting the difference in flight frequency. While higher frequencies raise the demand for AB (local) travel in the hub-and-spoke case, the longer travel time reduces it, making the net demand shift ambiguous.

5.3 Comparison of Productivity

The productivity of a higher frequency in raising the fare (γ / f_u^{H2}) must be driven lower than in the hub-and-spoke case to equate the over all gain ($\gamma(q_u^H + 1/2\,q_l^H) / f_u^{H2}$) to the marginal flight cost θ.

This can only happen if $f_u^H > f_u^F > f_l^F$, so that the productivity expressions satisfy $\gamma / f_u^{H2}\,(Hub-and-spoke) < \gamma / f_u^{F2}\,(Fully-connected, urban) < \gamma / f_l^{F2}\,(Fully-connected, local)$.

5.4 Comparison of the Aircraft Size

To compare the aircraft size for the two network types and routes, recall that $s_i^j = q_i^j / f_i^j$, $i = u, l$, $j = F, H$, $i \neq j$ and using (12) and (15), $s_i^j = \theta f_i^j / \gamma$.

In the fully-connected case, aircraft size for the AB (local) route $s_l^F = q_l^F / f_l^F = \theta f_l^F / \gamma$, and for the AH and BH (urban) route is $s_u^F = q_u^F / f_u^F = \theta f_u^F / \gamma$ and $f_u^F > f_l^F$. Therefore, $s_u^F > s_l^F$.

In hub-and-spoke, aircraft size for AH, BH(urban) routes is

$$s_u^H = \frac{(q_u^H + q_l^H)}{f_u^H} = \frac{q_u^H + q_l^H}{q_u^H + q_l^H/2} \frac{\theta f_u^H}{\gamma}. \tag{35}$$

Since $f_u^H > f_u^F$, the first ratio term on the right-hand side of (35), exceeds unity and it follows that $s_u^H > s_u^F > s_l^F$, so that the urban route of a hub-and-spoke network has larger aircraft than the urban route of the fully-connected network. In fully-connected network, the urban route has larger aircraft than the local route.

5.5 Comparison of the Fares

A final comparison focuses on the level of fares. After deregulation, average fares have declined in both the U.S. and Japan. Morrison and Winston found that deregulation accounts for about 58 percent of the observed decline in fares in the U.S.. In Japan, under the previous regulations, the Ministry of Transport set fares proportional to the distance without regard to the demand. Taura (2003) reports that in Japan, deregulation led to more intense competition and fare discounting in domestic trunk routes, but not in local routes, and that consumer welfare from local routes actually declined significantly.

To compare fares in each market, recall the traffic volume under fully-connected network (based on the first-order condition for q_u^j and q_l^j),

$$q_u^F = \frac{\alpha - \tau - \gamma / f_u^F}{2\beta_u}, \text{ and } q_l^F = \frac{\alpha - \tau - \gamma / f_l^F}{2\beta_l},$$

it follows that $q_u^F > q_l^F$. Recall traffic volume under hub-and spoke network,

$$q_u^H = \frac{\alpha - \tau - \gamma / f_u^H}{2\beta_u}, \text{ and } q_l^H = \frac{\alpha - \mu - \tau - \gamma / f_u^H}{2\beta_l},$$

it follows that $q_u^H > q_l^H$.

To compare P_u^F and P_u^H, insert q_u^j into fares across the network types,

$$p_u^F = \alpha - \beta_u q_u^F - \gamma / f_u^F = \alpha - \beta_u \left(\frac{\alpha - \tau - \gamma / f_u^F}{2\beta_u}\right) - \gamma / f_u^F = \frac{\alpha + \tau - \gamma / f_u^F}{2} \tag{36}$$

$$p_l^F = \alpha - \beta_l q_l^F - \gamma / f_l^F = \alpha - \beta_l \left(\frac{\alpha - \tau - \gamma / f_l^F}{2\beta_l}\right) - \gamma / f_l^F = \frac{\alpha + \tau - \gamma / f_l^F}{2} \tag{37}$$

$$p_u^H = \alpha - \beta_u q_u^H - \gamma / f_u^H = \alpha - \beta_u \left(\frac{\alpha - \tau - \gamma / f_u^H}{2\beta_u}\right) - \gamma / f_u^H = \frac{\alpha + \tau - \gamma / f_u^H}{2} \tag{38}$$

$$P_l^H = \alpha - \mu - \beta_l q_l^H - \gamma / f_u^H = \alpha - \mu - \beta_l \left(\frac{\alpha - \tau - \gamma / f_u^H}{2\beta_l}\right) - \gamma / f_u^H = \frac{\alpha - \mu + \tau - \gamma / f_u^H}{2}. \tag{39}$$

From this we see that if $f_u^H > f_u^F > f_l^F$, then $p_u^H > p_u^F > p_l^F$. With $q_u^H + \frac{1}{2} q_l^H > q_u^F > q_l^F$, the result $P_u^H > p_u^F > p_l^F$ thus follows, so that the fare in urban markets AH and BH is higher under both hub-and-spoke network and the fully-connected network. Matching the ambiguous comparison of AB (local) traffic levels and fares between the network types, this discussion has established the following results:

Proposition 4. *For the urban routes, traffic in city-pair markets, AH and BH, is higher in the hub-and-spoke network than in the fully-connected network and the local route frequency in the hub-and-spoke network is lower in both AH and BH markets ($q_u^H + \frac{1}{2} q_l^H > q_u^F > q_l^F$). The urban route hub-and-spoke market has the highest fare and the local route fully-connected market is the lowest ($P_u^H > p_u^F > p_l^F$). The comparison of AB (local) traffic levels and fares between the network types is ambiguous ($q_l^F > (<) q_l^H$ and $p_l^F > (<) p_l^H$). Airline chooses larger aircraft for the urban routes of the hub-and-spoke network and smaller aircraft for the local route under the fully-connected network. ($s_u^H > s_u^F > s_l^F$).*

5.6 Numerical Exercise Results

Comparisons of local traffic levels and fares between network types are ambiguous because they depend on exogenous parameters. To show how parameters affect the relative profitability and social welfare of the different networks requires numerical analysis. In conducting this exercise consumer surplus is measured by

$$\beta_i (q_i^j)^2 / 2 , \quad i = u, l , \quad j = F, H , \quad i \neq j . \tag{40}$$

Under the hub-and-spoke network, social welfare (SW^H) is

$$SW^H = \beta_u (q_u^H)^2/2 + \beta_l (q_l^H)^2/2 + 2q_u^H(\alpha - \beta_u q_u^H - \gamma / f_u^H - \tau) + q_l^H(\alpha - \mu - \beta_l q_l^H - \gamma / f_u^H - \tau) - 2\theta f_u^H , \tag{41}$$

Under the fully-connected network, social welfare (SW^F) is

$$SW^F = \beta_u (q_u^F)^2/2 + \beta_l (q_l^F)^2/2 + 2q_u^F(\alpha - \beta_u q_u^F - \gamma / f_u^F - \tau) + q_l^F(\alpha - \beta_l q_l^F - \gamma / f_l^F - \tau) - 2\theta f_u^F - \theta f_l^F . \tag{42}$$

The result of my numerical analysis is that consumer surplus tends to be greater under a fully-connected network because the higher costs of layover time and disutility of connection flights under hub-and-spoke. But airline profit tends to be greater under hub-and-spoke because it enables airlines to reduce costs.

The socially optimal network type depends on the exogenous parameters that determine the demand, the fixed and variable costs, and cost of layover time. See Mantani (2010) for detailed numerical exercise results of the effects of scale of demand for the urban route (β_u), fixed cost per flight (θ) and variable cost per passenger (τ).

6. Policy Analysis

I now turn attention to policy analysis, based on the numerical exercises of the previous section. Let us here posit a social planner with the power to dictate flight frequency and traffic. The planner's goal is to maximize social surplus, which equals total travel benefits of the consumer plus airline profit.

As shown in the results in chapter 5.6, the hub-and-spoke system is socially optimal when travel demand on the local route is low, when flights are expensive to operate, and when passengers place a high value on flight frequencies but are not excessively inconvenienced by the extra travel time required for a connecting trip. However, if fixed costs per flight and variable costs per passenger are small, and the local travel demand is similar to that of urban routes, then the fully-connected system is chosen by a social planner. The analysis also demonstrates the interesting possibility that a social planner might prefer a fully-connected system in some instances in which airline profits are greater under hub-and-spoke. That is a useful premise for considering actual and possible policies, and a premise that I shall adopt.

To increase the profitability to airlines of adopting fully-connected networks, the central government should exempt airlines from certain taxes. In Japan, airlines pay the following taxes: the landing fee, the air navigation service charge for air traffic control, the fuel tax, the fixed property tax for aircrafts and the airport facility charge. For instance, landing fees are imposed on a flat-rate based on the maximum take-off weight, not on the actual weight. It should instead be charged in accordance with seat occupancy and actual weight so that the perceived fixed expense per flight is less for many flights, promoting the adoption of full connectivity. Moreover, the central authority should also take steps to reduce the fixed property tax for aircraft. Such a tax has been levied only by Korea and Japan. Japanese airlines are burdened with especially heavy property tax amounting to as much as one billion yen for the first ten years upon purchase, which is ten times more than that in Korea.[9)]

These tax revenues are collected as "The Airport Development Special Account"[10)] and spent on airport construction and maintenance. At present, there are 98 airports in Japan, many of which were built based on overly optimistic forecasts for travel demand by the central and local governments. These airports are usually classified into two groups, the one administered by the central government and the other by the local governments. The distinction is ambiguous: airports in both categories are operated under the auspices of "The Airport Development Special Account" that charges airlines and consumers, and pays for running the unnecessary airports. The absence of a consistent classification causes diversity of airport administration among the central and local governments and leads to lack of accountability. To lessen these burdens and for the sake of healthier management of airports, formulation of consistent public policies and strategies is indispensable. This would lead to healthy reconsideration of airport-development projects, new subsidy systems and reformation of "The Airport Development Special Account" itself.

To further increase the social welfare, again under the premise that encouraging full-connectivity is on net beneficial, local governments could take steps to increase the demand for travel. An example of such is Ishikawa Prefecture. Beginning in 2003, at the initiative of the governor, the prefecture introduced a "Seating Rate Guarantee System" for Noto Airport. It has succeeded as a promotional and business strategy. As a result of this government initiative, All Nippon Airways (ANA) operates four daily flights (two roundtrips) on its Haneda route. The local government guar-

9) The Scheduled Airlines Association of Japan, "Proposal for Tax Reform (2010)"
10) It was included into "Social Capital Improvement Account" in 2008.

antees the seating rate, giving the airline an incentive for the continuous operation. If the seating rate is under the target rate, the prefecture pays guarantee money to overcome the airline deficit. And if the airline is over the target rate, it pays the local government. In fact, ANA has paid a reward to the local government ever since the program started. This system confirms that proactive public relations targeted at major urban areas can keep the travel demand high and revitalize local areas.

A subsidy system for remote islands to maintain life-line routes in some Okinawa and Hokkaido areas has long existed, and a discount plan for landing fees has been implemented in Yamagata and Hanamaki airports. However, to increase the demand for travel, more efforts by local authorities are needed. Such measures should be based on a long-term outlook, be consistent with the strategies of the central government, and respond to changes in consumers' demand and in airlines' incentives.

7. Conclusions

The novel aspect of this research is that I consider the impact of a monopoly airline's withdrawal from local service operations on scheduling, traffic, price and aircraft size in the asymmetric travel demand case, if it changes its network structure from a fully-connected to a hub-and-spoke network. I extend the research to consider the effects on consumer surplus, airline profitability and social welfare, and suggest policy implications. When the demand for urban and local routes is asymmetric, airline profit tends to be greater if it adopts a hub-and-spoke system while consumer surplus tends to be greater with a fully-connected network. The hub-and-spoke system is socially optimal when travel demand on the local route is low, when flights are expensive to operate, and when passengers place a high value on flight frequencies but are not excessively inconvenienced by the extra travel time required for a connecting trip. However, when fixed costs and variable costs are small, and the local travel demand is similar to that of urban routes, the fully-connected systems are

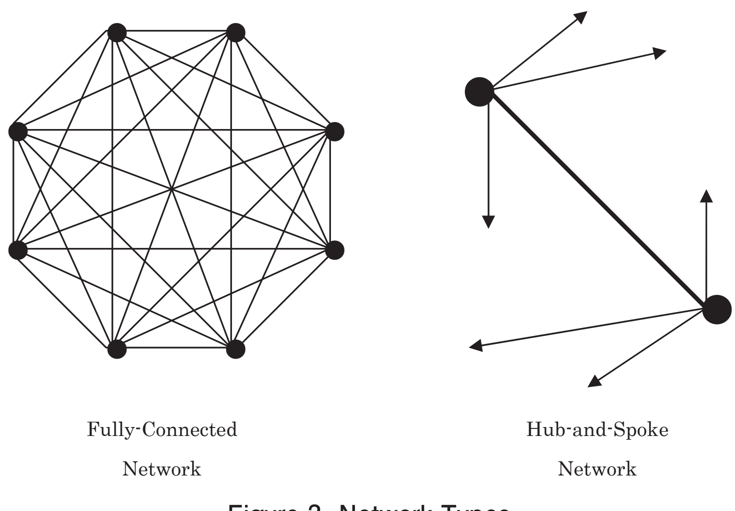

Figure 3 Network Types

chosen by a social planner. Frequency, traffic volume, and price are highest on the urban route of hub-and-spoke network. Frequency and price move together because the passengers' willingness to pay for air travel rises with frequency.

Following deregulation, major U.S. carriers have emphasized connecting service by developing hub-and-spoke operations. Figure 3 describes a network that has 7 destinations. There are 28 operating routes in the fully-connected network, while only one trunk route and 6 local routes are operated in the hub-and-spoke network. By combining passengers with different origins and destinations, a carrier can increase the average number of passengers per flight and thereby reduce costs.

In the U.S., deregulation prompted the growth of hub-and-spoke systems,[11] but in Japan it did not. This is partly because there are fewer airlines in Japan and the Japanese market itself is much smaller than in the U.S.. Also the hub airports (Haneda Airport in Tokyo and Itami Airport in Osaka) are each constrained to a limited number of slots. In fact, no major Japanese airline has yet developed a network from any region other than Tokyo. According to Tozaki (1995), the reasons for these differences included the urban structure of Japan, in which everything is concentrated into Tokyo metropolitan area and there is no political and economic bloc other than Tokyo. Also alternative transportation in the form of shinkansen (bullet train) is available for long distance travel in Japan.

Airlines around the world are encountering a growing wave of liberalization and are facing competitive pressures, both from new entrant low-cost airlines and re-structured legacy carriers, and now we stand on the threshold of a new age inside and outside Japan. Japanese aviation industry has factors that are specific to the country, different from any others, and it has a structure involving public policy, public transportation and airline profit maximization, so that the analyses focusing on the Japanese domestic market would be necessary. Central government needs to build a long-term strategy for civil aviation and it should be in accordance with the particular needs of each individual region. To maximize social welfare, appropriate policy maker and business operations take necessary specific actions such as reduction of the landing fee and exemption of aircraft fuel tax and property tax for aircrafts by government when airlines operate local routes with asymmetric demands. In addition, more efforts by local governments to increase the travel demand are needed. Such measures should be based on a long-term outlook, be consistent with the strategies of the central government, and respond to changes in consumers' demand and airlines' incentives.

The present analysis assumes asymmetric travel demand to better reflect the realities of the Japanese market. It clarifies the differences between networks for optimal choices by consumers, airlines, and for policy makers. This model captures in a simple way nearly all the key elements of an airline optimization problem. For the reasons of tractability, however, it focuses on the monopoly case. It is likely that many of the conclusions would carry over to an oligopoly version of the model. Future research might extend the analysis to consider the effect on international flights, the rivalry among low cost and full service carriers and the optimal subsidy system for airport management. In addition, it remains important to inquire studies regarding budget allocation for airport operations and policy recommendation achievement.

11) See Bailey, Graham and Kaplan (1985), Morrison and Winston (1995) and Berechman and Shy (1998).

References

(1)Bailey, E., Graham, D. and Kaplan, D. (1985). *Deregulating the Airlines (Regulation of Economic Activity)*, Cambridge, Massachusetts, The MIT Press.

(2)Berechman, J., Podder, S. and Shy, O. (1998). "Network Structure and Entry in the Deregulated Airline Industry," *Keio Economic Studies*, Vol.35, pp.71-82.

(3)Berechman, J., and Shy, O. (1998). *The Structure of Airline Equilibrium Networks*, in J.C.J.M. van de Bergh, P. Nijkamp, and P. Rietveld (eds): *Recent Advances in Spatial Equilibrium Modelling*, Berlin, Springer.

(4)Brueckner, J., Dyer, N. and Spiller, P. (1992). "Fare Determination in Airline Hub-and-Spoke Networks," *RAND Journal of Economics*, Vol.23, No.3, pp.309-333.

(5)Brueckner, J. (2004). "Network Structure and Airline Scheduling," *The Journal of Industrial Economics*, Vol.52, No.2, pp.291-311.

(6)Brueckner, J.K, and Flores-Fillol, R. (2007). "Airline Schedule Competition," *Review of Industrial Organization*, Vol.30, pp.161-177.

(7)Brueckner, J.K., and Zhang, A. (2001). "A Model of Scheduling in Airline Networks", *Journal of Transport Economics and Policy*, Vol.35, Part2, pp.195-222.

(8)Caves, D. W., Chistensen, L. R., and Tretheway, M. W. (1984). "Economies of Density versus Economics of Scale: Why Trunk and Local Service Airline Costs Differ," *RAND Journal of Economics*, Vol.15, pp.471-489.

(9)Hendricks, K., Piccione, M. and Tan, G. (1997). "Entry and Exit in Hub-Spoke Networks," *RAND Journal of Economics*, Vol.28, pp.291-303.

(10)Mantani, W. (2010). "*Network Structure and Airline Scheduling with Asymmetric Travel Demand*", Master's Thesis for Osaka School of International Public Policy, Osaka University.

(11)Morrison, S. and Winston, C. (1995). *The Evolution of the Airline Industry*, Washington D.C., The Brookings Institution.

(12)Shy, O. (2001). *The Economics of Network Industries*, New York, Cambridge University Press.

(13)Taura, G. (2005). "Statistical Analysis of Airline Fares After Deregulation [Kakaku Kisei Teppai Go no Koukuu Unchin Settei ni Tuiteno Toukeiteki Bunseki]," *Rikkyo Keizaigaku Kenkyu*, Vol.58, No.4, pp.192-220.

(14)Tozaki, H. (1995). "The Route Structure of Airlines and Community Development [Koukuu Rosen Kouzou to Chiiki Kaihatu]," The Research and Study [*Keizai Ronsou Bessatsu, Chousa to Kenkyu*], Kyoto University, Vol.8, pp.15-24.

(15)Tirole, J. (1988). *The Theory of Industrial Organization*, Cambridge, Massachusetts, The MIT Press.

(16)Wojahn, O. (2000). "The Impact of Passengers' Preferences regarding Time and Service Quality on Airline Network Structure," *Journal of Transport Economics and Policy*, Vol.36, pp.139-162.

(17)Yai, T. Hirata, T. and Yamada, N. (2008). "Airport Capacity Enhancement Measures Considering Air Traffic Control for Aerodrome Traffic," *Journal of Infrastructure Planning and Management D*, Vol.64, No.1, pp.122-133.