An Analysis of Fortress Hubs in Airline Networks

By Anming Zhang*

1. 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-and-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 per cent or more of the departures. By operating separate hub-and-spoke networks, major carriers compete head-to-head for the traffic between non-hub cities via trans-hub connecting services, but have a local monopoly in the spoke segments from their respective hubs to other cities in the networks. The situation is sometimes referred to as the "fortress hubs" phenomenon (Levine, 1987; Huston and Butler, 1988; Tretheway and Oum, 1992). As noted by Borenstein (1992), the fortress hubs have evolved to the point where one airline will generally fly to another airline's hub only from its own hub. United Airlines, for instance, offers non-stop service to Atlanta (Delta Airlines' major hub) only from Denver, Chicago-O'Hare and Washington-Dulles, three of United's four largest hubs.[1]

Although a number of papers have investigated the dramatic growth of hub-and-spoke systems under deregulation,[2] theoretical analysis of the fortress hubs phenomenon is relatively rare. Existing explanations for the lack of local competition in hub-and-spoke networks focus on the advantages that dominant airlines have in their local markets. For

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[1] 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 fortress hubbing 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).

[2] Recent theoretical work includes, for example, Hendricks *et al.* (1995a) and Oum *et al.* (1995).

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 per cent below the cost in a medium- or low-density network, thereby giving the high-density carrier a distinct cost advantage.[3] A locally dominant airline can possess other advantages because of such factors as frequent flyer programmes, 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-and-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 hub-and-spoke carriers. By operating separate hub-and-spoke networks, the carriers compete for the connecting traffic while each decides whether or not to enter its competitor's local markets. The explanation is based on a "network effect" of invading a competitor's local markets on the profit of one's *own* hub-and-spoke network. In particular, a negative network effect of local competition is identified: 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-and-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-and-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 were sufficiently strong. In these situations, therefore, the fortress hubs structure is an equilibrium outcome. In effect, it is further shown that fortress hubbing (that is, not entering the rival's local markets) can be each carrier's dominant strategy.

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 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, it is found (somewhat surprisingly) that when the economies of traffic density are important, the fortress hubs structure yields *higher* total social surplus than a structure of reciprocal local entry by hub-and-spoke carriers. Essentially, with the presence of strong increasing

[3] McShane and Windle (1989) contains another quantitative study on the (positive) effect of hubbing on airline cost efficiency and competitiveness. Their paper proposes a method to quantify the hub-and-spoke routing at the network level and finds that airline costs are reduced by 0.1 per cent for every 1 per cent increase in the resulting hub-and-spoke routeing variable.

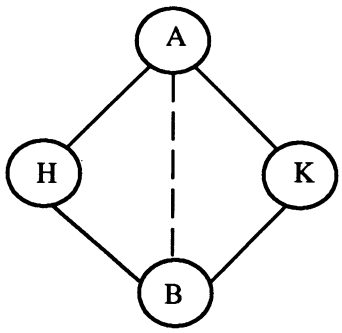

Figure 1
A Simple Air Transport System

returns, while local entry (if such entry does occur) benefits both the entry firm and passengers in the local markets where entry occurs, it may harm the incumbent hub-and-spoke carrier and passengers in other markets so that the net change in total surplus is negative.

Section 2 sets up the model. Section 3 examines the network and welfare effects of local competition, focusing on the case of a carrier's unilateral local entry. The possibility of fortress hubbing as a dominant strategy in airlines' rivalry is examined in Section 4. Section 5 contains concluding remarks.

2. The Model

We consider an air transport system that is likely to be the simplest structure in which the problem can be addressed. The basic model structure is similar to the hub-and-spoke network model developed by Brueckner and Spiller (1991). There are four cities: H, A, B and K in this system (see 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.

Two air carriers serve the system by operating hub-and-spoke networks. Carrier 1 hubs at H whereas carrier 2 hubs at K, each being the dominant carrier at its hub city. The base case, referred to as a fortress hub, is one in which the two airlines are monopolists in their respective local markets while competing for the traffic between non-hub cities through trans-hub competition.[4] 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-and-spoke

[4] The carriers also engage in competition for the traffic between hub cities H and K through non-stop service. For the framework used in this paper, competition in this market can be analysed separately from the other city-pairs and can be ignored without affecting the analysis of the paper.

systems. On a given spoke, say AH, aircraft carry both local (that is, AH) passengers and connecting (that is, AB) passengers. $C(Q)$ is used 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).

Each carrier may choose either to enter the other carrier's two local markets, denoted $e^i = 1$ (e for entry), or not to enter the other carrier's local markets, denoted $e^i = 0$.[5] In the event of local entry, the two carriers continue to serve their AHB and AKB networks through their respective hubs. Consequently, for each strategy profile (e^1,e^2) their profit functions may be expressed as:

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

where Q^i denotes firm i's output vector.

Given each of the four network configurations (e^1,e^2), we consider the equilibrium that arises when each firm chooses its profit-maximising quantities for each market, taking the quantities of the other firm as given at equilibrium values.[6] In the case of fortress hubs $(e^1 = e^2 = 0)$, for example, 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 in a hub-and-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.[7] Assuming the second-order conditions for profit maximisation, then equations (1) -(3), together with firm 2's first-order conditions, determine the fortress-hubs' equilibrium quantities.

[5] An alternative way to introduce local competition is for a carrier (Firm 1, say) to enter only one local market (for example, AK). This would 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.

[6] For concreteness we assume that airlines set quantities to maximise their profits. Brander and Zhang (1990, 1993) and Oum *et al.* (1993) find some evidence that rivalry between duopoly airlines is consistent with quantity setting behaviour.

[7] The external effect within hub-and-spoke networks is tested empirically in Brueckner *et al.* (1992), which demonstrates that the cost-reducing effect of networks indeed shows up in airfares.

To assess the effects of local competition in airline networks and to find the equilibrium entry strategy, the equilibriums under the four network configurations are compared to one another. Unfortunately, such comparisons are in general 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:

$$D(Q) = \alpha - (Q/2) \tag{4}$$

$$C'(Q) = 1 - \theta Q \tag{5}$$

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 equations (4) and (5), equilibrium quantities can be explicitly obtained for all four network configurations.[8] In all four cases, the second-order conditions for profit maximisation can be shown to reduce to $\theta < 1/3$. In addition, we consider the equilibrium that has both positive quantities and positive marginal revenues (marginal costs).

3. The Effects of Local Entry

In this section, the fortress hubs equilibrium is compared to the equilibrium under a "local invasion" structure, where Carrier 1 (say) unilaterally enters its opponent's local markets (AK and BK). The local invasion structure thus corresponds to $(e^1,e^2) = (1,0)$. The network and welfare effects of local competition can be clearly demonstrated through such a comparison. As indicated, the comparison is carried for equilibriums that have both positive quantities and positive marginal revenues (marginal costs). This requires that, under fortress hubs, $2/(1+\theta) < \alpha < 3/5\theta$ for $0 < \theta < 1/3$, and under local invasion,

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

$$\frac{2(18\theta^2-19\theta+3)}{(5\theta-1)(4\theta^2-3)} < \alpha < \frac{82\theta^2-63\theta+9}{4\theta(25\theta^2-21\theta+3)} \text{ for } \frac{3}{14}<\theta\le\frac{3}{10}, \tag{7}$$

$$\frac{2(18\theta^2-19\theta+3)}{(5\theta-1)(4\theta^2-3)} < \alpha < \frac{14\theta-3}{3(4\theta-1)} \text{ for } \frac{3}{10}<\theta\le\frac{1}{3}, \tag{8}$$

with no proper bounds for α existing for $1/6 \le \theta \le 3/14$. 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 invasion than under fortress hubs. Consequently, the bounds given by expressions (6)-(8) will make both the fortress hubs and local invasion solutions proper (and hence comparable). The following analysis will be within these bounds.

[8] It is noted that under these 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 in all four cases.

3.1 The network effect

We first state the following result:

Proposition 1:

Under local invasion, the invading firm (i) produces less (greater) output, and (ii) earns less (greater) profit, in its own hub-and-spoke network than under fortress hubs 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-and-spoke network, depending on the degree of increasing returns. (Note that the result is independent of demand level α, however.) 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-and-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 invasion 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-and-spoke networks is the economies of traffic density,[9] the circumstances under which local entry causes negative network effects are not unlikely to arise. In the present 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 in demand. 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 (that is, travel in different city-pairs) are *not* substitutes and the result arises instead through the cost complementarities of hub-and-spoke networks as well as the economies of traffic density.

[9] For a recent formalisation of this idea, see Hendricks *et al.* (1995a).

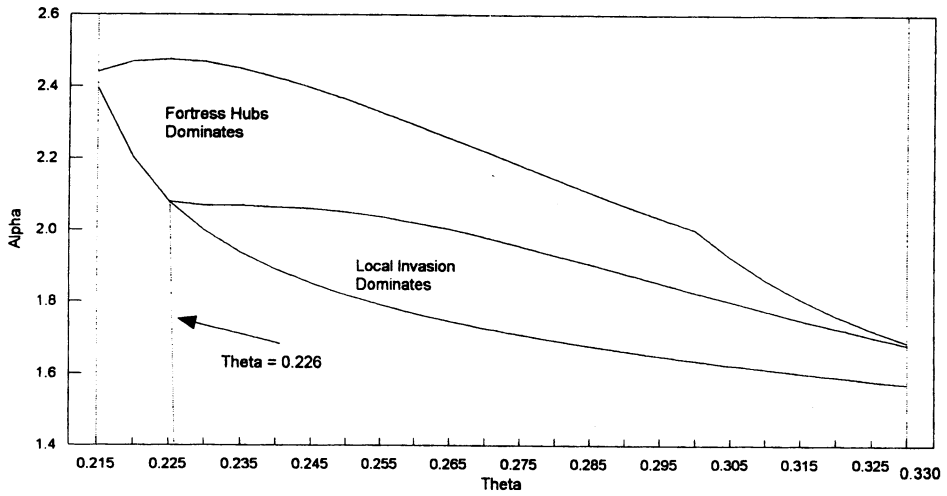

Figure 2
The Effect of Local Invasion on the Invading Firm's Profit

3.2 Total profit comparison

The negative network effect identified above, however, does not necessarily imply that an airline would 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, it can easily be 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 invasion. From Proposition 1, this involves a comparison of its total profits between the fortress hubs and local invasion equilibriums when increasing returns are relatively strong (that is, 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 expressions (7) and (8) that guarantee proper solutions. The intermediate curve demarcates the regions where the invading firm (carrier 1) earns greater profits under fortress hubs and under local invasion respectively. This intermediate curve is determined by setting equilibrium profits $\Pi^1(1,0) = \Pi^1(0,0)$. It can be seen from the diagram that local invasion 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.

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 fortress hubs structure remains as a Nash 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 localised market power.

3.3 Price and welfare comparisons

The dominance of hubs by single carriers has recently raised concerns about consumer protection, especially for local traffic at the hubs. Below, the effects of local invasion on consumer surplus and total social surplus is examined.

Proposition 3:
Under local invasion 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), and (iii) traffic is lower and fares are higher in the AB market, than under fortress hubs.

The proof of this result is in the Appendix. 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 those markets. Brueckner and Spiller (1991) have examined the impact of competition in a single market served by a monopoly hub-and-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-and-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, the effect of local invasion on total social surplus is examined. It is worth noting that when increasing returns are relatively weak (that is, $\theta < 1/6$), local invasion 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 (that is, $\theta > 3/14$), unilateral entry into a competitor's local markets will harm the invading firm's profit in its own hub-and-spoke network, and this negative network effect may or may not prevent such entry. Figure 2 has shown that for $\theta > 0.226$ and relatively low levels of demand, local invasion 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.

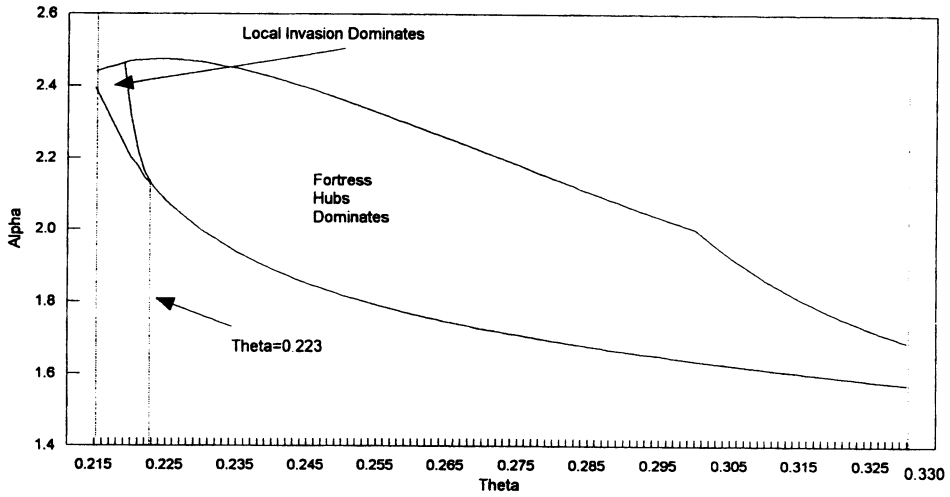

Figure 3
The Effect of Local Invasion on Welfare

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 invasion. 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 fortress hubs and local invasion are respectively superior in terms of total social surplus. As can be seen from the diagram, local invasion reduces total surplus as 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 invasion 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 invasion, while benefiting AK and BK passengers, imposes negative externalities for passengers outside the AK and BK markets so that 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 combine to give rise to the negative welfare result.

4. Fortress Hubbing as a Dominant Strategy

What happens if both carriers contemplate local entry? The two carriers face similar incentives. In this section we examine the non-cooperative Nash equilibrium in local entry in which each firm is assumed to choose its entry strategy given the entry strategy of the other firm. Since we have analysed the effect of unilateral entry, we now need to examine a carrier's response when its local markets are invaded. The carrier must decide whether or not to retaliate by entering the competitor's local markets. Specifically, we compare the local retaliation equilibrium under $(e^1,e^2) = (1,1)$ with the non-retaliation equilibrium under $(e^1,e^2) = (0,1)$. It can be verified that the bounds of expressions (6)-(8) will make both the local retaliation and non-retaliation solutions proper (and thus make all four network equilibriums comparable).

The result of this comparison for the retaliating firm's total profit is given in Figure 4 when $3/14 < \theta < 1/3$ (that is, when increasing returns are relatively strong). The upper and lower lines in the diagram again show the α-bounds that guarantee proper solutions, whereas the intermediate curve demarcates the regions where the retaliating firm (Carrier 1) earns greater profits under local retaliation and under non-retaliation respectively. It can be seen from the diagram that local retaliation reduces Carrier 1's total profit when $3/14 < \theta \leq 0.250$. For $\theta > 0.250$, it reduces Carrier 1's total profit when demand is relatively high. More importantly, a comparison of Figure 2 and Figure 4 reveals that the region where Firm 1's profit falls following local invasion strictly contains the region where firm 1's profit falls following local retaliation. Since the main reason for the total profit reduction is the negative network effect of local entry, this suggests that the network effect is even stronger (more negative) for local retaliation than for local invasion. Furthermore, for the regions (α,θ) where local invasion reduces Firm 1's profit, not entering the competitor's local markets is the dominant strategy for each airline, leading to:

Proposition 4:
For the regions (α,θ) where local invasion reduces the invading firm's total profit, as shown in Figure 2, fortress hubbing is each airline's dominant strategy.

Proposition 4 shows that when increasing returns are relatively strong and demand is relatively high, fortress hubbing is an airline's dominant strategy and, thus, the fortress hubs structure is the dominant strategy equilibrium. This is a stronger result than Proposition 2 which implies, for the same regions (α,θ), that fortress hubbing is a carrier's best strategy so long as the other carrier also adopts fortress hubbing. This suggests that fortress hubs may simply be a consequence of the nature of airline hub-and-spoke network rivalry with the cost complementarities and economies of traffic density inherent to such networks.

Apparently, for the regions (α,θ) where local retaliation raises the retaliating firm's total profit, as shown in Figure 4, local entry is each firm's dominant strategy. In effect, local entry is also each firm's dominant strategy when increasing returns are relatively weak (that is, when $\theta < 1/6$). Using the term "reciprocal local entry" to describe the situation in which each firm enters each other's local markets, we state the following result:

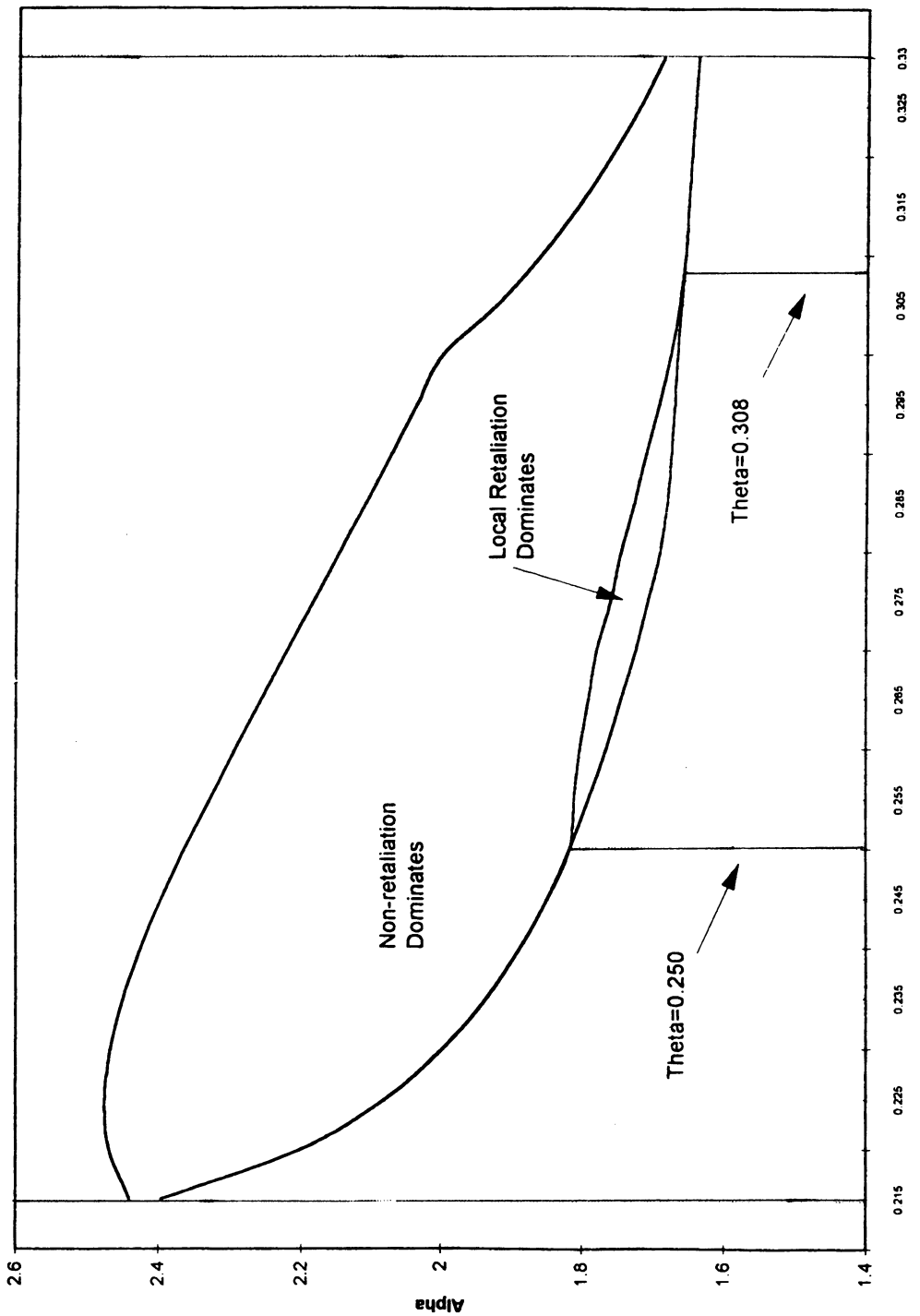

Figure 4
The Effect of Local Retaliation on the Retaliating Firm's Profit

Proposition 5:
(i) Reciprocal local entry is the dominant strategy equilibrium for the regions (α,θ) where local retaliation raises the retaliating firm's total profit, as shown in Figure 4, or for relatively weak increasing returns. (ii) Each firm earns greater profit under fortress hubs than under reciprocal local entry. (iii) For the regions (α,θ) specified in (i), rivalry in local entry results in a Prisoners' Dilemma for airlines.

The proof of parts (i) and (ii) is given in the Appendix. Part (iii) is a direct consequence of parts (i) and (ii): for the regions (α,θ) under consideration, although entry into a competitor's local markets is a dominant strategy for both firms, both are worse off under reciprocal local entry than under fortress hubs. The situation is a classic Prisoners' Dilemma; as such, there exists an incentive for fortress hubbing.[10] However, part (ii) of Proposition 5 ensures that the conflicting incentive does not exist for the case of fortress hubs: when fortress hubbing is the dominant strategy, both firms are strictly better off under fortress hubs than under reciprocal local entry.

Finally, it can easily be shown that when increasing returns are relatively strong (that is, $\theta > 3/14$), total surplus is lower under reciprocal local entry than under fortress hubs. (The intuitive explanation for this result is similar to the one given in Section 3.) With high θ, therefore, the reciprocal local entry equilibrium is socially sub-optimal and a move to fortress hubs would actually improve welfare. On the other hand, when increasing returns are sufficiently weak, namely, $\theta < 0.126$, total surplus is higher under reciprocal local entry than under fortress hubs. For intermediate degrees of increasing returns $0.126 \leq \theta < 1/6$, reciprocal local entry yields higher (lower) total surplus when demand is relatively low (high). Thus, whether local competition raises or lowers total surplus can critically depend on how important increasing returns to route traffic density are.

5. Concluding Remarks

This paper adopts a multiproduct and network approach to oligopolistic competition between airlines operating hub-and-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-and-spoke network rivalry with the cost complementarities and economies of traffic density inherent in such networks. In particular, 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-and-spoke network. The paper also shows that whether local competition in airline hub-and-spoke networks 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-and-spoke networks.

[10] Hence, in a super game framework, if firms do not discount future profits at too high a rate, it is possible to support fortress hubs as a subgame perfect Nash equilibrium by using trigger strategies that call for reversion to the dominant strategy equilibrium in the event of defection.

Appendix

A. This part provides the proofs of Propositions 1 and 3. Under the fortress hubs structure, the equilibrium quantities are:

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

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

where the superscript f stands for fortress hubs. Since local invasion lacks the symmetry of fortress hubs, its solution is more complex:

$$Q_{AH}^{1i} = Q_{BH}^{1i} = [(40\theta^3 - 108\theta^2 + 66\theta - 9)\alpha + 68\theta^2 - 60\theta + 9]/D_1 \tag{A3}$$

$$Q_{AH}^{1i} = 2[(-20\theta^3 - 4\theta^2 + 15\theta - 3)\alpha + 36\theta^2 - 38\theta + 6]/D_1 \tag{A4}$$

$$Q_{AK}^{1i} = Q_{BK}^{1i} = 2[(-60\theta^2 + 27\theta - 3)\alpha + 70\theta^2 - 29\theta + 3]/D_1 \tag{A5}$$

$$Q_{AK}^{2i} = Q_{BK}^{2i} = 2[(20\theta^3 - 30\theta^2 + 21\theta - 3)\alpha + 6\theta^2 - 17\theta + 3]/D_1 \tag{A6}$$

$$Q_{AB}^{2i} = 2[(20\theta^3 - 20\theta^2 + 21\theta - 3)\alpha + 64\theta^2 - 44\theta + 6]/D_1 \tag{A7}$$

where superscript i stands for local invasion, and $D_1 \equiv 140\theta^3 - 204\theta^2 + 81\theta - 9$.

Proof of Proposition 1.

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

$$\Delta Q_{AB}^2 \equiv Q_{AB}^{2i} - Q_{AB}^{2f} = 8\theta(1-3\theta)[3(1-4\theta)\alpha + 14\theta - 3]/(3-7\theta)D_1$$

Notice that both $1-3\theta$ and $3-7\theta$ are positive. Using the bounds of expressions (6)-(8), one can easily show that the bracketed term is also positive, so the sign of ΔQ_{AB}^2 is the same as the sign of D_1. Since D_1 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 invasion than under fortress hubs 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 (that is, the output level that maximises Carrier 1's profit) depends on Carrier 2's output. This best-response function has the same form for both fortress hubs and local invasion and can be obtained from equations (1)-(3) as

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

Apparently, Carrier 1's best response to the competitor's higher output is to deliver less output. Given $Q_{AB}^{1f} = Q_{AB}^{2f}$, the result on ΔQ_{AB}^2 will imply that when increasing returns are relatively strong (weak), Carrier 1 delivers less (greater) output in the AB market under local invasion than under fortress hubs. The outcomes will in turn affect Carrier 1's output decisions on its spoke routes. Referring to equations (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 invasion on Carrier 1's profit in its AHB network, it can be

calculated that

$$\Delta\Pi^1_{AHB} \equiv \Pi^{1i}_{AHB} - \Pi^{1f}_{AHB} = (x_1\alpha + y_1)\Delta Q^2_{AB}/(3-7\theta)D_1$$

where $x_1 \equiv -140\theta^4 + 76\theta^3 + 108\theta^2 + 69\theta + 9$ and $y_1 \equiv 266\theta^3 - 391\theta^2 + 159\theta - 18$. Using the bounds of expressions (6)-(8), one can show that the term $x_1\alpha + y_1$ has the same sign as D_1; 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 $Q^i_{AK} \equiv Q^{1i}_{AK} + Q^{2i}_{AK}$ under local invasion whereas it is $Q^f_{AK} \equiv Q^{2f}_{AK}$ under fortress hubs. From (A1), (A5) and (A6),

$$\Delta Q_{AK} \equiv Q^i_{AK} - Q^f_{AK} = (-46\theta^2 + 25\theta - 3)[3(1-4\theta)\alpha + 14\theta - 3]/(3-7\theta)D_1$$

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_1 is positive for $\theta > 3/14$ and negative for $\theta < 1/6$). Hence, $P^i_{AK} < P^f_{AK}$.

Finally, consider the AB market. Proposition 1 has shown that local invasion 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 invasion on total AB traffic. Let $Q^i_{AB} \equiv Q^{1i}_{AB} + Q^{2i}_{AB}$ and $Q^f_{AB} \equiv Q^{1f}_{AB} + Q^{2f}_{AB}$ be total traffic in the AB market. Using (A2), (A4) and (A7), we can calculate

$$\Delta Q_{AB} \equiv Q^i_{AB} - Q^f_{AB} = 4\theta(1-5\theta)[3(1-4\theta)\alpha + 14\theta - 3]/(3-7\theta)D_1$$

which is negative for all θ. Consequently, $P^i_{AB} > P^f_{AB}$. *Q.E.D.*

B. This part contains the proof of Proposition 5. Under the local retaliation structure, which is the same as reciprocal local entry, the equilibrium quantities are

$$Q^{1r}_{AH} = Q^{1r}_{BH} = Q^{2r}_{AK} = Q^{2r}_{BK} = 2[(4\theta^2 - 6\theta + 3)\alpha + 2\theta - 3]/D_2 \quad \text{(A8)}$$

$$Q^{1r}_{AK} = Q^{1r}_{BK} = Q^{2r}_{AH} = Q^{2r}_{BH} = 2[(-12\theta + 3)\alpha + 14\theta - 3]/D_2 \quad \text{(A9)}$$

$$Q^{1r}_{AB} = Q^{2r}_{AB} = 2[(-4\theta^2 - 4\theta + 3)\alpha + 12\theta - 6]/D_2 \quad \text{(A10)}$$

where superscript r stands for local retaliation, and $D_2 \equiv 28\theta^2 - 36\theta + 9$, which is positive for $0 < \theta < 1/3$. The non-retaliation equilibrium quantities are the same as those under local invasion with the role of the two carriers being reversed.

Proof of Proposition 5.

We first prove the second part of the proposition. It can be computed that

$$\Pi^{1f} - \Pi^{1r} = -(x_2\alpha + y_2)Q^{1r}_{AK}/2(3-7\theta)^2 D_2$$

where $x_2 \equiv 1680\theta^4 - 2756\theta^3 + 1200\theta^2 - 81\theta - 27$ and $y_2 \equiv 2744\theta^4 - 4620\theta^3 + 2178\theta^2 - 243\theta - 27$. Using the lower bounds given in expressions (6)-(8), one can show that $x_2\alpha + y_2 < 0$ for $0 < \theta < 1/3$. Hence, $\Pi^{1f} > \Pi^{1r}$.

As for part (i), a comparison of Figure 2 and Figure 4 yields the first part of (i), whereas by Proposition 1 the second part follows if one can show that $\Pi^{1r} > \Pi^{1n}$ when $0 < \theta < 1/6$ (superscript n for non-retaliation). It can be computed that:

$$\Pi^{1r} - \Pi^{1n} = 2(x_3\alpha + y_3)Q^{1r}_{AK}/D_1^2 D_2$$

where x_3 and y_3 are some functions (8th degree polynomial) of θ. The term $x_3\alpha + y_3$ can be shown to be positive for $0 < \theta < 1/6$, implying $\Pi^{1r} - \Pi^{1n} > 0$, as desired. *Q.E.D.*

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