TOPIC 8
AVIATION AND AIRPORTS

THE EFFECTS OF LOCAL COMPETITION IN HUB-SPOKE NETWORKS

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Abstract

This paper suggests an explanation for the lack of local competition in airline hub-spoke networks. A negative network effect of local competition is identified: entry into a competitor's local markets may reduce the entry carrier's profit in its own hub-spoke network. As a result, even if a carrier could derive a positive profit from the invaded markets, it would not enter those markets if the negative network effect is sufficiently strong.

Prize

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INTRODUCTION

Airline deregulation in the US has had profound impacts on industry structures and air carriers' route systems. The "effective" number of carriers at the national level has fallen from 8.9 in 1978 to 8.0 in 1988 (Brueckner and Spiller 1994; see also Morrison and Winston 1990). Major carriers have also converted from linear route structures to hub-spoke networks, causing greater carrier concentration at many airports. US Department of Transportation (1990) reports that at 20 of the 27 largest airports in the US, each with annual enplanements exceeding 4.5 million passengers, one or two carriers control 50 percent or more of the departures. By operating separate hub-spoke networks, major carriers compete head-to-head for the traffic between nonhub cities via trans-hub connecting services, but have a local monopoly in the spoke segments from their respective hubs to other nonhub cities in the networks. The situation is sometimes referred to as the "fortress hubs" phenomenon (Huston and Butler 1988). As noted by Borenstein (1992), the fortress hubs have evolved to the point that one airline will generally fly to another airline's hub only from its own hub. United Airlines, for instance, offers nonstop service to Atlanta (Delta Airlines' major hub) only from Denver, Chicago-O'Hare and Washington-Dulles, three of United's four largest hubs.

Recent empirical work by Borenstein (1989), Bailey and Williams (1988), Huston and Butler (1988), Evans and Kessides (1993) and others finds strong evidence that average prices for local traffic to and from hub airports are significantly higher than prices on other routes. This finding is consistent with the observed trend towards increased hub dominance by airlines seeking to capture local monopoly rents. While routes to and from a hub airport are more likely to be non-competitive, routes served on a connecting basis through those same airports are usually competitive (see, for example, Brueckner and Spiller 1994).

Existing explanations for the lack of local competition in airline hub-spoke networks focus on the advantages that dominant airlines have in their local markets. For example, dominant carriers at their hubs can channel traffic from a large number of cities onto a particular spoke segment. An entrant to the segment would be virtually unable to access this traffic and, as a result, would be confined to a small market share (Oum et al. 1995). Brueckner and Spiller (1994) report that the marginal cost of carrying an extra passenger in a high-density network is 13-25 percent below the cost in a medium or low-density network, thereby giving the high-density carrier a distinct cost advantage. McShane and Windle (1989) contain another quantitative study on the (positive) effect of hubbing on airline cost efficiency and competitiveness. They propose a method to quantify the hub-spoke routing at the network level and find that airline costs are reduced by .1 percent for every 1 percent increase in the resulting hub-spoke routing variable. A locally dominant airline can possess other advantages because of such factors as frequent flyer programs, travel agent commission override programs, and control of sunk and scarce airport facilities (Levine 1987; Borenstein 1991, 1992; Kahn 1993). Recently, Hendricks et al. (1995b) offer a very interesting explanation for the lack of local competition by examining the strategic interaction between a "national" hub-spoke carrier and a "regional" carrier who contemplates whether or not to enter a single spoke segment of the national carrier.

In this paper, an alternative explanation for the lack of local competition is presented in the context of two similar carriers who both operate hub-spoke networks. The explanation is based on a "network effect" of invading a competitor's local markets on the profit of *own* hub-spoke network. In particular, we identify a negative network effect of local competition: when the economies of traffic density are important, entry into a competitor's local markets will reduce the entry firm's profit in its own hub-spoke network. Essentially, such entry would make the rival firm behave more aggressively in the connecting market where the two carriers engage in trans-hub competition. This induces own output to fall in that market which in turn raises the marginal cost on own spoke routes and, thus, reduces the traffic throughout own hub-spoke network. The traffic reduction may lower the profit the entry firm can derive from its own network, giving rise to the negative network effect of local entry. Because of this network effect, even if a carrier could derive a positive profit from the invaded local markets, it would not enter those markets if the negative network effect is sufficiently strong.

The second objective of this paper is to point out a welfare result of local competition. The dominance of hubs by single carriers naturally gives rise to questions about the consumer protection, especially for local traffic to/from the hubs on journeys that cannot conveniently be made to, from or via other hubs. Using the simple framework of this paper, we find, somewhat surprisingly, that when the economies of traffic density are important, entry into a competitor's local markets (if such entry does occur) will *reduce* total social surplus. In effect, while such entry benefits both the entry firm and passengers in the local markets where entry occurs, it harms the incumbent hub-spoke carrier as well as connecting passengers and passengers in other local markets so that the net change in total surplus is negative.

The next section sets up the model. Then the following 2 sections examine the network effects of local competition and the impacts on price and welfare. The final section contains concluding remarks.

A NETWORK COMPETITION MODEL

We consider an air transport system that is likely the simplest structure in which the problem can be addressed. The basic model structure is similar to the hub-spoke network model developed by Brueckner and Spiller (1991). There are four cities: H, A, B and K in this system (Figure 1) and, hence, six potential city-pair markets in which passengers originate in one city and terminate in the other. For convenience, we assume that demand is symmetric across city-pairs. Thus, the inverse demand function for the ith city-pair is given by $P_i = D(Q_i)$, with Q_i representing the number of (round-trip) passengers in market i.

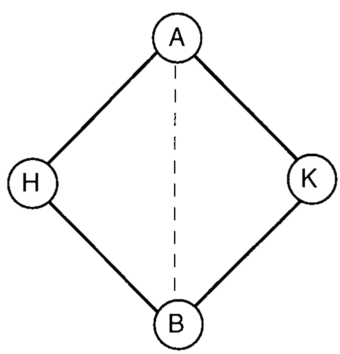

Figure 1 A simple air transport system

Two air carriers serve the system by operating hub-spoke networks. Carrier 1 hubs at H whereas carrier 2 hubs at K, each being the dominant carrier at its hub city. Our base case, referred to as "local monopoly", is one in which the two airlines are monopolists in their respective local markets while competing for the traffic between nonhub cities through trans-hub competition. The carriers also engage in competition for the traffic between hub cities H and K through nonstop service. For the framework used in this paper, competition in this market can be analyzed separately from the other city-pairs and can be ignored without affecting the analysis of the paper. Thus, carrier 1's network consists of A, H and B, whereas carrier 2's network consists of A, K and B. In each network, although there are three city-pair markets, aircraft are flown only on two spoke routes owing to the nature of hub-spoke systems. On a given spoke, say AH, aircraft carry both local (ie AH) passengers and connecting (ie AB) passengers. We use C(Q) to represent a carrier's round-trip cost of carrying Q passengers on a spoke route. This route cost function reflects increasing returns to traffic density, with C(Q) satisfying $C'(Q)>0$ and $C''(Q)<0$ (Caves et al. 1984; Brueckner and Spiller 1994).

Under local monopoly, firm 1's profit may be expressed as (superscript m for local monopoly)

$$\Pi^{1m} = D(Q^1_{AH})Q^1_{AH} + D(Q^1_{BH})Q^1_{BH} + D(Q^1_{AB} + Q^2_{AB})Q^1_{AB} - C(Q^1_{AH} + Q^1_{AB}) - C(Q^1_{BH} + Q^1_{AB})$$

Given the symmetry of the structure, there is a symmetric profit function for firm 2. We consider the equilibrium that arises when each firm chooses its profit-maximizing quantities for each market, taking the quantities of the other firm as given at equilibrium values. (For concreteness we assume that airlines set quantities to maximize their profits. Brander and Zhang (1990) and Oum et al. (1993) find some evidence that rivalry between duopoly airlines is consistent with quantity setting behaviour.) Firm 1's first-order conditions can be written as,

$$D(Q^1_{AH}) + Q^1_{AH}D'(Q^1_{AH}) = C'(Q^1_{AH} + Q^1_{AB}) \quad (1)$$

$$D(Q^1_{BH}) + Q^1_{BH}D'(Q^1_{BH}) = C'(Q^1_{BH} + Q^1_{AB}) \quad (2)$$

$$D(Q^1_{AB}+Q^2_{AB}) + Q^1_{AB}D'(Q^1_{AB}+Q^2_{AB}) = C'(Q^1_{AH} + Q^1_{AB}) + C'(Q^1_{BH} + Q^1_{AB}) \quad (3)$$

In the above equations, marginal revenue in each market is represented by the left-hand side, which is set to equal the marginal cost of serving a passenger in that market. The cost complementarities inherent to a hub-spoke network are evident in these equations. Referring to (1), for example, it is clear that the marginal cost of serving a passenger in the AH market falls when Q^1_{AB} increases. Assuming the second-order conditions for profit maximization, then the system (1)–(3), together with firm 2's first-order conditions, determine the local-monopoly equilibrium quantities.

To assess the effects of local competition in airline networks, the local-monopoly equilibrium will be compared to the equilibrium under a "local competition" structure, where carrier 1 enters its opponent's two local markets, AK and BK. (An alternative way to introduce local competition is for carrier 1 to enter only one local market, eg AK. This will lack the symmetry of the present formulation between AK and BK and add some algebraic complexity, while the basic results of the paper remain unchanged.) The two carriers continue to serve their AHB and AKB networks through respective hubs; consequently, their profit functions can be written as (superscript c for local competition),

$$\begin{aligned}\Pi^{1c} = \; & D(Q^1_{AH})Q^1_{AH} + D(Q^1_{BH})Q^1_{BH} + D(Q^1_{AB}+Q^2_{AB})Q^1_{AB} \\ & + D(Q^1_{AK}+Q^2_{AK})Q^1_{AK} + D(Q^1_{BK}+Q^2_{BK})Q^1_{BK} \\ & - C(Q^1_{AH}+Q^1_{AB}) - C(Q^1_{BH}+Q^1_{AB}) - C(Q^1_{AK}) - C(Q^1_{BK}) \\ \Pi^{2c} = \; & D(Q^1_{AB}+Q^2_{AB})Q^2_{AB} + D(Q^1_{AK}+Q^2_{AK})Q^2_{AK} + D(Q^1_{BK}+Q^2_{BK})Q^2_{BK} \\ & - C(Q^2_{AK}+Q^2_{AB}) - C(Q^2_{BK}+Q^2_{AB})\end{aligned}$$

Again, each firm chooses quantities to maximize its profit, given the quantity choice of its competitor. The forms of first-order conditions for the AH, BH and AB markets remain the same as before, while first-order conditions in the AK market become

$$D(Q^1_{AK}+Q^2_{AK}) + Q^1_{AK}D'(Q^1_{AK}+Q^2_{AK}) = C'(Q^1_{AK}) \quad (4)$$

$$D(Q^1_{AK}+Q^2_{AK}) + Q^2_{AK}D'(Q^1_{AK}+Q^2_{AK}) = C'(Q^2_{AK} + Q^2_{AB}) \quad (5)$$

for carriers 1 and 2, respectively (there are also two symmetric conditions for the BK market). The resulting eight-equation system determines the equilibrium quantities (five variables for carrier 1 and three for carrier 2).

As indicated above, we want to examine the effects of local competition by comparing the solution of local monopoly to the solution of local competition. Unfortunately, such a comparison is intractable unless more structure is imposed on the model. Following Brueckner and Spiller (1991), we assume that both demand and marginal cost functions are linear:

$$D(Q) = \alpha - \frac{Q}{2} \tag{6}$$

$$C'(Q) = 1 - \theta Q \tag{7}$$

where α and θ are positive parameters. α represents the level of demand, whereas θ measures the extent of increasing returns to traffic density, with higher values of θ representing higher degrees of increasing returns.

Given (6) and (7), equilibrium quantities can be explicitly obtained for both local monopoly and local competition. It is noted that under both solutions, an arbitrage condition needs to be imposed under which the fare in the AB market cannot exceed the sum of the separate fares for the two spokes. Otherwise, travellers would have an incentive to purchase the spoke tickets separately. It can be easily verified that this arbitrage condition holds for both solutions. Furthermore, in both cases, the second-order conditions for profit maximization can be shown to reduce to $\theta < 1/3$. In addition, we consider the equilibrium that has positive quantities and positive marginal revenues (marginal costs). This requires that, under local monopoly, $2/(1+\theta) < \alpha < 3/5\theta$ for $0<\theta<1/3$, and under local competition,

$$\frac{2(16\theta - 3)}{10\theta^2 + 15\theta - 3} < \alpha < \frac{68\theta^2 - 60\theta + 9}{\theta(100\theta^2 + 96\theta + 15)} \quad \text{for } 0 < \theta < \frac{1}{6} \tag{8}$$

$$\frac{2(18\theta^2 - 19\theta + 3)}{(5\theta - 1)(4\theta^2 - 3)} < \alpha < \frac{82\theta^2 - 63\theta + 9}{4\theta(25\theta^2 + 21\theta + 3)} \quad \text{for } \frac{3}{14} < \theta \leq \frac{3}{10} \tag{9}$$

$$\frac{2(18\theta^2 - 19\theta + 3)}{(5\theta - 1)(4\theta^2 - 3)} < \alpha < \frac{14\theta - 3}{3(4\theta - 1)} \quad \text{for } \frac{3}{10} < \theta < \frac{1}{3} \tag{10}$$

with no proper bounds for α existing for $1/6 \leq \theta \leq 3/14$. For both $0 < \theta < 1/6$ (referred to as "relatively weak" increasing returns) and $3/14 < \theta < 1/3$ (referred to as "relatively strong" increasing returns), a comparison of the bounds in the two cases reveals that the bounds are tighter under local competition than under local monopoly. Consequently, the bounds given by (8)–(10) will make both the local-monopoly and local-competition solutions proper (and hence comparable). The analysis in what follows will be carried within these bounds.

THE NETWORK EFFECT OF LOCAL COMPETITION

We first state the following result:

Proposition 1

Under local competition, the invading firm

(i) produces less (greater) output

(ii) earns less (greater) profit

in its own hub-spoke network than under local monopoly as increasing returns are relatively strong (weak).

Proposition 1 identifies a "network effect" of local competition: entry into a competitor's local markets may either enhance or harm the entry firm's profit in its own hub-spoke network, depending on the degree of increasing returns. Note that the result is independent of demand level α, however. A look at the proof (given in the Appendix) indicates an explanation for this result. Each network (carrier) offers essentially two products: local and connecting services. When carrier 2's local markets are invaded, its connecting traffic will rise (fall) as increasing returns are relatively strong (weak). This response by the rival carrier has the following consequences for the invading carrier's traffic and profit in its own hub-spoke network. First, it induces the invading carrier's traffic to fall (rise) in the connecting market. Second, referring to (1) and (2), it is clear that lower (higher) connecting traffic leads to an increase (decrease) in marginal cost on the AH and BH legs of the network and thus lowers (raises) local traffic levels for carrier 1. Finally, the change in the invading carrier's profit in its own network is shown to follow the same pattern as its output change in the connecting market.

Thus, when increasing returns are relatively strong, local entry causes the rival firm to behave more aggressively in the connecting market by committing to a higher traffic level, so as to exploit the economies of density. This induces own output to fall in that market which will raise marginal costs on the spoke routes and thus reduce own traffic throughout the network. The reduction in traffic raises marginal costs and lowers the profit which the entry firm can derive from its own network. In these cases, there is a negative network effect of competing in a competitor's local markets. On the other hand, when increasing returns are relatively weak, local entry reduces the rival's output in the connecting market which in turn induces own output and own profit to rise in its network, generating a positive network effect. As many analysts believe that the main reason for hub-spoke networks is the economies of traffic density (see Hendricks et al. 1995a, for a recent formalization of the idea), the circumstances under which local entry causes negative network effects are not unlikely to arise. In our context, it is the negative network effect that is especially interesting.

Our negative network effect is similar in spirit to a result obtained by Judd (1985), in which entering a rival firm's market (and thus producing a second product) may reduce the entry firm's profit in its primary product if the two products in question are substitutable. With the products being substitutes, some consumers may switch to the second product as the duopoly competition in that market drives down its price. In our case, however, the products (ie travel in different city-pairs) are *not* substitutable and the result arises instead through the cost complementarities of hub-spoke networks as well as the economies of traffic density.

The negative network effect identified above, however, does not imply that an airline would necessarily not invade the other airline's local markets. To show that the negative network effect can indeed prevent local entry, we must examine the overall profit effect of local competition.

More specifically, assuming that carrier 1 incurs no costs in association with its entry into carrier 2's local markets, then it can be easily shown that carrier 1 will earn strictly positive profits from the invaded markets. Thus if there were no negative network effects, entry by carrier 1 would be profitable. With the presence of negative network effects, however, the carrier must weigh the profit gain from the invaded markets against the profit loss from its AHB network to determine the overall desirability of local entry. From Proposition 1, this involves a comparison of its total profits between the local-monopoly and local-competition equilibria when increasing returns are relatively strong (ie when $3/14 < \theta < 1/3$).

The result of this comparison is given in Figure 2. The upper and lower lines in the diagram show the α-bounds given by (9) and (10) that guarantee proper solutions. The intermediate curve demarcates the regions where the invading firm (carrier 1) earns greater profits under local monopoly and under local competition respectively. This intermediate curve is determined by setting $\Pi^{1c} = \Pi^{1m}$. It can be seen from the diagram that local competition reduces the invading firm's total profit when $3/14 < \theta \leq 0.226$. For $\theta > 0.226$, it reduces the invading firm's total profit when demand is relatively high, leading to Proposition 2.

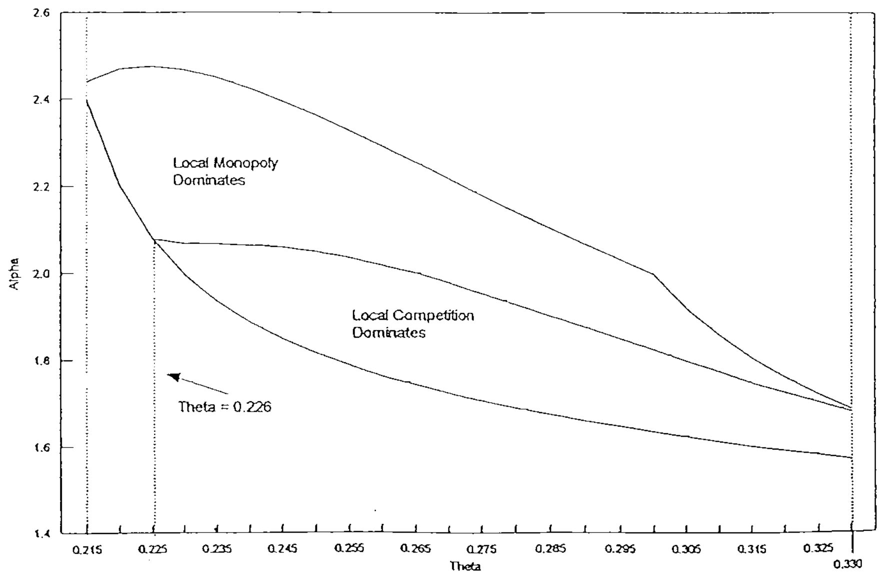

Figure 2 The effect of local competition on the invading firm's profit

Proposition 2

The negative network effect identified in Proposition 1 can prevent an airline from competing in the rival airline's local markets.

Proposition 2 shows that the negative network effect can indeed prevent an airline from competing in a competitor's local markets. In these situations, given the network structure of the other carrier, neither carrier has an incentive to enter the other's local markets, so the local monopoly structure ("fortress hubs") remains as an equilibrium outcome. This suggests that the negative network effect identified in this paper may serve as one of the potential sources of a dominant airline's localized market power.

PRICE AND WELFARE COMPARISONS

The dominance of hubs by single carriers has recently raised concerns about the consumer protection, especially for local traffic at the hubs. In this section, we examine the effects of local competition on consumer surplus and total social surplus. We have the following result (the proof is given in the Appendix):

Proposition 3

Under local competition in markets AK and BK,

(i) traffic levels in AK and BK are higher and fares are lower

(ii) traffic levels are lower (higher) and fares are higher (lower) in markets AH and BH as increasing returns are relatively strong (weak)

(iii) traffic is lower and fare is higher in the AB market

than under local monopoly.

Proposition 3 suggests that while competition in markets AK and BK benefits local AK and BK passengers, it may impose negative externalities for passengers outside of those markets. Brueckner and Spiller (1991) have examined the impact of competition in a single market served by a monopoly hub-spoke airline on the fares in all other monopoly markets in the network. They find that such competition is likely to increase the fares in the monopoly markets owing to the cost complementarities of hub-spoke networks. The second part of Proposition 3 is similar to their result, while the third part shows that local competition can further impose negative externalities for the *connecting* passengers who have already faced head-to-head competition between the two carriers.

Next, we examine the effect of local competition on total social surplus. It is worth noting that when increasing returns are relatively weak (ie $\theta < 1/6$), local competition increases the invading firm's profit (Proposition 1) and can be shown to raise both total consumer surplus and total social surplus, independent of the demand level. On the other hand, when increasing returns are relatively strong (ie $\theta > 3/14$), entry into a competitor's local markets will harm the invading firm's profit in its own hub-spoke network, and this negative network effect may or may not prevent local competition. Figure 2 has shown that for $\theta > 0.226$ and relatively low levels of demand, local competition will occur as the invading firm's profit gain from the invaded markets dominates the profit loss from its own network. We point out, however, that while such competition generates a private gain to the invading firm (as well as gains to the AK and BK passengers), overall it is socially undesirable.

To show this, we add the net change in consumer surplus to the change in profits of both carriers to determine the overall welfare impact of local competition. The total surplus calculation thus involves subtracting total airline costs from the sum of the areas under the demand curves in the five city-pair markets. The result of this calculation is given in Figure 3 for the case of relatively strong increasing returns $3/14 < \theta < 1/3$. The upper and lower lines in the diagram again show the α-bounds that guarantee proper solutions. The intermediate curve demarcates the regions where local monopoly and local competition are respectively superior in terms of total social surplus. As can be seen from the diagram, local competition reduces total surplus so long as $\theta > 0.223$. Consequently, for all the cases where the invading firm's profit gain from the invaded markets dominates the profit loss from its own network and, hence, entry occurs, the resulting local competition is actually welfare reducing.

The intuitive explanation behind this result is as follows. For the regions (α, θ) where firm 1's total profit rises after entry, local competition reduces firm 2's traffic throughout its network, which raises firm 2's marginal costs and lowers its profit. The fall in firm 2's profit is sufficiently large to offset the gain by firm 1 so that the change in total producer surplus is negative. Furthermore, as discussed above, for the regions (α, θ) under consideration, local competition, while benefiting AK and BK passengers, imposes negative externalities for passengers outside of the AK and BK markets so the net change in consumer surplus may be negative. (The change in total consumer surplus can be shown to follow a pattern similar to Figure 3, with the intermediate curve being further outward.) These effects are combined to give rise to the negative welfare result.

CONCLUDING REMARKS

This paper adopts a multiproduct and network approach to oligopolistic competition between airlines operating hub-spoke networks. The paper suggests an explanation for the well-known "fortress hubs" phenomenon in deregulated airline markets. The lack of local competition may simply be a result of the nature of airline hub-spoke network rivalry with the cost complementarities and economies of traffic density inherent to such networks. The paper also shows that whether local competition will reduce or increase total social surplus in general depends on the degree of increasing returns to traffic density. When increasing returns are relatively weak, local competition tends to increase total surplus. On the other hand, when increasing returns are relatively strong, local competition tends to reduce total surplus. This suggests that a careful examination of the extent of increasing returns may be warranted when one examines the welfare impacts of local competition in hub-spoke networks.

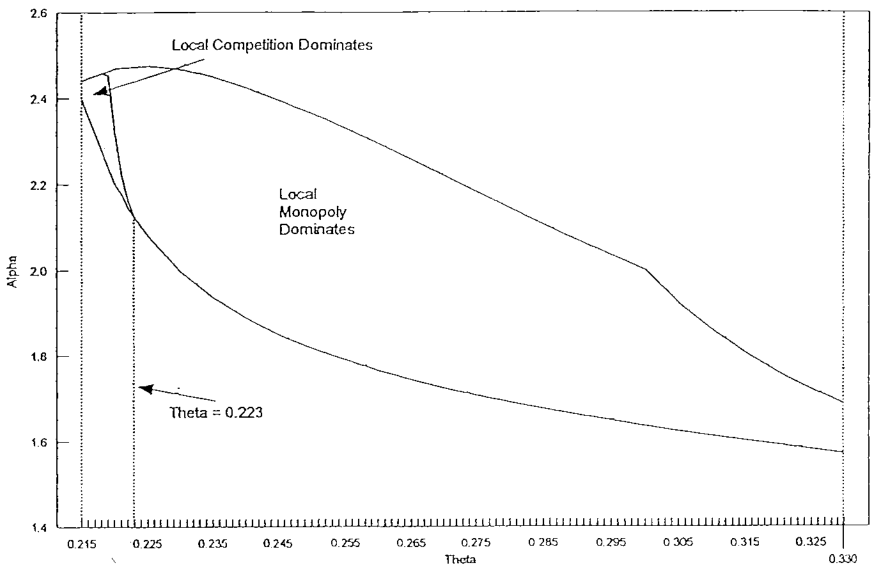

Figure 3 The effect of local competition on welfare

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REFERENCES

Bailey, E.E. and Williams, J.R. (1988) Sources of economic rent in the deregulated airline industry, *Journal of Law and Economics* 31, 173-202.

Borenstein, S. (1989) Hubs and high fares: dominance and market power in the US airline industry, *Rand Journal of Economics* 20, 344-365.

Borenstein, S. (1991) The dominant-firm advantage in multiproduct industries: evidence from the US airline industry, *Quarterly Journal of Economics* 106, 1237-1266.

Borenstein, S. (1992) The evolution of US airline competition, *Journal of Economic Perspectives* 6, 45-74.

Brander, J.A. and Zhang, A. (1990) Market conduct in the airline industry: an empirical investigation, *Rand Journal of Economics* 21, 567-583.

Brueckner, J.K. and Spiller, P.T. (1991) Competition and mergers in airline networks, *International Journal of Industrial Organization* 9, 323-342.

Brueckner, J.K. and Spiller, P.T. (1994) Economies of traffic density in the deregulated airline industry, *Journal of Law and Economics* 37, 379-415.

Caves, D.W., Christensen, L.R. and Tretheway, M.W. (1984) Economies of density versus economies of scale: why trunk and local service airline costs differ, *Rand Journal of Economics* 15, 471-489.

Evans, W.N. and Kessides, I. (1993) Localized market power in the US airline industry, *Review of Economics and Statistics* 75, 66-75.

Hendricks, K., Piccione, M. and Tan, G. (1995a) The economics of hubs: the case of monopoly, *Review of Economic Studies* 62, 83-99.

Hendricks, K., Piccione, M. and Tan, G. (1995b) Entry and exit in hub-spoke networks, mimeo.

Huston, J.H. and Butler, R.V. (1988) The effects of fortress hubs on airline fares and service: the early returns, *Logistics and Transportation Review* 24, 203-215.

Judd, K. (1985) Credible spatial competition, *Rand Journal of Economics* 16, 153-166.

Kahn, A.E. (1993) The competitive consequences of hub dominance: a case study, *Review of Industrial Organization* 8, 381-405.

Levine, M.E. (1987) Airline competition in deregulated markets: theory, firm strategy, and public policy, *Yale Journal on Regulation* 4, 393-494.

McShane, S. and Windle, R. (1989) The implications of hub-and-spoke routing for airline costs and competitiveness, *Logistics and Transportation Review* 25, 309-330.

Morrison, S.A. and Winston, C. (1990) The dynamics of airline pricing and competition, *American Economic Review (Papers and Proceedings)* 80, 389-393.

Oum, T.H., Zhang, A. and Zhang, Y. (1993) Inter-firm rivalry and firm-specific price elasticities in deregulated airline markets, *Journal of Transport Economics and Policy* 27, 171-192.

Oum, T.H., Zhang, A. and Zhang, Y. (1995) Airline network rivalry, *Canadian Journal of Economics*, forthcoming in the November issue.

US Department of Transportation (1990) Secretary's task force on competition in US domestic airline industry, Industry and route structure, US Department of Transportation, Washington, DC.

APPENDIX

This appendix provides the proofs of Propositions 1 and 3. The equilibrium quantities are: under the local-monopoly structure,

$$Q_{AH}^{1m} = Q_{BH}^{1m} = Q_{AK}^{2m} = Q_{BK}^{2m} = \frac{(3-2\theta)\alpha - 3}{3-7\theta} \quad (A1)$$

$$Q_{AB}^{1m} = Q_{AB}^{2m} = \frac{2(1+\theta)\alpha - 4}{3-7\theta} \quad (A2)$$

and under the local-competition structure,

$$Q_{AH}^{1c} = Q_{BH}^{1c} = \left(\left(40\theta^3 - 108\theta^2 + 66\theta - 9\right)\alpha + 68\theta^2 - 60\theta + 9\right)/D \quad (A3)$$

$$Q_{AB}^{1c} = 2\left(\left(-20\theta^3 + 4\theta^2 + 15\theta - 3\right)\alpha + 36\theta^2 - 38\theta + 6\right)/D \quad (A4)$$

$$Q_{AK}^{1c} = Q_{BK}^{1c} = 2\left(\left(-60\theta^2 + 27\theta - 3\right)\alpha + 70\theta^2 - 29\theta + 3\right)/D \quad (A5)$$

$$Q_{AK}^{2c} = Q_{BK}^{2c} = 2\left(\left(20\theta^3 - 30\theta^2 + 21\theta - 3\right)\alpha + 6\theta^2 - 17\theta + 3\right)/D \quad (A6)$$

$$Q_{AB}^{2c} = 2\left(\left(-20\theta^3 - 20\theta^2 + 21\theta - 3\right)\alpha + 64\theta^2 - 44\theta + 6\right)/D \quad (A7)$$

with $D \equiv 140\theta^3 - 204\theta^2 + 81\theta - 9$. Since local competition lacks the symmetry of local monopoly, its solution is more complex.

Proof of Proposition 1

We start the proof with a result on the effect of local competition on carrier 2's connecting output. Using (A2) and (A7), it can be calculated that

$$\Delta Q_{AB}^{2} \equiv Q_{AB}^{2c} - Q_{AB}^{2m} = 8\theta(1-3\theta)\left[3(1-4\theta)\alpha - (3-14\theta)\right]/(3-7\theta)D$$

Notice both $1-3\theta$ and $3-7\theta$ are positive. Using the bounds (8)–(10), one can easily show that the bracketted term is also positive, so the sign of ΔQ_{AB}^{2} is the same as the sign of D. Since D is positive for $3/14 < \theta < 1/3$ and negative for $0 < \theta < 1/6$, carrier 2 produces greater (less) output in the AB market under local competition than under local monopoly as increasing returns are relatively strong (weak).

This result has important implications for the invading firm's traffic and profit in its own network. Consider first the connecting market where the two carriers engage in interhub competition. In this market, carrier 1's "best" output (ie output level that maximizes carrier 1's profit) depends on carrier 2's output. This best-response function has the same form for both local monopoly and local competition and can be obtained from (1)–(3) as

$$Q_{AB}^{1} = -\frac{1-\theta}{2(1-3\theta)} Q_{AB}^{2} + \frac{(1+\theta)\alpha - 2}{1-3\theta}$$

Apparently, carrier 1's best response to the competitor's higher output is to deliver less output. Given $Q_{AB}^{1m} = Q_{AB}^{2m}$, the result on ΔQ_{AB}^{2} will then imply that when increasing returns are relatively strong (weak), carrier 1 delivers less (greater) output in the AB market under local competition than under local monopoly. The outcomes will in turn affect carrier 1's output decisions on its spoke routes. Referring to (1) and (2), it is clear that lower (higher) AB traffic leads to an increase (decrease) in marginal cost on the AH and BH legs of the network and thus lowers (raises) AH and BH traffic levels for carrier 1.

As for the effect of local competition on carrier 1's profit in its AHB network, it can be calculated that

$$\Delta\Pi^{1}_{AHB} \equiv \Pi^{1c}_{AHB} - \Pi^{1m}_{AHB} = (x\alpha + y)\Delta Q^{2}_{AB} / (3 - 7\theta)D$$

where $x \equiv -140\theta^4 + 76\theta^3 + 108\theta^2 - 69\theta + 9$ and $y \equiv 266\theta^3 - 391\theta^2 + 159\theta - 18$. Using the bounds (8)–(10), one can show that the term $x\alpha + y$ has the same sign as D; consequently, $\Delta\Pi^{1}_{AHB}$ has the same sign as ΔQ^{2}_{AB}. Using the result on ΔQ^{2}_{AB} leads to the second part of Proposition 1. Q.E.D.

Proof of Proposition 3

The second part of the proposition follows directly from Proposition 1. Now consider the first part. In the AK market, total traffic is $Q^{c}_{AK} \equiv Q^{1c}_{AK} + Q^{2c}_{AK}$ under local competition whereas it is $Q^{m}_{AK} \equiv Q^{2m}_{AK}$ under local monopoly. From (A1), (A5) and (A6),

$$\Delta Q_{AK} \equiv Q^{c}_{AK} - Q^{m}_{AK} = (-46\theta^2 + 25\theta - 3)[3(1 - 4\theta)\alpha - (3 - 14\theta)]/(3 - 7\theta)D$$

Since $-46\theta^2 + 25\theta - 3 < 0$ and > 0 for $\theta < 1/6$ and $\theta > 3/14$ respectively, ΔQ_{AK} is positive for all θ (recall that D is positive for $\theta > 3/14$ and negative for $\theta < 1/6$). Hence, $P^{c}_{AK} < P^{m}_{AK}$.

Finally, consider the AB market. Proposition 1 has shown that local competition increases one carrier's traffic while simultaneously decreasing the output of the other. Whether the connecting passengers are better off depends on the effect of local competition on total AB traffic. Let $Q^{c}_{AB} \equiv Q^{1c}_{AB} + Q^{2c}_{AB}$ and $Q^{m}_{AB} \equiv Q^{1m}_{AB} + Q^{2m}_{AB}$ be total traffic in the AB market. Using (A2), (A4) and (A7), we can calculate

$$\Delta Q_{AB} \equiv Q^{c}_{AB} - Q^{m}_{AB} = 4\theta(1 - 5\theta)[3(1 - 4\theta)\alpha - (3 - 14\theta)]/(3 - 7\theta)D$$

which is negative for all θ. Consequently, $P^{c}_{AB} > P^{m}_{AB}$. Q.E.D.