A note on the competitive advantage of large hub-and-spoke networks

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Abstract

This note explores the extent to which airlines operating large hub-and-spoke networks secure a competitive advantage. More specifically, this paper explores the intricate relationship which arises among productive efficiencies and profitability when the size of the hub-and-spoke network expands. To this end, Brueckner and Spiller (1991, International Journal of Industrial Organization 9, 323–342) airline economics model is generalized by allowing the size of the hub-and-spoke network to vary. The central result shows that, although the model exhibits decreasing returns to firm/network size (RTNS), nonetheless there is a competitive advantage to increasing the size of a network. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

It has been recognised that the structure of airline networks plays an important role in understanding airline economics (see, e.g., Levine, 1987). The hub-and-spoke [hereafter, HS] structure has been extensively adopted in the US airline industry and this structure is likely to flourish around the world as a consequence of airline liberalisation and the growing trend toward privatization of this industry. Today, there is growing evidence in the transportation literature that other deregulated industries such as the trucking industry and the freight industry generally have adopted some form of HS networking as method of delivery.

Airlines adopt the HS structure as a result of profit maximization behaviour. Indeed, some combination of cost economies and demand (marketing) benefits are expected to arise from this...
structure. The cost-side benefits as well as the demand-side benefits from HS operations have been highlighted in the literature. HS networks allow airlines to exploit important productive efficiencies due primarily to the presence of economies of traffic density and economies of scope (see, inter alia, Caves et al., 1984; Brueckner et al., 1992; Brueckner and Spiller, 1994; Keeler and Formby, 1994). Besides increased production efficiency, an airline with a large presence in a hub airport gains significant customer loyalty advantages through marketing devices such as frequent flyer programmes and travel agency commission overrides. The existence of such marketing devices combined with the fact that travellers value HS network characteristics (higher frequencies of service, wider variety/selection of destinations, etc.), allow a HS airline to exercise some monopoly power at the hub airport. Airport concentration and airport dominance at a hub ensure a degree of protection from competition – in part due to the control of scarce airport facilities – further exacerbating the market power of a HS airline (see Borenstein, 1989, 1991, 1992; Berry, 1990). In a recent paper, Berry et al. (1996) provide further empirical evidence of the joint presence of cost-side and demand-side benefits arising from hubbing operations.

The present paper only focuses on the cost side benefits. In contrast to the previous literature on airline economics, this paper explicitly deals with the competitive advantages associated with the size of a HS network. This is an important issue given the current trend of consolidation in the US airline industry and the blossoming of international alliances throughout the world. From a cost point of view, mergers and, to some extent, alliances allow airlines to expand the size of the network with the following two main advantages: (a) less duplication of capital investment, in particular the fixed/sunk costs associated with a new station, and (b) higher traffic density, and therefore higher load factor in the different markets of the network, ceteris paribus (i.e. when flight frequency and aircraft type are constant). The rationalization of operations together with better exploitation of some cost economies are expected to reduce the unit costs of transporting a passenger and/or of operating a flight on a particular market/route. Moreover, because airlines operate on a network, spillover effects into other markets/routes are expected to arise following a network expansion (whatever the expansion is due to a merger, an alliance or a carrier’s own growth strategy). The recent wave of strategic alliances in the US has led some commentators to recognize that, to some extent, network size matters in this business when it comes to long term financial performance (Flint, 1998). This could be due to cost and/or demand considerations. Recent empirical evidence on the US airline industry suggests that a large multihub route network is an effective strategy to secure a competitive advantage (Bania et al., 1998).

The main motivation of this paper is to analytically explore the extent to which airlines operating large HS networks secure a competitive advantage. More specifically, this paper explores the intricate relationship which arises among productive efficiencies and profitability when the size of the HS network expands. To this end, Brueckner and Spiller (1991) airline economics model is adapted to analyze an important question of interest: To what extent does the size of a HS network provide a cost advantage? The main result shows that, although the model exhibits decreasing returns to firm/network size (RTNS), there is a competitive original advantage to

\footnote{In this paper, it is assumed that a network expansion arises through the addition of a new endpoint or spoke. Whether this expansion is the result of the carrier’s growth strategy or is the consequence of a merger (alliance) of nonoverlapping networks/routes, is not discussed in the formal model.}
increasing the size of a network. The main force that drives this result is the spillover effects on traffic, fares, and costs throughout the HS network. Under fairly mild economic assumptions, the result of the model suggests that when a carrier adds an endpoint to its HS network, the positive leverage effect on the revenue side dominates the effect on the cost side. As it will become apparent from the analysis, the cost-side effect is rather complex as it is a combination of a negative effect (since there is a fixed cost associated with the addition of a new endpoint to the network), and a positive effect due to the economies of traffic density.

Every economic model has its caveats, and this paper is no exception. There are potential cost disadvantages related to extensive hubbing that are not modelled in this paper. First, HS operations increase circuity which, in turn, negatively affects airline costs (extra fuel consumption, extra cruise time, extra fixed costs associated with take-off/landing operations, etc.). Second, congestion at the hub airport can severely limit the expansion of the HS network. More aircraft movements potentially increase airside and groundside delays, which are costly for both the airline and its customers. For the sake of analysis, this paper assumes a perfectly elastic supply of airport capacity at the hub \(^2\) (infrastructure, gates, terminals, etc.). Finally, an increase in aircraft operations, associated with the expansion of a HS network, becomes more costly as the airline operates at near maximum capacity. \(^3\) Clearly, depending on the cases at hand, some of these issues can play an important role in the decision of network size expansion. Here, for analysis sake, we assume that extensive hubbing does not increase operating costs, and that economies of traffic density are not exhausted as traffic volume increases, and/or as the network expands.

This note is organized as follows. The model and its assumptions are discussed in Section 2, while Section 3 presents the main results of this note. Section 4 discusses the welfare implications of these results. Section 5 concludes.

2. The model

Consider a symmetric airline network, which is likely to be the simplest structure in which the problem can be addressed. The basic model structure is similar to the HS network model developed by Brueckner and Spiller (1991). In this paper, it is supposed that a monopoly airline operates a \(N\) city network, \((N > 2)\), where the central city in the system is the hub and the other cities are the spokes. Fig. 1 illustrates such an omnidirectional HS network for the \(N = 5\) case. Assuming that residents of each city have a demand for air travel to every other city of the network, there are \(N(N - 1)/2\) city-pair markets in such a network. It is assumed that the airline is able to serve 100% of the potential \(N(N - 1)/2\) city-pairs in its network. \(^4\) These city-pairs can be split into \((N - 1)\) nonstop hub-inclusive markets, and \((N - 2)(N - 1)/2\) connecting (nonhub)

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\(^2\) Whether this assumption is realistic or not greatly depends on the case at hand. For example, in 1987, American Airlines was able to develop a hub at Raleigh-Durham because it was grossly underused.

\(^3\) The existence of an active and competitive rental market for aircraft may substantially lessen the cost of increasing capacity.

\(^4\) Clearly, as \(N\) becomes very large there is a potential for some itineraries to become too circuitous to successfully market to travellers. This arises whenever the angle between the spokes connecting two spoke airports through the hub becomes very small (see, e.g. Oum and Tretheway, 1990).
markets. Demand is symmetric across markets. The inverse demand function for round-trip travel in any given city-pair market $ij$ is given by $P(q_{ij})$, with $q_{ij}$ representing the number of round-trip passengers in the market $ij$. Accordingly, $q_{ij}$ represents the number of passengers travelling from city $i$ to city $j$ and back, plus the number of passengers travelling from city $j$ to city $i$ and back.

Although the airline serves $N(N-1)/2$ markets, aircraft are flown only on $(N-1)$ legs. HS networking implies that, on a given leg, aircraft carry both local (i.e. nonstop passengers) as well as connecting (i.e. with the same origin/destination but with different destinations/origins) passengers. This traffic consolidation along each leg allows an airline to exploit important returns to traffic density (RTD). Basically, the factors that account for these economies are: more intensive use of capital; use of larger, more efficient airplanes; and spread of fixed city-specific costs over more passengers. In order to capture this key feature of airline economics, it is assumed that the airline faces increasing RTD throughout the network.

RTD arise when traffic growth, within a given network, is larger in percentage terms than the (associated) percentage increase in costs. Following Brueckner and Spiller (1991), the cost function $C(Q)$ represents the airline’s round-trip cost of carrying a traffic volume of $Q$ passengers on a particular leg of the network. Total traffic density per leg, $Q$, includes both (hub-inclusive) nonstop passengers, as well as connecting passengers. $C(Q)$ allows for increasing returns to density stemming from hubbing operations. Consequently, $C(Q)$ satisfies the following properties: $C'(Q) > 0, C''(Q) \leq 0$. Since the solution to the monopolist’s problem is symmetric across markets, let $q_h$ denote the traffic in each hub-in-

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Footnotes:

5 This is clearly a restrictive assumption, only justifiable on the grounds of analytical tractability. Ideally, one would distinguish between the demand for hub-inclusive markets, and the demand for nonhub market, with the latter demand inferior to the former. Although such a model would be more appealing, it is believed that the main results of the paper would still hold.

6 Empirical evidence on returns to density is provided, inter alia, by Caves et al. (1984), Brueckner and Spiller (1994) and Keeler and Formby (1994). Besides empirical evidence of returns to traffic density, other empirical studies underscore the cost advantage of hubbing. McShan and Windle (1989), for example, suggest that a 10% increase in hubbing is associated with a 1.1% decline in unit cost, all else equal. Hansen and Kanafani (1989), however, have failed to show that hubbing significantly increases operational efficiency.

7 As pointed out to me by an anonymous referee, RTD apply to any fixed network, HS or fully-connected. However, exploitation of RTD is expected to be more effective in a HS network, all else equal.
clusive market and \( q_m \) denote the traffic in each nonhub market. Denoting \( R(q_m) = P(q_m)q_m \) as the revenue function on market \( m, m = h, c \), profit from the overall network can be expressed as

\[
II = (N - 1)R(q_h) + (N - 2)(N - 1)/2 \, R(q_c) - (N - 1)[C(Q) + F]. \tag{1}
\]

In a symmetric network, the total volume of traffic transported on each leg, \( Q \), is equal to \( q_h + (N - 2)q_c \). \( F \) represents the fixed costs associated with aircraft operations on a particular leg. Fixed costs at the leg level arise as the airline experiences some cost indivisibilities in ground operations (gates, ticket offices, ground crew, etc.). Since every time a new city is added to the network, another set of these costs must be incurred, total fixed costs throughout the network, \((N - 1)F\), rise as the number of cities (endpoints) served in the network increases. RTNS, also sometimes misleadingly referred to as ‘economies of scale’, arise when the addition of a new endpoint to the network and its associated traffic growth (holding traffic density constant in the new markets as for the airline’s system overall) is larger in percentage terms than the (associated) percentage increase in costs (Caves et al., 1984). According to Caves et al. (1984) and Kumbhakar (1990), RTNS can be defined as

\[
\text{RTNS} = \frac{1}{\epsilon_Q + \epsilon_N}, \tag{2}
\]

where \( \epsilon_Q \) is the elasticity of total cost with respect to output, and \( \epsilon_N \) is the elasticity of total cost with respect to points served. 8 Formally, given the specification of the model, we have that

\[
\epsilon_Q = \frac{\partial TC}{\partial Q} \frac{Q}{TC} = C'(Q) \frac{Q}{C(Q) + F} = \frac{MC}{AC}, \tag{3}
\]

\[
\epsilon_N = \frac{\partial TC}{\partial N} \frac{N}{TC} = \frac{C(Q) + F + (N - 1)C'(Q)Q}{TC} \tag{4}
\]

where \( TC \equiv (N - 1)[C(Q) + F] \), MC is marginal cost, AC is average cost, and \( Q' = \partial Q \partial N \). The latter accounts for the change in traffic from adding another endpoint to the network. Notice that RTD are defined by Caves et al. (1984) and Kumbhakar (1990) as the inverse of \( \epsilon_Q \). By assumption, we have that RTD \( \geq 1 \), i.e. AC \( \geq MC \), since \( C'(Q) > 0 \) and \( C''(Q) \leq 0 \).

By and large, empirical studies have suggested that constant “returns to scale” exist for rather broad ranges of airline traffic (see, inter alia, Caves et al. (1984), Keeler and Formby (1994), Tretheway and Oum (1992) and Antoniou (1991) survey article.). In other words, adding or dropping cities from an airline network (while adjusting total passengers to keep density per route constant) does not really affect unit cost (per passenger). More recent econometric studies challenge the constant RTNS paradigm for the airline industry (see, e.g., Kumbhakar, 1990). At this stage of the analysis, no a priori assumption is made on the nature of the RTNS. This will rather be determined by the model. 9 Interestingly, notice that the cost specification implicitly assumes that the airline is able to reap economies of scope due to the multimarket nature of its HS operation. The source of these economies of scope is to be mainly found in the presence of RTD,

8 For the sake of analysis \( N \) is treated as a continuous variable, although it is clearly a discrete variable.

9 In particular, the magnitude of \( \epsilon_N \), and therefore of RTNS, will depend on the sign of \( Q' \), and on its interactions with the variables of the model.
since by combining nonstop and connecting passengers, the airline achieves a cost advantage by jointly providing a large number of diversified city-pairs instead of specialising in the production of a single city-pair. The larger the size of the network the more important the economies of scope, all else equal. This arises as fixed ground facilities and personnel at the hub, as well as aircraft, can be more intensively employed.

Profit maximization implies that the (multimarket) monopolist sets marginal revenue in each city-pair market to equal the marginal cost of a passenger in the market. Given the symmetry of the model and expression (1), the following two sets of first order conditions must be satisfied in equilibrium:

\[ R'(q_h) - C'(q_h + (N - 2)q_c) = 0 \quad \forall h \text{ markets}, \]
\[ R'(q_c) - 2C'(q_h + (N - 2)q_c) = 0 \quad \forall c \text{ markets}. \]

The first order conditions associated with nonhub markets (see Eq. (6)) show that marginal cost is twice as important as in the hub-inclusive markets (see Eq. (5)). This arises because on the nonhub markets passengers are transported on two legs. In order to derive useful results, let us assume that both marginal revenue and marginal cost functions are linear, and given by \( R'(q_m) = \alpha - q_m > 0 \), and \( C'(Q) = \beta - \theta Q > 0 \), \( \forall m = h, c \), respectively. The intercept (level) of demand is represented by \( \alpha > 0 \), while \( \beta > 0 \) is the intercept of marginal cost. Finally, \( \theta \geq 0 \) captures the extent of increasing returns to density. Constant marginal cost per leg would imply \( \theta = 0 \). Given the above specifications, the solutions to equations Eqs. (5) and (6) yield the following equilibrium values:

\[ q_h^* = \frac{\alpha[1 - \theta(N - 2)] - \beta}{1 - \theta(2N - 3)} = \frac{[1 - 2\theta(N - 2)]S_i + \theta(N - 2)S_{ii}}{1 - \theta(2N - 3)}, \]
\[ q_c^* = \frac{\alpha(1 + \theta) - 2\beta}{1 - \theta(2N - 3)} = \frac{(1 - \theta)S_i + 2\theta S_{ii}}{1 - \theta(2N - 3)}, \]

where \( S_i \equiv \alpha - \beta > 0 \), \( S_{ij} \equiv \alpha - 2\beta > 0 \), and \( S_i > S_{ii} \). It can be easily shown that the second order conditions for profit maximization reduce to \( \theta < 1/(2N - 3) \equiv \bar{\theta}, \forall N > 2 \). Given the later condition it is readily verified that both quantities are positive. In addition, in order to have positive marginal revenues (and positive marginal costs), the following inequalities must hold

\[ 2 < \alpha/\beta \leq 1/[\theta(N - 1)], \quad \forall \theta \leq \frac{1}{2(N - 1)} \equiv \theta < \bar{\theta}, \quad N > 2. \]

Hereafter, it is assumed that, in equilibrium, the requirements of Eq. (9) are satisfied. Given quantities Eqs. (7) and (8), gross profit (net of fixed costs) from the network is

\[ \text{Gross profit} = \sum_{i=1}^{N} R(q_i) - \sum_{i=1}^{N} C(q_i) \]

\[ \text{subject to}\]

\[ \sum_{i=1}^{N} q_i = T \]

\[ \text{and}\]

\[ \alpha > 0, \quad \beta > 0, \quad \theta \geq 0. \]

\[ \text{That is, more hours flown per day.} \]

\[ \text{Other, important, channels through which economies of scope might arise in HS networks include, inter alia, product marketing and product advertising (see Levine, 1987). There is also a diversification argument in favour of large HS network size. The large number of city-pairs served allows an airline to minimize its dependence on any particular market or group of markets (e.g. leisure oriented markets) as well as to reduce the risks, and therefore the costs, involved in adding a new endpoint to its network (Wheeler, 1989).} \]

\[ \text{Because } \theta < \bar{\theta}, \text{ } \bar{\theta} \text{ represents the correct upper bound. I would like to thank an anonymous referee for pointing out this to me.} \]
Lemma 1. In equilibrium, traffic in the hub-inclusive market is equal or larger than traffic in the nonhub market, i.e., \(q^*_h \geq q^*_c\).

Since the proof of Lemma 1 is straightforward, it will be omitted. The result of Lemma 1 is not surprising since the cost of transporting a passenger in a nonhub market is twice as important as the cost of transporting a passenger in a hub-inclusive market, all else being equal. Notice that the model prevents arbitrage opportunities from arising, i.e. fares are such that \(2P^*_h \geq P^*_c\) (explicit expressions of optimal fares \(P^*_m, m = h, c\), are detailed in the Appendix A); otherwise there would be an incentive for the nonhub (connecting) passenger to buy two separate hub-inclusive tickets.

3. Comparative statics

Lemma 2. In equilibrium, quantities Eqs. (7) and (8) are increasing in \(\theta\) and \(N\), and decreasing in \(\beta\), while their associated prices are decreasing in \(\theta\) and \(N\), and increasing in \(\beta\). See Proof in Appendix A.

Although the results of Lemma 2 are not fundamentally original (see Brueckner et al. (1992) for an intuitive discussion), they are important for our subsequent analysis. First, higher RTD \(\theta\) lower the marginal cost of the leg, providing an incentive to increase quantities and to decrease fares. Second, as the number of endpoints in the network \(N\) expands, traffic rises and fares decrease in all markets. This result is closely related to the previous one, that is, a more effective exploitation of increasing returns to density is allowed as a result of a higher traffic volume \(Q\) on the leg. Finally, the last part of Lemma 2 states that an increase in the cost \(\beta\) reduces quantities and increases prices, a standard outcome in industrial organization models.

Lemma 3. In equilibrium, the model exhibits decreasing returns to network size, i.e. \(\text{RTNS} < 1\). See Proof in Appendix A.

Lemma 3 shows that the addition of a new endpoint to the HS network, and its associated traffic growth results in a rise of the unit costs (per passenger). However, as it will become apparent in the subsequent analysis, the addition of a new endpoint to the HS network can still be
profitable if the airline is able to reap further economies. Such economies arise as a combination of more effective exploitation of RTD and economies of scope.

**Lemma 4.** In equilibrium, quantities (7) and (8) are increasing in \( z \). \( P_h \) is increasing (decreasing) in \( z \) whenever \( 0 \leq \theta_h (\theta_h < \theta \leq \theta_c) \), while \( P_c \) is increasing (decreasing) in \( z \) whenever \( \theta \leq \theta_c (\theta_c < \theta \leq \theta) \), with \( \theta_h > \theta_c, \forall \theta \leq \theta \), and \( N > 2 \). See Proof in Appendix A.

The first part of Lemma 4 shows that higher demand \( z \) raises traffic in both types of markets. The second part of Lemma 4 suggests that higher demand affects both fares in a direction that depends on the magnitude of the return to density \( \theta \). Both fares decline when the increase in demand is associated with relatively high returns to density. Clearly, this result is driven by the decreasing marginal cost assumption. In contrast, when returns to density are relatively weak, both fares increase as demand rises (i.e. the usual demand effect dominates).

**Proposition 1.** Assume that the net profit per leg is always positive, that is \( \pi^* - F > 0 \), \( \forall \theta \leq \theta \), and \( N > 2 \), then the net profit from the overall network increases as the size of the network \( N \) increases. See Proof in Appendix A.

The result of Proposition 1 is the central result of this note. Given the assumptions of the model, in particular a perfectly elastic supply of capacity at the hub, this result indicates that it is profitable for the airline to increase the number of endpoints served in the HS network. Several economic forces drive this result. First, note the leverage effect on revenues: an increase in \( N \) by one unit boosts the number of potential markets by \( 2/(N - 1) \) per cent. For example, adding an additional endpoint when \( N = 5 \) yields a 50% increase in the number of potential markets. This is an important feature of airline HS systems. In turn, this implies that the additional fixed cost \( F \) associated with a new endpoint can be shared among \( (N - 1) \) new markets, i.e., one new hub-inclusive market and \( (N - 2) \) new nonhub markets. Clearly, the larger \( N \) the lower the share of the fixed cost incurred by each market. Second, the addition of a new city in this HS network stimulates traffic density on the other legs of the hub, generating further economies. Indeed, as \( N \) increases, the volume of connecting traffic increases on all legs, allowing for a more effective exploitation of the RTD, all else equal. The combination of more effective exploitation of RTD and economies of scope provide an incentive to expand the network size, although the HS network exhibits decreasing RTNS (see Lemma 3). These combined effects leave the airline with a larger network at a competitive advantage and potentially exacerbate the problem of market foreclosure in deregulated markets. In fact, in such a HS network, potential entry into a market is more likely to be foreclosed the lower the demand \( z \), and the larger: (a) the network size \( N \), (b) the RTD \( \theta \), and (c) the fixed cost \( F \). These results confirm the ‘fortress hubs’ phenomenon observed in the US airline industry (see e.g. Zhang, 1996), where major carriers each operate distinct ‘mega’ hubs. Because majors have a significant competitive advantage on markets to/from these hubs,

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14 This point has been informally addressed by Oum and Tretheway (1990).
direct competition on those markets from nonhub carriers, such as Southwest Airlines, is rather limited.  

Lemma 5. In equilibrium, the profit from the overall network increases as demand \( x \) increases. Additionally, the profit from the overall network increases as returns to density \( \theta \) intensify, and decreases as the cost \( \beta \) increases. See Proof in Appendix A.

The change in profit resulting from a change in demand is the combination of the change in traffic (or quantity) and the change in fare in all markets. It has been shown in Lemma 4 that for sufficiently high RTD, an increase in \( x \) induces higher traffic and lower fares, suggesting that the net effect on profit could be ambiguous. The result of Lemma 5 unambiguously shows that the (positive) traffic effect dominates the (potentially negative) fare effect for all values of RTD allowed by the model. When airlines compete through different HS networks, i.e. when each airline operates a distinct hub, this result shows that the airline which operates the higher demand network (associated with, e.g., larger city populations or higher per capita income) secures a competitive advantage, all else equal. In addition, when RTD are sufficiently high, travellers in the high demand network enjoy lower fares (in all markets) than the travellers in the low demand network, ceteris paribus (see Lemma 4). Finally, the results in the last part of Lemma 5 are very intuitive. Higher RTD lower costs, while a lower marginal cost intercept reduces costs, improving the overall profitability, all else equal.

4. Welfare implications

The welfare implications of the model are briefly discussed in this section. Given the specifications of the model, in particular the linear marginal revenue functions \( R'(q_m), \forall m = h, c \), it can be readily shown that, in equilibrium, consumer surplus in each city-pair market \( m \) is equal to \((q_m^*/2)^2\). Consequently, in equilibrium, consumer surplus throughout the network, CS, is equal to

\[
CS^* = \frac{N - 1}{8} \left[ 2(q_h^*)^2 + (N - 2)(q_c^*)^2 \right],
\]

where \( q_h^* \) and \( q_c^* \) are given by expressions (7) and (8), respectively. Social welfare, the sum of producer net profit and consumer surplus, corresponds to \( W^* = II^* - (N - 1)F + \ CS^* \), where gross profit \( II^* \) is given by expression (10).

Proposition 2. In equilibrium, social welfare \( W^* \) increases as: (a) RTD \( \theta \) increase, (b) demand \( x \) increases, (c) cost \( \beta \) decreases, and (d) the size of the network \( N \) increases. See Proof in Appendix A.

The results of Proposition 2 are mainly derived from the analysis of the previous section. Results (a)–(c) are standard in industrial organization models: cost economies and/or increase in

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15 In some cases, there are also important barriers (both physical and financial) to hub entry for new entrants. Such barriers increase the cost of operating at the hub airport.
demand are always associated with an increase in social welfare. Given the assumptions of the model, in particular that the airline is able to serve 100 per cent of the potential city-pairs in its HS network, it is not surprising that social welfare increases as the size of the network increases. Under the presence of RTD, there is a significant potential for productive efficiencies to be gained in such a large HS network. Since these efficiencies translate into lower fares, the gains are shared among the airline and the travelling public which clearly enhances social welfare. \(^{16}\) In other words, these results show that there is a positive network effect associated with an increase in network size. In terms of competition policy, these results suggest the following two main remarks. First, a monopolist can potentially achieve a better exploitation of economies of traffic density, and therefore better internalize the positive network effects. Second, there are potential social benefits associated with a network expansion. When such an expansion arises through an airline merger these benefits have ultimately to be weighted against the increase in market power. In fact, given the specifications of the model, it could be the case for a monopoly airline to be socially preferable to oligopoly competition. Indeed, Brueckner and Spiller (1991) and recently Nero (1996) have shown that competition diverts traffic, raises the cost of the leg, reduces profits, and potentially reduces social welfare when RTD are important and demand is relatively strong.

5. Conclusion

The central result of this note suggests that, given the assumptions of the model, increasing the number of endpoints served in a HS network can be a sound profit-enhancing strategy. This result arises notwithstanding the presence of decreasing RTNS. A crucial assumption of the paper is that the elasticity of capacity supply at the hub is infinite. The main results of the paper are driven by the network HS structure and by the RTD, two key features in the airline industry. Because of the HS network structure, an increase in the size of the network has spillover effects throughout the network. Larger HS networks provide cost benefits that translate into higher traffic and lower fares throughout the network, all else equal. Larger HS networks also bring demand benefits, which in turn might translate into more decisive competitive advantage and potentially greater market power. Although there are both demand side benefits and cost side benefits from hubbing, (some degree of) competition is likely to survive in the airline industry because it is not a pure commodity business. By focusing the analysis on the cost benefits we have been able to provide a simple model that addresses the relationship among network size, productive efficiencies and profitability. Clearly, further research would be needed to integrate the cost side benefits with the demand side benefits in a unified structural model. \(^{17}\) The main results of the paper are likely to hold even if competition is introduced into the model.

Admittedly, there are other sources of profitability in the airline industry besides the size of the HS network. Ability to operate in market niches and to provide differentiated services, low labour

\(^{16}\) Clearly, the problem of externalities (principally congestion, air pollution, and noise) at the hub airport is exacerbated as the size of the network increases. When taken into account, such externalities are likely to negatively affect a broader definition of social welfare (see, e.g. Nero and Black, 1998).

\(^{17}\) A promising approach in this direction can be found in Oum et al. (1995).
costs (secured by stronger management bargaining power), and high operational efficiency of capital \(^{18}\) are all examples of additional sources of profitability for airlines. Prosperity can exist outside the pure HS model, which the consistent performance of Southwest Airlines exemplifies. Clearly, there is a limit for bigger to be always better in this industry. In the real world, larger cities with larger demands in their catchment area are added first to the network, so that the marginal profitability from increasing the network size eventually vanishes. \(^{19}\) Also, both airside and groundside congestion costs, as well as the complexity of hub operations and hub management, eventually offset the cost-related benefits from extensive hubbing. Needless to say, further empirical research is needed to determine the optimal size of HS networks. However, the fact that very large HS networks exist (e.g. like those concentrated around Atlanta or around Dallas-Forth-Worth) indicates that the benefits from extensive hubbing are not easily exhausted. This paper is aimed at formally illustrating this point, although it recognizes that several complex forces are at work in the real world.

All in all, these results might suggest that large, foreclosed HS networks do not necessarily lead to an increase of market power (i.e. higher fares) when some of the productive efficiencies stemming from RTD and economies of scope are passed on to consumers. Mergers that form a large, global, HS network should not be considered per se as anti-competitive. This is especially important in light of the European airline industry where: (a) carriers with overlapping networks often compete in relatively thin markets, and (b) network expansion until recently has been hampered on the grounds of economic regulation, ownership structure, and/or geographic characteristics.

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Appendix A

Proof of Lemma 2. First, note the optimal prices \(P^*_h\) and \(P^*_c\) are given by the following expressions:

\[
P^*_h = \frac{\alpha[1 - \theta(3N - 4)] + \beta}{2[1 - \theta(2N - 3)]} > 0, \quad \forall \theta \leq \theta_0, \quad N > 2, \tag{A.1}
\]

\[
P^*_c = \frac{\alpha[1 - \theta(4N - 5)] + 2\beta}{2[1 - \theta(2N - 3)]} > 0, \quad \forall \theta \leq \theta_0, \quad N > 2. \tag{A.2}
\]

\(^{18}\) For example by achieving minimum aircraft turnaround time.

\(^{19}\) I would like to thank an anonymous referee for pointing this out.
Note that by virtue of the positive marginal condition (see inequality (9)), both price expressions are strictly positive. Using Eqs. (7) and (8) and Eqs. (A.1) and (A.2), we have that

\[ \frac{\partial q^*_b}{\partial \theta} = \frac{S_i + S_u(N-2)}{[1 - \theta(2N-3)]^2} > 0, \quad \frac{\partial q^*_c}{\partial \theta} = \frac{2 S_i + S_u(N-2)}{[1 - \theta(2N-3)]^2} > 0, \]

\[ \frac{\partial P^*_b}{\partial \theta} = -\frac{S_u(N-1) + \beta}{2[1 - \theta(2N-3)]^2} < 0, \quad \frac{\partial P^*_c}{\partial \theta} = -\frac{S_u(N-1) + \beta}{[1 - \theta(2N-3)]^2} < 0, \]

\[ \frac{\partial q^*_b}{\partial \beta} = -\frac{1}{1 - \theta(2N-3)} < 0, \quad \frac{\partial q^*_c}{\partial \beta} = -\frac{2}{1 - \theta(2N-3)} < 0, \]

\[ \frac{\partial P^*_b}{\partial \beta} = \frac{1}{2[1 - \theta(2N-3)]} > 0, \quad \frac{\partial P^*_c}{\partial \beta} = \frac{1}{1 - \theta(2N-3)} > 0. \]

\[ \frac{\partial q^*_b}{\partial \theta} = \frac{\partial q^*_c}{\partial \theta} > 0, \quad \frac{\partial P^*_b}{\partial \theta} < 0, \quad \frac{\partial P^*_c}{\partial \theta} < 0, \quad \forall \theta \neq 0. \]

Proof of Lemma 3. First, using expressions (3) and (4), Eq. (2) becomes:

\[ \text{RTNS} = \frac{(N-1)[C(Q) + F]}{(N-1)[C'(Q)[Q + NQ'] + N[C(Q) + F]],} \quad (A.3) \]

where \( Q' = (\partial q^*_b/\partial N) + q^*_c + (N-2)(\partial q^*_c/\partial N) \). It is easy to show that expression (A.3) is less than unity if \( \{(N-1)[C'(Q)[Q + NQ'] + N[C(Q) + F]] > 0 \). By virtue of Lemma 2, we have that \( Q' > 0 \). Consequently, given that \( C(Q), C'(Q), Q, F > 0 \), and \( N > 2 \), expression (A.3) is strictly less than unity, suggesting decreasing economies of firm/network size. \( \Box \)

Proof of Lemma 4. Using Eqs. (7) and (8), we have that

\[ \frac{\partial q^*_b}{\partial \theta} = \frac{1 - \theta(N-2)}{1 - \theta(2N-3)} > 0, \quad \frac{\partial q^*_c}{\partial \theta} = \frac{1 + \theta}{1 - \theta(2N-3)} > 0 \quad \forall \theta \leq \theta < \frac{1}{N-2}, \quad N > 2 \]

and using Eqs. (A.1) and (A.2), we have that

\[ \frac{\partial P^*_b}{\partial \theta} = \frac{1 - \theta(3N-4)}{2[1 - \theta(2N-3)]} = \left\{ \begin{array}{ll} \geq 0 & \text{when} \quad \theta \leq [1/(3N-4)] \equiv \theta_b, \\ < 0 & \text{when} \quad \theta_b < \theta \leq \theta, \end{array} \right. \]

\[ \frac{\partial P^*_c}{\partial \theta} = \frac{1 - \theta(4N-5)}{2[1 - \theta(2N-3)]} = \left\{ \begin{array}{ll} \geq 0 & \text{when} \quad \theta \leq [1/(4N-5)] \equiv \theta_c, \\ < 0 & \text{when} \quad \theta_c < \theta \leq \theta, \end{array} \right. \]

\[ \Box \]

Proof of Proposition 1. First, let us assume that the net profit per leg, is positive, that is

\[ \pi^* - F = \frac{(N-2)[S_i^2 - \theta(2S_i - S_u)]^2 + 2S_i^2}{4[1 - \theta(2N-3)]} - F > 0. \quad (A.4) \]
Clearly, condition (A.4) holds for sufficiently low $F$. Let us denote $\bar{F}$ the upper bound for the fixed cost, i.e. $F \leq \bar{F}$, such that the net profit per leg is always positive. Using expression (10), net profit at the network level corresponds to $\Pi^* = \Pi - (N - 1)F$. The net change in profit (i.e. marginal profitability of the overall network) from increasing the size of the network is given by

$$\frac{\partial \Pi^*}{\partial N} = \frac{\left(S^2_{ii} - \theta(2S_i - S_{ii})^2\right) \left[(1 - N \theta)(2N - 6) + (3 - 5 \theta)\right] + 2(1 + \theta)S^2_i}{4[1 - \theta(2N - 3)]^2} - F. \quad (A.5)$$

Expression (A.5) is positive for sufficiently low $F$. Let us denote such a binding fixed cost $\tilde{F}$, where $F \leq \tilde{F}$. If we can show that $\tilde{F} > \bar{F}$, $\forall \theta \leq \theta$, and $N > 2$, then we know that when expression (A.4) is positive, expression (A.5) is also positive. From the comparison of expressions (A.4) and (A.5) we have that the inequality

$$\frac{(N - 2)\left[S^2_{ii} - \theta(2S_i - S_{ii})^2\right] + 2S^2_i}{4[1 - \theta(2N - 3)]^2} > \frac{S^2_{ii} - \theta(2S_i - S_{ii})^2}{4[1 - \theta(2N - 3)]^2},$$

amounts to

$$(N - 1)\left\{\left[S^2_{ii} - \theta(2S_i - S_{ii})^2\right](1 - \theta) + 4 \theta S^2_i\right\} > 0 \quad \text{or} \quad [S_{ii}(1 - \theta) + 2 \theta S^2_i] > 0, \quad \text{which is always verified.}$$

Therefore, whenever $F$ is such that $F \leq \tilde{F}$, we have that expression (A.5) is positive, i.e. the profit from the overall network is increasing in the size of the network. The result of Proposition 1 is valid irrespective of $N$, as long as inequalities (9) hold. Clearly, Proposition 1 is very strong since the only condition is that the net profit per leg be positive. Remarkably, the result of Proposition 1 holds even when the cost function displays constant marginal costs ($\theta = 0$). $\square$

**Proof of Lemma 5.** Given expression (10), we have that

$$\frac{\partial \Pi^*}{\partial \alpha} \equiv \frac{(N - 1)\partial \pi^*}{\partial \alpha} = \frac{(N - 1)\left[(N - 2)S_{ii} + \alpha(1 - \theta(N - 2))\right]}{2[1 - \theta(2N - 3)]} \geq 0$$

$\forall \theta \leq \theta < \frac{1}{N - 2}, \quad N > 2,$

and,

$$\frac{\partial \Pi^*}{\partial \theta} \equiv (N - 1)\frac{\partial \pi^*}{\partial \theta} = (N - 1) \frac{\left[(N - 2)S_{ii} + S_i\right]^2}{2[1 - \theta(2N - 3)]^2} > 0,$$

$$\frac{\partial \Pi^*}{\partial \beta} \equiv (N - 1)\frac{\partial \pi^*}{\partial \beta} = -(N - 1) \frac{(N - 1)S_{ii} + \beta}{1 - \theta(2N - 3)} < 0. \quad \square$$
Proof of Proposition 2. Straightforward differentiation implies that
\[
\frac{\partial W^*}{\partial \theta} = \frac{\partial \Pi^*}{\partial \theta} + \frac{\partial CS^*}{\partial \theta} = \frac{\partial \Pi^*}{\partial \theta} + \frac{N-1}{4} \left[ 2q_h \frac{\partial q_h^*}{\partial \theta} + (N-2)q_c \frac{\partial q_c^*}{\partial \theta} \right] > 0,
\]
\[
\frac{\partial W^*}{\partial \alpha} = \frac{\partial \Pi^*}{\partial \alpha} + \frac{\partial CS^*}{\partial \alpha} = \frac{\partial \Pi^*}{\partial \alpha} + \frac{N-1}{4} \left[ 2q_h \frac{\partial q_h^*}{\partial \alpha} + (N-2)q_c \frac{\partial q_c^*}{\partial \alpha} \right] > 0,
\]
\[
\frac{\partial W^*}{\partial \beta} = \frac{\partial \Pi^*}{\partial \beta} + \frac{\partial CS^*}{\partial \beta} = \frac{\partial \Pi^*}{\partial \beta} + \frac{N-1}{4} \left[ 2q_h \frac{\partial q_h^*}{\partial \beta} + (N-2)q_c \frac{\partial q_c^*}{\partial \beta} \right] < 0,
\]
and,
\[
\frac{\partial W^*}{\partial N} = \frac{\partial \Pi^{**}}{\partial N} + \frac{\partial CS^*}{\partial N} = \frac{\partial \Pi^{**}}{\partial N} + \frac{1}{8} \left[ 2q_h^2 + (2N-3)q_c^2 \right] + \frac{N-1}{4} \left[ 2q_h \frac{\partial q_h^*}{\partial N} + (N-2)q_c \frac{\partial q_c^*}{\partial N} \right] > 0,
\]
since \((\partial \Pi^{**}/\partial N) > 0\), by virtue of Proposition 1, and \((\partial CS^*/\partial N) > 0\). \(\square\)

References


