

THE LEADER'S CURSE IN THE AIRLINE INDUSTRY

GUY ARIE, SARIT MARKOVICH AND MAURICIO VARELA

ABSTRACT. This paper studies the effect of the airline industry's operational time-line and carrier network structure on multi-market competition. Airline carriers typically commit to a rigid capacity of seats via the planned flights schedule long before market competition for selling these seats begins. While in regular markets such a two stage setting has no effect on competitive behavior, the airline industry has two important features that give rise to strategic interactions. First, the network structure: while Direct carriers' capacity decisions are on a route level, Hub carriers' capacity decisions are on a hub-spoke level; giving Hub carriers flexibility in the utilization of allocated capacity. This extra flexibility is a double-edged sword - while Hub carriers are better able to adjust to market shocks, Direct carriers enjoy a market leadership advantage, analogous to Stackelberg leadership. This effect is especially important when markets are asymmetric (e.g. have different demand curves) as it allows the Direct carriers to focus on the more profitable routes. Second, network coverage: firms can be more aggressive in a market if their rival serves a much larger network. Intuitively, a small carrier serving only a handful of cities has no choice but to utilize its capacity in that small set of routes. If the small carrier places excessive capacity on its legs, a large Hub carrier would use its flexibility and redirect its installed capacity to other, less aggressive routes. Small carriers allow themselves to be overly aggressive because they do not internalize the effect of the large carriers reaction on other markets. We evaluate the implications for welfare and merger analysis and cite empiric evidence from existing studies that support our theoretic results. More specific empiric tests are in progress.

1. INTRODUCTION

Timing of decisions have critical effects on market outcome. The most famous example considers a Cournot duopoly with sequential moves—a Stackelberg game. There, a firm that can commit to move first increases its profits by capturing a larger market share than its competitor. The first mover can commit to a higher capacity because of the second mover's flexibility - its ability to back-off. The tradeoffs between commitment and flexibility have been largely studied in the literature, where the advantages of flexibility emerge mainly from its informational advantages under uncertainty.¹ In this paper we take these ideas and apply them to multi-market competition in the airline industry. Airline carriers have to commit to a certain flight schedule—and thus to a certain capacity—well before selling tickets and assigning seats on routes, a decision that is costly to change (see e.g. Lohatepanont and Barnhart (2004) and Oum, Zhang and Zhang (1995)). Coupled with the network structure

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In progress and incomplete. Please do not circulate without the authors permission. This version still has errors which are entirely our fault. We thank participants in the 2009 Spring IIOC meetings for comments on an earlier version. Comments are very welcome.

¹See for example, Spencer and Brander (1992); Ellingsen (1995) and van Damme and Hurkens (1999)

choice (i.e., Hub-and-Spoke vs Point-to-Point), this timing may endogenously create a leader-follower structure. In the scheduling stage, Point-to-Point carriers (hereafter, Direct carriers) commit to route capacities, while Hub-and-Spoke carriers (hereafter, Hub carriers) commit only to aggregate capacities from each destination to their hub. Hub carriers are thus more flexible when allocating seats in the second stage and become followers. While under uncertainty flexibility implies operational efficiencies, as in the commitment literature, we find that in many cases the strategic effect of this flexibility could be negative as it gives small, Direct carriers a leader-like advantage. This allows point to point carriers to be more aggressive on some routes, as if the carrier's costs are lower. When markets are asymmetric in terms of demand the optimal network structure for a small carrier may be a Direct network, as it allows the carrier to "cherry pick" the more attractive routes and thus offers higher profits per unit of capacity.

Our analysis considers two main types of carriers: Direct carriers who fly Point-to-Point, and Hub-and-Spoke carriers. The recent rapid growth of Low Cost Carriers (hereafter LCCs) has attracted a lot of attention. However, while the term LCC refers to airlines with a lower operating cost structure than traditional airlines, LCCs are not necessarily Direct carriers. Indeed, Direct carriers tend to be LCCs; i.e. Southwest Airlines.² Nevertheless, some LCCs actually operate a Hub and Spoke network; i.e., Frontier Airlines. We refer to such carriers as Small Hub carriers and consequently look at three different kinds of carriers: Large Hub carriers, Small Hub carriers and Direct carriers. The model then focuses on the tradeoffs between the Direct business model and the Hub business model, as well as on the effects of multi-market competition in networks that differ in size and coverage.

In order to study these effects, we construct a two-stage oligopolistic model with two carriers serving routes between several cities.³ Each carrier can be of two types: Direct or Hub. In the first stage carriers choose capacities and in the second stage the carriers compete by setting quantities on each route.⁴ To illustrate, assume the world presented in figure 1. There are three cities (1,2,3) which create three markets (1-2, 1-3, 2-3). A Hub carrier and a Direct carrier serve all three markets with city 1 as the hub city (only for the Hub carrier). While the direct carrier must commit to all three market quantities in the first stage, the hub carrier only commits to two aggregated capacities and has (some) flexibility to distribute capacities between markets in the second stage. Suppose that given the quantities presented in the figure, the Hub carrier allocates 40 seats to the (2,3) route (i.e. $X = 40$). If a new carrier unexpectedly adds 10 seats on route (2,3), the Direct carrier is "stuck" with the first stage capacity of 40 seats. However, the Hub carrier can re-optimize and divert some seats from (2,3) to the

²Some Direct carriers use "focus cities", where connections are often available by default, due to the number of destination served by the carrier. Compared to hubs, flights from focus-cities are often less frequent, served by smaller aircraft, and cater more to origin-destination traffic instead of connecting traffic.

³The main results are then generalized to more than two carriers.

⁴This construction implies two key assumption: second stage competition is in strategic substitutes and capacity changes are infinitely costly. We discuss these assumptions and the theoretical and empirical support for them below.

(1,2) and (1,3) routes - for example setting $X = 35$. In other words, for a Direct carrier the first stage capacities determine the seats available on each route. For a Hub carrier the first stage capacities only determine the seats available between each spoke and the hub (a leg). The complete capacity allocation by the Hub carrier is done after the Direct carrier commits to route level quantities.

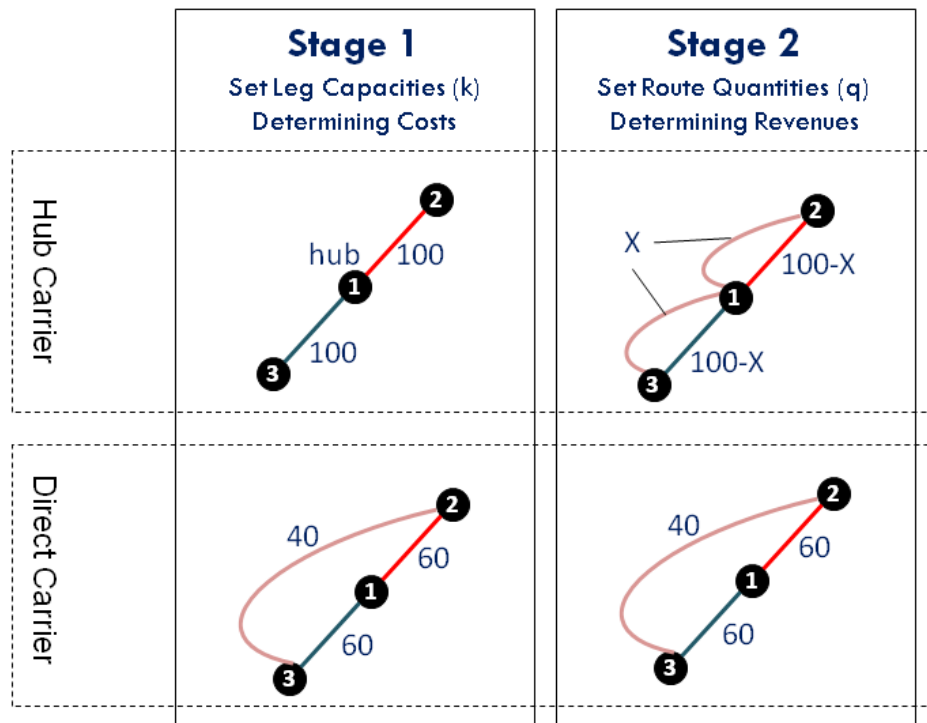


FIGURE 1.1. Three city example with a Hub and a Direct carrier. City '1' is used as the Hub. In the second stage, the Hub can choose which how much quantity to allocate to the 2-3 route and how much to leave to the 1-2 and 1-3 routes. The Direct carrier is forced to choose the division of quantities in the first stage.

Our main finding is that a Large Hub carrier's flexibility might serve as a disadvantage as a result of its network type as well as of its large network size. Hub carriers balance marginal revenue across markets. Consequently, Hub carriers accommodate an increase of rival capacity in one market by "taking advantage" of their flexibility and diverting capacity to other markets. As Direct carriers do not have this flexibility, they are able to commit to more aggressive quantities in some markets, knowing that their Hub rivals will accommodate. The magnitude of the large Hub carrier's disadvantage and the rival's advantage (this is not necessarily a zero sum game), depends not only

on the rival's type but also on the degree of network overlap between the carriers. Because aggregate capacities are fixed, the Hub carrier's accomodation reduces profitability of other markets. If two carriers' networks completely overlap, both carriers internalize this effect on other markets and refrain from being overly aggressive. However, one carrier's network may be completely nested in his rival's large network. In such cases, excess capacity by the small carrier mostly damages profitability in markets he does not serve causing small carriers to be more aggressive.

Interestingly, this internalization effect depends on the degree of network overlap rather than the difference in network size between carriers. This distinguishes the empirical implications of our model from the collusion based models of multi-market contact (cf. Bernheim and Whinston (1990)). Specifically, our model predicts that whether carriers are softer on a route depends not only on the degree of multi-market contact but also whether the overlap is on routes that use the same first stage capacities (i.e. *flight legs*). It is therefore possible to compare the predictions by comparing conduct on routes that exhibit general multi-market contact and routes that exhibit this more specific capacity sharing multi-market contact. Gimeno and Woo (1999), which we discuss in section 3.1 perform this comparison and find support for our model's predictions.

A note is in place. The airline market is a very complex one where carriers' and consumers' behavior is affected by many factors. Our analysis focuses on the differences between carriers in network type and network coverage. Consequently, our model abstracts away from factors that have been extensively studied in other papers. Specifically, we set the cost of operating either type of network equal; assuming away economies of spoke-density (e.g. Brueckner and Spiller (1994)) or the cost advantage LCCs enjoy. In addition, we assume the same demand curve for both carrier types, so that consumers' preference and heterogeneity (Berry, Carnall and Spiller (1996)) are not accounted for.⁵We model a non-cooperative game; collusive behavior (as in, e.g. Evans and Kessides (1994)) is assumed infeasible. Finally, as there are no fixed costs per route and quantities/capacities are assumed continuous, so issues regarding utilization and entry are not modeled (e.g. Berry (1992); Hendricks, Piccione and Tan (1997)).

There is by now a large theoretical and empirical literature on the post-deregulation airline industry. This literature has traditionally focused on many issues regarding the restructuring and pricing of flights and other airline services. One of the most debated aspects of the industry restructuring is the large shift in network structure; from Point-to-Point to Hub-and-Spoke. Operationally, the literature finds that a large Hub network provides the optimal and most profitable network structure (see i.e., Lederer and Nambimadom (1998)). The

⁵The literature is inconclusive on whether consumers prefer Hub and Spoke or Point to Point flights. Oum, Zhang and Zhang (1995); Brueckner, Dyer and Spiller (1992) among others suggest that customers value the high frequency of flights and network reach associated with Hub and Spoke carriers over the shorter flight time offered by point to point carriers. However, we are not aware of an empirical test of consumer preferences.

economic analysis mostly also favors the Hub and Spoke model. Borenstein (1989) found evidence of airlines being able to exercise market power and charge a premium on routes to and from their routes. Hub cities are generally located in high demand markets, and therefore such “Hub Fortress” effects are important in determining overall carrier profitability. In a theoretical analysis, Oum, Zhang and Zhang (1995) show that competitive forces increase carriers incentives to adopt a hub and spoke model as the lower costs deter entry and because staying a direct carrier while a rival is a hub carrier implies a competitive disadvantage. Hendricks, Piccione and Tan (1997) find that a Hub carrier has much more to lose by exiting a hub-spoke link than a Direct carrier. This induces Hub carriers to be more aggressive. Hendricks, Piccione and Tan (1999) establish conditions under which Hub and Spoke networks dominate Point-to-Point network in equilibrium. The hub efficiency gains were estimated empirically by Reiss and Spiller (1989); Berry (1992); Brueckner and Spiller (1994); Brueckner, Dyer and Spiller (1992); Liu and Lynk (1999) among many others.

Recent studies, using data with widespread low-cost and Direct carriers, attempt to tackle these issues and explain the observed success of Direct carriers and LCCs. In particular, Ito and Lee (2003) study the LCC phenomena and estimate factors that influence LCCs’ entry decision. Their study shows that LCCs’ entry decisions follow a simple and economic rationale: enter markets with high density and high consumer prices and avoid markets in which one city is a network hub. Their analysis suggests that the LCCs’ entry is still in progress, where in the long run LCCs’ penetration is estimated to reach 55% of the markets. Their study, however, does not distinguish between Direct LCCs and Hub LCCs, nor does it provide an explanation to the LCCs’ behavior. Extending the empirical literature to dynamic games, Aguirregabiria and Ho (2006) propose a dynamic oligopoly model to estimate the different benefits a Hub-and-Spoke network offers. In particular, they measure the contribution of demand, cost and strategic factors to explain the propensity to adopt a hub-and-spoke network. Their analysis finds that the most important factor to explain the switch toward Hub networks is the effect of the hub’s size on the cost of entering new routes. Eliminating these hub-size effects on entry costs reduces carriers’ propensity to adopt a hub-and-spoke network significantly. All other factors seem to play a minor role in explaining a carrier’s choice of network type. Focusing on carriers’ heterogeneity, Ciliberto and Tamer (2007) use a 2002 dataset to allow for the possibility of multiple equilibria. The authors find that accounting for heterogeneity generates indeed multiple equilibria, where different Hub carriers respond differently to the entry of different LCCs. Their results suggest that competition in the airline industry is affected by both the type of carriers and their size.

The next section details the model and the main theoretical results. The third section provides empirical evidence in support of the main result of the paper - the size and types effects. The final section concludes.

2. MODEL

The baseline model is a two-stage game with two carriers and \bar{M} cities. A market is a city pair; that is, round trip tickets between cities 1 and 2, starting from either 1 or 2. The \bar{M} cities therefore generate $\frac{\bar{M} \cdot (\bar{M} - 1)}{2}$ markets. Carriers can be of two types: a Hub & Spoke carrier (H) which serves its markets through a hub city; or a Direct carrier (D) - flying Point-to-Point. The set of markets a carrier serves and the type of carrier is given exogenously at the outset of the game. We use M to denote the set of all cities: $M = \{1, 2, \dots, \bar{M}\}$. A letter superscript (M^j) denotes the subset of cities that a specific carrier j can potentially serve. Γ is the set of all city pairs (i.e. markets): $\Gamma = \{\langle m_1, m_2 \rangle : m_1 \in M, m_2 \in M, m_1 < m_2\}$. A letter superscript (Γ^j) denotes the subset of routes that is potentially served by a specific carrier. A subscript (Γ_m^j) denotes all routes served by carrier j with city m as a start or end point.

We assume a two-stage game where in the first stage carriers simultaneously choose capacities at a cost. A Hub carrier (H) sets capacity between spoke cities and its hub (k_m^H for each $m \in M^H$)—a leg. A Direct carrier (D) sets capacity between each city pair (k_n^D $n \in \Gamma^D$)—a route. Capacity has a constant marginal cost set at $2c$ per route and c for a hub-spoke leg⁶. In the second stage carriers choose quantities to sell costlessly on each route (denoted q_n^j). Carriers can only sell up to installed capacity, where the limit in capacity is defined on legs (spoke-to-hub) for Hub carriers and on routes (spoke-to-spoke) for Direct carriers. That is, for a Direct carrier, the total quantity sold on market $\langle 1, 2 \rangle$ cannot exceed $k_{\langle 1, 2 \rangle}^D$ while for a Hub carrier the total quantity sold on all markets incoming and outgoing of city 1 cannot exceed k_1^H . Price is then given by decreasing, log-concave and continuous inverse demand curves $P_n(Q)$. We allow for demand to vary across markets and define *symmetric markets* to be markets where for any market quantity Q and any pair of markets n, n' : $\frac{P_n(Q)}{c_n} = \frac{P_{n'}(Q)}{c_{n'}}$. Markets n, n' are *asymmetric* if this equality is violated.

The two stage model implies three main assumptions. First, we assume that in the airline industry leg seats allocations are set in advance of route level competition and are costly to change. This assumption is supported both by industry studies (see e.g., Lohatepanont and Barnhart (2004)) and academic analysis Oum, Zhang and Zhang (1995). Designing an airline flight schedule is a complicated and highly automated procedure. Changing a scheduled flight requires re-optimization of aircrafts, crew assignments etc. and is usually avoided. Second, we assume that second stage competition is at the route level and is well approximated by a Cournot model. The motivation for this assumption is to ensure competition is in strategic substitutes.⁷ Brander and Zhang (1990)

⁶As a Hub carrier needs two legs to complete a route, our setting assumes no carrier has operational efficiencies over the other. This simplifying assumption permits us to distill the effects of network size and network type that are not related to operational efficiencies.

⁷Kreps and Scheinkman (1983) show that a two stage game with capacity decisions in the first stage and Bertrand pricing competition in the second stage results in a Cournot equilibrium. This result cannot be extended to our context. To see this, modify the Kreps and Scheinkman (1983) model to let only one firm set capacities in the first stage. It is immediate that the equilibrium of this game is not the Stackelberg (or Cournot) equilibrium. For our model predictions to hold, it is required that airline second stage competition does not transform the first stage game to a game of strategic complements.

and Oum, Zhang and Zhang (1993) empirically test whether competition between American Airlines and United Airlines fits better a Cournot or Bertrand competition and conclude that the data supports the Cournot model. Assuming Cournot competition is also a better first order proxy for the airlines' use of yield management systems. These are designed to identify the market clearing price for the airline's capacity given demand and rival capacity estimates (e.g. Smith, Leimkuhler and Darrow (1992)).⁸ Finally, we assume that there is no uncertainty between the first and second stage. This a heroic assumption that would be interesting to remove in future research. Initial investigations of the effects of uncertainty are presented in the conclusion. To a first order, uncertainty in demand should have a stronger effect on firm profit than on firm conduct (i.e. capacity and quantity choice) and thus leave the main predictions of our model unchanged.

We present the model in two steps. First, we discuss the intuition with a simple three cities example. We then generalize the results to the case of \bar{M} cities.

2.1. Three City Example. The simplest setup that captures the model's main dynamics is a three city model. Let $\bar{M} = 3$ where city 1 is a hub (see figure 1). Each city pair n is a market characterized by a (possibly unique) inverse demand function $P_n = a_n - b_n Q_n$. We assume that a Hub carrier serves all three markets ($\langle 1, 2 \rangle, \langle 1, 3 \rangle, \langle 2, 3 \rangle$), possibly competing with a rival - carrier A. While there are three effective markets, in the first stage, the Hub carrier chooses only two capacities: $k_{1,2}$ and $k_{1,3}$. In the second stage, the Hub carrier chooses how to allocate these capacities. That is, what portion of $k_{1,2}$ ($k_{1,3}$) would be serving market $\langle 1, 2 \rangle$ ($\langle 1, 3 \rangle$) and what quantity would be allocated for the market $\langle 2, 3 \rangle$ ($\langle 2, 3 \rangle$). The main result of our model posits that carriers' capacity decisions are determined by their own network-type (Hub-and-Spoke or Point-to-Point) and the network-type of their rivals. Specifically, in our three-city example, the Hub carrier's capacity decisions depend on whether carrier A is a Direct carrier or a Hub carrier.

For example, let carrier A be a Direct carrier which serves all three markets. As a Direct carrier, carrier A does not have the flexibility of adjusting capacities in the second stage. Thus, it commits to its capacity decisions in the first stage. There is an endogenous asymmetry between the two carriers now: only the Hub carrier makes a decision in the second stage. Economic intuition similar to the Stackelberg analysis (Stackelberg (1934)) suggests that the Direct carrier will be more aggressive in terms of capacity, as its capacity decision in the first stage can serve as a strategic commitment. That is, the Direct carrier can commit to a certain point on the Hub carrier's best response curve where its profits are higher than in the Cournot outcome⁹. Taking advantage of its flexibility, the Hub carrier then accommodates the increase in capacity and reduces its quantity in that market. The commitment advantage allows the Direct carrier to increase capacity (relative to the Cournot outcome) in

⁸It does not matter for our results if yield management is done on a route or a leg level.

⁹Our benchmark comparison is the duopolistic Cournot outcome, where capacities for both carriers are set at $q^c = \frac{a-c}{3b}$.

markets it finds to be more profitable. If both carriers serve the entire network, this effect is available only to Direct carriers that compete with a Hub carrier. The difference in network type allows Direct carriers to be more aggressive in more profitable markets and implicitly cherry-pick the profitable routes to focus on.

The Direct carrier's strategic commitment is valuable only when the three markets have asymmetric demand curves. When markets have symmetric demand curves, the commitment leadership is meaningless. The intuition behind this result rests on the notion that the strategic interaction in one market affects the interaction in other routes as well. In general, when both carriers serve the entire network, if the Hub carrier sets the Cournot quantities in the first stage, any deviation by the Direct carrier from the Cournot quantities in a certain market forces the Hub carrier to shift quantity to other markets. Since the Direct carrier serves these markets as well, the Hub carrier's reallocation of quantity may negatively affect the Direct carrier's profitability in these markets. Consequently, when choosing whether to deviate from the Cournot quantities, the Direct carrier tallies the additional profits from its aggressiveness with the lost profits in other markets. It is this cost-benefit calculations that make deviation from the Cournot outcome not profitable when markets have symmetric demand curves. Put differently, the Direct carrier internalizes the effect of its capacity decisions in one market on its profitability in other markets. If markets are symmetric, the Direct carrier's additional profits from its aggressiveness in one market balance out with the lost profits in other markets where it has to back off. Consequently, in equilibrium, the Direct carrier would choose not to deviate from the Cournot quantities - not to take advantage of its ability to commit.

The value of commitment in the case of symmetric markets becomes significant again when the Direct carrier does not serve all markets. Assume, for example, the case where all three markets are symmetric and that carrier A is a Direct carrier serving only market $\langle 1, 2 \rangle$. As before, if the Direct carrier commits to being aggressive in market $\langle 1, 2 \rangle$, the Hub carrier would divert some of its quantity to markets $\langle 1, 3 \rangle$ and $\langle 2, 3 \rangle$. Unlike the previous case, however, now the Hub carrier's reallocation of quantity does not affect the Direct carrier's profitability. Consequently, the Direct carrier finds it profitable to strategically commit to being aggressive in market $\langle 1, 2 \rangle$.

Finally, if all markets are served by two Hub carriers, in equilibrium there is no strategic interaction and the Cournot outcome is obtained in all markets. The following table summarizes the strategic interaction in the three city model:

Setting	3 City Outcome
Two identical Hub carriers	Cournot quantities in all routes
Hub facing Direct. Both serve all markets. Symmetric markets	Cournot quantities in all routes
Hub facing Direct. Both serve all markets. Asymmetric markets	Direct: quantity exceeds Cournot in some market(s); below Cournot in remaining markets. Hub: accommodates
Hub facing Direct. Direct carrier serves a single route	Direct: quantity exceeds Cournot. Hub: accommodates. No effect on other routes.
Two Hub carriers facing a Direct. Direct carrier serves a single route	Direct: quantity exceeds the 3 player Cournot outcome. Hub carriers: quantity is below the 3 player Cournot outcome. Cournot outcome in remaining markets.
Hub facing three Direct carriers. Each Direct serves a single route	Direct: quantity exceeds Cournot in each market. Hub: accommodates

2.2. Multi-City Model. This section generalizes the results from the 3-city example to the \overline{M} -cities case. We first solve the second stage problem, starting with the Direct carrier. A Direct carrier with network Γ^D makes its second stage quantity choice on route $n \in \Gamma^D$ based on its first stage capacities k_n^D and its rival's second stage quantity allocation, q_n^- . The Direct carrier's maximization problem can be written as follows:

$$\Pi^D = \max_{q_n^D} \sum_{n \in \Gamma^D} P_n(q_n^D, q_n^-) q_n^D \quad \text{subject to } q_n^D \leq k_n^D$$

First order condition (FOC) and complementarity condition are then

$$\frac{\partial P_n(q_n^D, q_n^-)}{\partial q_n^D} q_n^D + P_n(q_n^D, q_n^-) = \lambda_n^D; \quad \lambda_n^D \geq 0 \perp k_n^D - q_n^D \geq 0$$

A Direct carrier would utilize all its capacity on a route unless the carrier's marginal revenue from this route is zero for a lower capacity¹⁰. It is not surprising that the solution in equilibrium is $q_n^D = k_n^D$, a result we prove below.

For a Hub carrier with network Γ^H and hub-spoke legs $m \in M^H$, quantity decision per route $n \in \Gamma^H$ depends on its first stage capacities k_m^H and its rival's second stage quantity allocation q_n^- :

$$\begin{aligned} \Pi^H &= \max_{q^H} \sum_{n \in \Gamma^H} q_n^H P_n(q_n^H, q_n^-) \\ \text{subject to} & \quad \text{for all legs } m \in M^H \quad \sum_{n \in \Gamma_m^H} q_n^H \leq k_m^H \end{aligned}$$

¹⁰Theoretically, there could be q_n^D, q_n^- such that $\frac{\partial P_n(q_n^D, q_n^-)}{\partial q_n^D} q_n^D + P_n(q_n^D, q_n^-) < 0$ and $q_n^D < k_n^D$. In those cases the Direct carrier would not use all of its installed capacity and $\lambda_n^D = 0$.

where Γ_m^H is the subset of Γ^H that includes the leg m . The Hub carrier's FOC for the route $\langle m_1, m_2 \rangle$ is

$$\frac{\partial P_{\langle m_1, m_2 \rangle} \left(q_{\langle m_1, m_2 \rangle}^H, q_{\langle m_1, m_2 \rangle}^- \right)}{\partial q_{\langle m_1, m_2 \rangle}^H} q_{\langle m_1, m_2 \rangle}^H + P_{\langle m_1, m_2 \rangle} \left(q_{\langle m_1, m_2 \rangle}^H, q_{\langle m_1, m_2 \rangle}^- \right) = \lambda_{m_1}^H + \lambda_{m_2}^H$$

The Hub carrier's FOC for a route between spoke m and the hub is

$$\frac{\partial P_m \left(q_m^H, q_m^- \right)}{\partial q_m^H} q_m^H + P_m \left(q_m^H, q_m^- \right) = \lambda_m^H$$

The complementarity condition is

$$\lambda_m^H \geq 0 \perp k_m^H - \sum_{n \in \Gamma_m^H} q_n^H \geq 0$$

Under full capacity utilization, the Hub carrier assigns each leg a strictly positive shadow price (λ_m^H) and optimally sets the marginal revenue of a seat on that leg exactly to the shadow price. As a route seat is composed of two "leg seats" (one seat in each leg), the marginal revenue of a route equals exactly the sum of the shadow prices on the legs composing this route ($MR_{\langle m_1, m_2 \rangle} = \lambda_{m_1}^H + \lambda_{m_2}^H$). When demand on a market changes, a hub carrier adjusts quantities across the entire network until marginal revenue in all markets equals the implied shadow prices again.¹¹

The second stage equilibrium quantities are determined by the best responses above. Equilibrium is defined as a vector $Q^*(k)$ which maps the vector of leg-capacities, k , to a vector of route quantities that are an equilibrium in the second stage. The following lemma identifies the main characteristics of the equilibrium correspondence.

Lemma 1. *In equilibrium :*

- (1) *For every vector of capacities k , the vector of equilibrium quantities $Q^*(k)$ exists and is upper semi-continuous.*
- (2) *For a hub carrier, and two non-hub cities m_1 and m_2 , let $MR_{\langle m_1, m_2 \rangle}$ be the marginal revenue for the hub carrier on the route between the two cities, and MR_{m_i} be the marginal revenue for the hub carrier on the route from city $m_{i=1,2}$ to the hub. In any second stage equilibrium $MR_{\langle m_1, m_2 \rangle} = MR_{m_1} + MR_{m_2}$*

Proof. The first part is standard as each carrier's best response is upper-semi continuous in rival quantities. The second part follows from the first order conditions of the Hub carrier's problem. \square

2.2.1. First Stage Solution. To solve the first stage, we assume that minor changes in first stage capacities do not affect equilibrium selection if the second stage supports multiple equilibria. Then, for every vector of capacities k , the second stage outcome $Q(k)$ can be regarded as a continuous function. For notational simplicity, we let

¹¹Note that this implies that the equilibrium is the same whether airlines yield management systems price at the leg or route level.

$Q_n(k)$ denote the aggregate quantity assigned to route n given $Q(k)$, and let $q_n^j(k)$ denote the quantity supplied by carrier j . The Direct carrier's maximization problem is then:¹²

$$\Pi^D = \max_{\{k_n^D\}_{n \in \Gamma^D}} \sum_{n \in \Gamma^D} [q_n^D(k) \cdot P_n(Q_n(k))] - \sum_{n \in \Gamma^D} c_n \cdot k_n^D$$

The Hub carrier's problem is :

$$\Pi^H = \max_{\{k_m^H\}_{m \in M^H}} \sum_{n \in \Gamma^H} [q_n^H(k) P_n(Q_n(k))] - \sum_{m \in M^H} c_m \cdot k_m^H$$

Note that the only difference between the Hub and Direct carrier's maximization problem in the first stage is the set of segments the carriers consider: legs or routes. The core of the analysis is reflected in the carriers' first stage first order conditions. After simplifications presented in the appendix, the condition can be written as:

$$(2.1) \quad MR_l^j + S_l^j = c_l \quad \text{for any leg } l \text{ served by carrier } j$$

where S_l^j is defined to be the *network-structure effect*, given by:

$$(2.2) \quad S_l^j = \sum_n q_n^j P_n' \cdot \frac{dq_n^{-j}}{dk_l^j}$$

It is the network-structure effect that makes our game different from a static Cournot game with cost of c . Indeed, if both S_l^D and S_l^H were zero the equilibrium would be the same as in a Cournot game, where each firm equalizes marginal revenue to marginal cost in each market. However, in many cases the effect in our model is not zero. The sign of S_l^J determines whether carrier J is more or less aggressive, in terms of capacity, relative to the simple Cournot game. Specifically, when $S_l^j > 0$ carrier j is more aggressive in markets that use leg l . For a Direct carrier this implies a larger capacity in the single market l . For a Hub carrier, S_l^j affects all markets to or from the spoke l . In a Direct vs. Hub setting, the Hub carrier's network structure effect is zero. Based on Lemma 1 in Farrell and Shapiro (1990), the sign of the deviation by the Direct carrier then determines the sign of the change from the Cournot outcome.¹³

Corollary 2. *In a Direct vs. Hub competition market quantities are larger (smaller) than the Cournot equilibrium outcome if and only if the Direct carrier's network-structure effect in that market is positive (negative)*

Before we analyze the components of the network structure effect, we first verify that all carriers will use all their capacity in the second stage and so the second stage solution is interior. Second stage decisions depend on

¹²Recall, we abstract from efficiency advantages and thus set $c_n = c$ for a hub-spoke route and $2 \cdot c$ for a route connecting two spokes.

¹³The Lemma states that if a single firm deviates from the Cournot quantities, the overall change in quantity in the market moves in the same direction as the change by the deviating firm regardless of the deviating firm's strategy. Given our setting, the Lemma applies in our game.

own leg capacities and rival's actual route quantities. Thus, capacity that will not be used does not affect rival's first stage decisions or own revenues but does generate additional costs.

Lemma 3. *There is no excess capacity in the game : $q_n^D = k_n^D \forall n \in \Gamma^D$ and $\sum_{n \in \Gamma_m^H} q_n^H = k_m^H \forall m \in M^H$.*

Proof. Assume, first, that there is some excess capacity for a direct carrier on route n : $q_n^D < k_n^D$. By the complementarity condition, it must be that $\lambda_n^D = 0$. Then $\frac{dq_n^D}{dk_n^D} = 0$. Clearly for all other routes n' , $\frac{dq_{n'}^D}{dk_n^D} = 0$. As the rival's reaction to a change in k_n^D is indirect through the second stage quantities is $\frac{dq}{dk_n^D} = 0$ the derivative of the direct carrier's profit with respect to capacity $\frac{d\Pi^D}{dk_n^D} = -c_n$ and so the carrier's profits increase by reducing k_n^D . If the excess capacity is on a hub-Spoke segment for a Hub carrier, then the marginal revenue on that route is zero and by similar arguments the hub carrier does strictly better by reducing capacity. \square

2.3. The Competitive Effects of Network Structure. Differences in network structure between carriers determine the equilibrium strategic effect on a leg and through it the deviation from the Cournot equilibrium outcomes. Equation 2.2 identifies three components of the network-structure effect for each market: my rival's reaction $\left(\frac{dq_n^{-j}}{dk_i^j}\right)$, the market effect of my rival's reaction (P'_n) and my "interest" in the specific market (q_n^j) . To isolate the connection between carrier network type and the competitive outcome we first start with the case of two carriers serving the same markets, with the only difference being the carrier type (Direct vs. Hub-and-Spoke) and then evaluate the effect of different network coverage. For simplicity, we assume that a Hub carrier has a single Hub.

2.3.1. Hub vs. Direct with Identical Networks. Lemma 3 implies that if a carrier increases capacity in leg l the additional capacity will be sold. Whether an increase in capacity would induce a response from the opponent then depends on the opponent's type. The Hub carrier recognizes that an increase in its capacity on any specific legs would not be accommodated by its rival. The $\frac{dq_n^{-j}}{dk_i^j}$ element in the definition of S^j in equation 2.2 is zero if the rival carrier is a Direct carrier. Thus, there are no strategic implications for additional capacity by the Hub carrier : $S_l^H = 0$ for all of the Hub carrier's legs. In contrast, Lemma 1 implies that the second stage reaction $q^H(k)$ is governed by the equality $MR_{m_1, m_2} + MR_{m_3, m_4} = MR_{m_1, m_3} + MR_{m_2, m_4}$. Specifically, when the Direct carrier increases capacity in market (1, 2), $MR_{1,2}^H$ decreases. The Hub increases marginal revenue in routes that do not use legs 1 and 2 ("unconnected" routes) by diverting seats away from these routes as well as the original 1,2 route. The diverted seats are used by the Hub carrier in routes that use legs 1 or 2 ("connected" routes), causing a decrease in marginal revenue in these routes. These reactions are captured by $\frac{dq_n^H}{dk_l^H}$. The total effect on the Direct carrier's profitability from deviating in a single route is the sum of the Hub's reaction multiplied by the market reaction (P'_n) and the Direct's quantity (q_n^D) over *all* markets . If market demand in all markets is

identical (implying $q_n^D = q_{n'}^D = q^D$ and $P_n' = P_{n'}' = P'$), the total effect would equal the aggregate change in the Hub carrier's quantities over all markets, multiplied by the constant $q^D \cdot P'$. However, as the Hub carrier would still use all of its capacity in the second stage, this aggregate change is exactly zero and thus the strategic effect for the Direct carrier is zero. If demand varies across markets, this sum will generally be different than zero at the Cournot quantities (except for pathological cases). Relative to the Cournot benchmark, the Direct carrier will deviate by adding capacities on some markets and removing capacities from others. The Direct carrier's ability to commit in the market is thus a type of Stackelberg leadership, but it is not the classical Stackelberg leadership. The opponent is simultaneously choosing *aggregate* quantities, so some commitment is made in the first stage by the opponent as well. The leadership matters only when *capacity allocation across markets* is important. Strategic returns for Direct networks exist only if demand varies across markets such that some markets are more profitable than others.

Proposition 4. *If markets are symmetric and all carriers serve all markets, then $S_l^j = 0$ for all carriers in all legs. The game's equilibrium in each market is the Cournot equilibrium with first stage costs. In converse, if demand varies across markets, $\frac{P_n(Q)}{c_n} \neq \frac{P_{n'}(Q)}{c_{n'}}$, and markets are served by a Direct and a Hub carrier, then equilibrium quantities in each market are different than in the Cournot equilibrium. The Direct carrier's profits are higher than the Hub carrier's profits and than the Cournot profits.*

Proof. See above for intuition, and the appendix for a proof. The effect on profits follows from the fact that a Direct carrier can always induce the market to arrive at the Cournot outcome by setting the Cournot quantities. Since the Direct carrier *chooses* to deviate, its profits are higher. \square

When the Direct carrier picks market n to dominate, it has an incentive to reduce capacity in connected markets and increase capacities in unconnected markets. The Hub carrier's reaction reduces the market clearing price (and thus marginal revenues) in connected markets and has the opposite effect on unconnected markets. In addition, reducing capacity in connected markets by the Direct carrier "encourages" the Hub carrier to move more of its quantity out of the desired route. Applying corollary 2, it follows that some routes will be served with less than the Cournot equilibrium quantities, while others would be served more. The equilibrium outcome for one market depends on its "attractiveness" relative to the other markets. In previous studies, the negative outcome relative to the Cournot benchmark occurs when there is some overall upper bound to capacity, increasing marginal costs or possible collusion. Our analysis shows that in the airline industry, the network structure effect can result in the same outcome without these assumptions. The strategic advantage for the Direct carrier is its ability to commit in the first stage to serve the more profitable markets. This commitment is a best response to the Hub's first stage capacities only if the Direct carrier also reduces capacities in the less desirable markets.

Corollary 5. *In a Direct vs. Hub competition, if both carriers serve all markets and demand varies across markets, some markets would be served at quantities lower than the Cournot quantities.*¹⁴

2.3.2. Two Carriers with Different Networks. To isolate the role of network coverage, consider two carriers (A and B) serving cities M^A and M^B and carrier B using a Hub-and-Spoke network. Furthermore, assume that all of the network's markets are symmetric. The set of all markets (N) can be divided to three groups : markets that are served by both carriers (N^*) , markets served only by carrier A (N^A) and markets served only by carrier B (N^B) . Letting q^C denote the quantity sold per firm in the Cournot duopoly equilibrium in each market, equation 2.2 at the Cournot quantities is simplified to

$$(2.3) \quad S_i^A = q^C P'(2 \cdot q^C) \cdot \sum_{n \in N^*} \frac{dq_n^B}{dk_i^A}$$

Markets served only by carrier A do not affect S_i^A because $\frac{dq_n^B}{dk_i^A} = 0$ in these markets (B cannot react in markets it does not serve). Markets served only by carrier B do not affect S_i^A because $q^A = 0$ in those markets. By symmetry, the remaining markets have identical quantities and price derivatives at the Cournot equilibrium. Thus, the strategic effect of deviating in first stage quantities on a leg depend only on the fraction of the rival's response that is in the shared network ($\sum_{n \in N^*} \frac{dq_n^B}{dk_i^A}$). If both carriers serve the same markets $N^* = N^A = N^B$ the sum of the rival's response over all markets is exactly zero and so $S^A = 0$ in all legs.

If the carrier's networks do not fully overlap, the sign of S_i^A depends on carrier's A type and the specific network overlap. If A is also a Hub carrier, extra capacity to leg l will be spread along all of A's routes that use this leg, decreasing the marginal revenue in these routes. B's leg capacities are set and so it is limited to redistributing seats along its routes that use the same leg ("connected routes"). As the routes are symmetric, B will not gain by the redistribution unless some of its connected routes are not served by A and thus did not suffer the decrease in marginal revenues. If such routes exist, B would divert quantity from the routes served also by A to routes that are not served by A ($\sum_{n \in N^*} \frac{dq_n^B}{dk_i^A} < 0$) and the overall effect for A is positive.

If carrier A is a Direct carrier and adds capacity in a single route l (recall that for a Direct carrier a route is a leg), B will redistribute seats to all of its other routes that are connected to l , diverting seats from unconnected markets. $\frac{dq_n^B}{dk_i^A}$ will be negative for market l and unconnected markets and positive for connected markets. The overall effect for A thus depends on the exact routes it serves. Connected markets that overlap with carrier B reduce the network structure effect and other markets (weakly) increase it. The effect of multi-market competition

¹⁴It may be tempting to assume some ordering between routes that allows identifying which markets are served more or less than Cournot. However, even with four cities, it is easy to construct examples to show that the sign of the deviation in any market cannot be determined independently from costs and demand primitives in *all* other markets served by *all* carriers in that market. Section 3 uses a specific variant of this result to test the model's validity.

between two carriers varies between markets and depends on the overlap in connected markets rather than overlap in general. The next proposition summarizes :

Proposition 6. *In a two carrier competition, if all markets are symmetric*

- (1) If both carriers (A and B) are Hub carriers and $M^A \subset M^B$ then $S_l^A > 0$ for all legs in carrier A's network. In equilibrium, carrier A's quantities exceed the Cournot quantities, and carrier B's quantities, in markets where it competes with carrier A, are below the Cournot quantities.
- (2) If two Hub carriers' networks overlap only partially ($M^A \setminus M^B \neq \emptyset$ and $M^B \setminus M^A \neq \emptyset$) then $S_l^A > 0$ and $S_l^B > 0$ for $l \in M^A \cap M^B$
- (3) If markets n and n' are served by two carriers, A and B. Let $\rho(n)$ denote the fraction of markets connected to market n that both carriers serve. If $\rho(n) > \rho(n')$ the carriers will compete softer in n than in n' .

Proof. In the Appendix. An intuitive explanation is provided above. □

To illustrate the implications, consider two large Hub carriers that overlap on a small subset of their networks. For example, while Delta and Northwest both serve a very extensive network in the US, the location of their main hubs (Atlanta and Minneapolis, respectively) implies that most of their domestic US networks do not overlap¹⁵. On routes served by both Delta and Northwest, if Northwest sets leg capacities to support second stage quantities that are higher than the Cournot outcome, Delta's reaction will be mostly in markets not shared by Northwest. Consequently, Northwest will not internalize the effect in these markets. As a result, Northwest would have a positive strategic effect in the shared routes and would thus set larger capacities on legs that serve overlapping markets. A similar effect applies to Delta. As the commitment is at the leg level rather than the route level, if all markets are otherwise identical both carriers will end up with a slightly positive network structure effect on the legs that serve the overlapping markets, increasing quantities in all markets served by these legs, overlapping or not.

Network overlap implies multi-market contact. Bernheim and Whinston (1990) is the first formal study of multi-market contact (MMC) and suggests that in some cases MMC decreases competition by facilitating collusion. The main prediction of the collusive effects of MMC and of proposition 6 is identical - carriers compete softer if their networks overlap. However, the distinction made in part 3 of the proposition suggests a possible test to the validity of our model. Specifically, the effect of MMC on collusion in market n does not depend on the degree of overlap in connected vs. unconnected markets. In contrast, in our model, MMC reduces competition in a market only if there is a high degree of overlap in connecting markets. In section 3.1 we discuss the existing empirical evidence and suggest that it indeed supports the validity of our model.

¹⁵This is the exact opposite to American Airlines and United Airlines, which have close hubs and mostly overlapping networks.

2.3.3. *More Than Two Carriers.* The preceding discussion was limited to two carriers with at least one large Hub carrier. The construction of the network structure effect does not change when we increase the number of carriers.¹⁶ Therefore, all the previous results except corollary 2 continue to hold. The next proposition extends corollary 2 to the general oligopoly case.

Proposition 7. *Overall market quantities in a market are larger (smaller) than the Cournot outcome if and only if the sum of the carriers' strategic effects is positive (negative)*

Proof. See appendix. □

We conclude this section with a simple limit result. Assume that one carrier in a market is so large and flexible that it can costlessly absorb any market change by diverting capacity to its connected markets without having an effect on its profits in these other markets. While this setting is ruled out in our model by assumption, there are application related reasons to consider this case. Examining the US domestic market, we find that most markets served by the major Hub-and-Spoke carriers are extremely small relative to the capacity the carriers assign to both legs of the routes. For example, the Des Moines, IA - Tampa Bay, FL market is extremely small relative to the capacity major carriers (United, AA, and Delta) allocate to flights from these cities to its hubs. In any equilibrium, if for some reason United Airlines would be forced out of the Des Moines - Tampa Bay market, it will be able to easily reallocate the seats to other domestic or international flights without having a noticeable effect on its profits.¹⁷ Simple analysis shows that if a Direct carrier can serve such a market, it will become a Stackelberg leader in this market. Indeed, the market is served twice a week by a Direct carrier - Allegiant Airlines¹⁸. While it is difficult to isolate the strategic effect from other considerations (in particular preferences toward non-stop flights), we would expect Allegiant to be significantly more aggressive than any other carrier when targeting travelers that have no strong preference to any specific airline.¹⁹

2.4. **Welfare and Horizontal Mergers.** The effects identified above have implications on welfare and antitrust policy, specifically with regards to mergers. The discussion will focus on mergers between carriers of the same type (mergers between two Hub carriers or two Direct carriers) as these are the dominant cases.²⁰ The analysis builds on Farrell and Shapiro (1990) (FS), which analyze equilibrium welfare effects in Cournot competition. In FS, horizontal mergers have two effects: a merger decreases the numbers of competitors and potentially decreases

¹⁶With J carriers, the effect of carrier A is simply $S_l^A = \sum_{n \in N^*} q_n^A P'_n \cdot \left(\sum_{j \in J, j \neq A} \frac{dq_n^j}{dk_l^A} \right)$

¹⁷For example, based on the DB1B data detailed below, we estimate that in Q4 of 2007, the median route (weighted by passengers) for a large carrier used less than 0.5% of the domestic seats on the legs used for that route.

¹⁸Allegiant Airlines sells only point to point routes.

¹⁹As our empirical section focuses on quantities rather than prices, we leave this point for future research.

²⁰Kim and Singal (1993) and Morrison (1996) review the major airline mergers in the US in the 1980's - all of which were between Hub carriers.

the (marginal) variable costs of the merged firm. Our analysis assumes that firms have identical marginal costs but the network structure effect changes equilibrium quantities as if marginal costs are different. As a result, mergers that increase the network structure effect (S_i^j in equation 2.1) may increase total welfare and consumer surplus even if the merging firm does not enjoy any efficiencies in variable costs; an outcome impossible in the FS single market Cournot analysis. If the merger does introduce cost efficiencies, our analysis shows how the FS analysis can be augmented in the airline setting for the effect of changes in network structure.

The analysis for mergers that do not affect variable costs is based on the following corollary derived from proposition 7:

Corollary 8. *Consumer and Total Surplus in a market are higher (lower) than in the Cournot outcome if and only if the sum of the network structure effects over all carriers serving the market is positive (negative).*

Determining whether the overall effect of a merger on all markets is in general positive or negative is impractical as it depends on many factors. Indeed, the main conclusion from our analysis is that evaluating mergers only on a route level base can be misleading. The structure of all affected carriers before and after the merger determines the overall effect. To illustrate these considerations, we consider some of the more common types of mergers and horizontal alliances that occurred in the airline industry in the last thirty years. In extreme cases, a merger could change the type of equilibrium a market is in: from Stackelberg to Cournot. Assume, for example, a merger between a large carrier and a small carrier. In the markets served by the small carrier, the merger removes a small, and thus a more aggressive, player. Consequently, quantity in these markets would reduce by more than the decrease that results from moving from $N - 1$ to N players. Quantity in these markets decreases also because we are moving from a Stackelberg-like market structure to a Cournot-like equilibrium.²¹ In contrast, a merger between two large carriers, which preserves competition in all markets, removes a Stackelberg-follower or a Cournot player and thus the drop in welfare is smaller. Obviously, there are many possibly negative implications for a merger between two very large carriers. The reduction in the level of competition affects more markets and the merger may result in too much market power (capacity and control of hubs) in the hands of a single carrier, decreasing welfare in known ways. Nevertheless, our model suggests that mergers that eliminate a large player while keeping markets competitive may result in higher welfare than mergers that eliminate small but efficient carriers.

Corollary 9. *Assume three Hub carriers A, B, C serving cities $M^A \subset M^B \subset M^C$. If a merger does not introduce operational efficiencies then the welfare in markets served by A is reduced more in a merger that involves carrier A than in a merger that involves carriers B or C .*

²¹The effect remains but is less pronounced if there are several small players and several large players.

If a merger increases the sum of the network structure effects on all legs without decreasing the number of carriers, quantity sold (and thus welfare) will increase on all routes even without any variable cost reductions. In the special case that the merging carriers do not overlap and do not have strong network structure effects before the merger, the merging carriers' rivals will see an increase in their network structure effect after the merger. The merged carriers legs serve many more routes post merger and thus make the merged carriers more flexible. As a result, the merger rivals become more aggressive and overall quantity and welfare increase.

While this may seem an extreme case, it in fact has implications to an important issue in the airline industry - antitrust immunity for international alliances. International alliances that are given antitrust immunity are essentially given permission to act as a merged firm for the short term analysis. These alliances are typically between very large carriers that have low strategic effects in their existing routes. Park and Zhang (2000) study the main north Atlantic alliances in the 1990's (British Airways/USAir, Delta/Sabena/Swissair, KLM/Northwest, and Lufthansa/United Airlines).²² Their analysis concludes that a complementary alliance (between carriers with low network overlap e.g., BA/USAir, KLM/NW, LH/UA) is likely to increase total seat miles sold and consumer surplus. In contrast, a parallel alliance (between carriers with high network overlap e.g., DL/SN/SR), is likely to reduce total seat miles sold and consumer surplus²³. The condition $M^A \cap M^B = \emptyset$ is required for two reasons. First, it guarantees that the merger does not reduce the level of competition in any market. Second, from proposition 6 we know that a small overlap generates a positive network effect which would be lost in the merger.

Corollary 10. *In the special case of a merger between two carriers A and B such that (i) $M^A \cap M^B = \emptyset$, (ii) at least one carrier is not a monopolist on all its routes, (iii) $S^A = S^B = 0$ on all legs served by either carrier, and (iv) the merged carrier serves all of A's and B's pre-merger routes, then the merger increases consumer and total surplus even absent any cost efficiencies.*

In the previous example, the merger increased the rival firms' network effect and thus had a positive effect on welfare. For the merging firms, the merger can only reduce their own network effect as the merged firm internalizes more deviations than the two pre-merger firms. This negative effect of the merger is not due to any reduction in competition. It could be that A and B never competed before the merger. The merger makes the carriers more flexible and thus "softer" in terms of capacity, causing a reduction in welfare.

Corollary 11. *Consider a merger between two carriers A and B such that all of the network effects for A's and B's rivals are zero. In the absent of any cost efficiencies, the merger weakly reduces surplus .*

²²Not all alliances were granted "antitrust immunity". See the discussion in Park and Zhang (2000) for details.

²³Of course, the result is due also to a likely reduction in variable costs and an increase in consumer utility from flying. These are investigated by Park and Zhang (2000) .

To summarize, small carriers increase welfare through their commitment power. Mergers make carriers larger, flexible and “softer” and thus tend to reduce welfare even without any direct effect on competition or efficiency. The negative welfare effect of mergers is larger for smaller carriers and for carriers with significant network overlap.

3. EMPIRICAL EVIDENCE

Our model finds that the network-structure effect generates inter-dependencies between markets, connected as well as unconnected. The degree of interdependency depends on the carriers' type and the network overlap. This section presents two empirical tests of our model's predictions. First, we test the predictions of our model on the effect of network overlap. Specifically, we test the predictions that differ from the standard multi-market collusion predictions (e.g. Evans and Kessides (1994)). Second, we test for evidence that changes in flexibility on a route affects competitive outcomes on other routes. This is a unique prediction of our model.

3.1. The Effect of Network Overlap. As we mention in section 2, network overlap implies multi-market contact (MMC), which in turn may facilitate collusion; decreasing the level of competition in the market. The collusive effects of MMC are empirically similar to the prediction of proposition 6 - carriers compete softer if their networks overlap. This main result has been verified in previous studies (e.g. Evans and Kessides (1994)). However, the distinction made in part 3 of the proposition provides a possible test to the validity of our model. Specifically, the proposition states that MMC decreases competition between carriers on a route only to the extent that MMC is on routes connected to this route.

To test this prediction, one can examine changes in the intensity of competition on a route as a function of changes in the degree of network overlap between the carriers competing on the route, distinguishing between overlap in connected and unconnected markets. The hypothesis resulting from our model is that

Conjecture 12. *The reduction of rivalry from multimarket contacts is greater for contacts in markets that share the same origin or destination.*

The reduction of rivalry on route n stems from carrier A internalizing its rivals' reaction to excess capacity on a leg that is used for the route. If a rival's reaction is limited to routes that carrier A does not serve, “rivalry” on route n would increase. Therefore, we can refine the conjecture as follows:

Conjecture 13. *Carrier A will be more aggressive in market n if A's rivals serve connected markets that A does not serve.*

These predictions can be tested based on the results reported in Gimeno and Woo (1999) (hereafter GM99).²⁴ There, the authors test the effect of multi market contact in connected and unconnected markets on carrier price (yield). The models of interest for us are Models 3 and 4 in Table 3 (p. 252). The models specification is

$$Price_{imt} = \beta X_{imt} + \theta_1 MMC_{imt}^{Connected} + \theta_2 MMC_{imt}^{Unconnected} + \theta_3 NC_{imt}^{Connected} + \theta_4 NC_{imt}^{Unconnected}$$

The model uses a panel of US domestic scheduled passenger flights from 1984 to 1988 (DB1A) with an observation defined as a carrier-route-year. X_{imt} is a set of controls. The variables of interest are :

- $MMC_{imt}^{Connected}$ - a count measure of the degree of multi-market contact between carrier i and its rivals in market m over markets *connected* to m
- $MMC_{imt}^{Unconnected}$ - a count measure of the degree of multi-market contact between carrier i and its rivals in market m over markets *unconnected* to m
- $NC_{imt}^{Connected}$ - a count measure of the number of *connected* markets that carrier i 's rivals serve and i does not.
- $NC_{imt}^{Unconnected}$ - a count measure of the number of *unconnected* markets that carrier i 's rivals serve and i does not.

According to conjecture 1 θ_1 should be positive and θ_2 insignificant, while according to the collusion hypothesis θ_1 and θ_2 should be positive and similar. Conjecture 2 predicts that θ_3 will be negative. Our model says nothing about θ_4 , which we include for completeness and as a control. The results reported in GM99 are provided in table 1. Model 3 focuses only on the collusion hypothesis and sets $\theta_3 = \theta_4 = 0$. Model 4 is the full specification.²⁵ Both models strongly support our conjectures. The effect of multi-market contact in connected markets (θ_1) is positive and significant while the effect for unconnected markets (θ_2) is statistically insignificant in model 3 and barely significant at the 10% level in model 4. The null hypothesis that the effect of multi-market contact is independent of whether the contact is in connected or unconnected markets ($\theta_1 = \theta_2$) is rejected at the .01% level, further confirming conjecture . Model 4 also provides strong support for conjecture 2. The coefficient of interest (θ_3) is negative and significant at the .01% level while the control (θ_4), is much smaller in magnitude. The null hypothesis $\theta_3 = \theta_4$ is rejected at the .01% level.

²⁴The analysis in GM99 interprets the results reported below as evidence that carriers' capabilities in markets connected to market n make them stronger competitors in market n . GM99 refer to connected markets as markets that offer "strong resource sharing" capabilities and unconnected markets as markets that offer "weak resource sharing" capabilities. The presentation here uses the concepts use in our analysis and focuses only on the relevant part of the results. The original complete table from GM99 is provided in the appendix for reference.

²⁵These are the only reported specifications in GM99 that include our variables of interest.

Independent Variable	Model 3	Model 4
MMC Connected (θ_1)	2.31*** (0.32)	1.75*** (0.37)
MMC Unconnected (θ_2)	0.03 (0.03)	0.05 ⁺ (0.03)
NC Connected (θ_3)		-0.97*** (0.25)
NC Un-connected (θ_4)		-0.04 (0.32)
Probability of rejection for $\theta_1 = \theta_2$	> 0.999	> 0.999
Probability of rejection for $\theta_3 = \theta_4$		> 0.999

TABLE 1. Parameters of interest from models 3 and 4 in GM99, table 3. Standard errors are reported in paranthesis. The dependent variable is price. A superscript *** denotes estimates significant at the .001 level. ⁺ denotes significance at the .1 level.

3.2. Changes in Flexibility - In Progress.

4. CONCLUSION

Airline carriers compete on many markets. In this paper, we identified a new connection between the airline industry's mechanics and market competition. Carriers schedule flights before competing and different carriers have different flexibility in their use of scheduled flights. Direct carriers commit to an allocation of seats per market (route) when scheduling flights, while Hub carriers have the ability to use seats allocated to a single leg for many routes - all the routes using this leg. Hub carriers' flexibility increases with the size of their network - the number of routes that can use each leg. When a less flexible carrier (a direct or a small hub carrier) competes with a more flexible carrier, the former can take advantage of its rival's flexibility and commit to an aggressive seat capacity for the shared market. The commitment advantage allows direct carriers to pick the most profitable markets to dominate, forcing their hub carrier rivals to accomodate.

The effect identified here can explain observed trends in multi-market competition in the airline industry. An increase in network overlap between carriers motivates softer competition. Our model departs from the existing interpretation of this trend in two important ways. First, the softer competition may not indicate even implicit collusion. With low overlap carriers did not internalize the effect of being more aggressive on a specific market on their rival's other markets. As carriers' networks increase in overlap, the degree of internalization increases and carriers become softer. Second, softer competition in a market depends on overlap in connected markets rather than on general network overlap as these are the markets affected by "local" aggressive strategies. This refinement in prediction is confirmed by the results present in Gimeno and Woo (1999). We also find indirect empirical support for our model in the reaction of carriers to changes in the competitive environment of the networks they serve. When a carrier's network changes to make it less flexible on a route, the carrier's market share will increase, especially if it's rival is a direct carrier.

We conclude with several possibilities for extending the analysis. First, cost efficiencies stemming from economies of scope are often seen as a central advantage of the Hub and Spoke system (cf. Oum, Zhang and Zhang (1995)). Therefore, a possible tradeoff for a carrier could be extending its network at the cost of changing from a point-to-point to a hub and spoke network. As a result, direct carriers may be less likely to enter new routes, as these reduce their strategic advantage in the routes they already operate. Consequently, a Direct carrier would tend to first grow internally within a market (by adding frequency) and only then, if at all, enter new markets. Our model assumed carriers' networks are exogenously given, abstracting away from these considerations. Second, our analysis assumed a seat on a route is a homogenous good, while it is well known that each market is split to different product "classes". Incorporating product choice with network choice is an interesting challenge for future research.

Finally, it is often suggested that the the airlines market has a high degree of demand uncertainty²⁶. If uncertainty is resolved between the first (capacity setting) stage and the second stage, hub carriers have an advantage compared to direct carriers (and similarly large hub carriers to small ones). We expect that this advantage would be reflected more in profits than in behavior (i.e. capacity allocation).²⁷ More generally, van Damme and Hurkens (1999) consider a Cournot model with demand uncertainty that is resolved over time and two firms that choose when to commit to capacities and show that if uncertainty is sufficiently large, the only equilibrium is a Cournot equilibrium - neither firm would like to move first. It is interesting that the main result from van Damme and Hurkens (1999) connects the timing choice with the firm's underlying costs. In their Theorem 1 van Damme and Hurkens (1999) (p.) conclude that the Stackelberg equilibrium in which the efficient [lower cost] firm leads and the inefficient [higher cost] firm follows is the risk dominant equilibrium of the endogenous quantity commitment game and that this equilibrium maximizes producer and consumer surplus. These results suggest that under demand uncertainty with two carriers that have different cost structures, if uncertainty exists but is not too large, the equilibrium in which the low cost carrier serves as a direct carrier and the high cost carrier as a hub carrier maximizes welfare and producer surplus.

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²⁶We have learned this from discussions with practitioners but could not find documented evidence

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APPENDIX A. FORMAL REACTION FUNCTIONS ANALYSIS

The size effect can be illustrated by considering the large Hub carrier's reaction function in a two-carriers setting. For now, let the small carrier be a single market Direct carrier. In a simple Cournot game, all players set marginal revenue to marginal cost. In the subgame of our setting, the Hub carrier balances marginal revenue

across all markets ²⁸. If the Direct carrier increases quantity, marginal revenue for the Hub carrier in this market drops. While in a static Cournot game the Hub carrier will reduce capacity and recover costs so that $MR=MC$, the Hub carrier in our model already sank its costs and instead balances marginal revenues. To do this, the Hub carrier pulls some quantity out of this market and places it in other markets it serves; reducing marginal revenue in these markets as well. Thus, the amount by which the Hub carrier has to increase marginal revenue in order to satisfy the FOCs of the subgame is less than that of a simple single-market Cournot game. This implies that the quantity the Hub carrier pulls out is smaller than that of the simple single-market Cournot game. As Figure A.1 shows, the Hub carrier's reaction curve, $q^H(q^D)$, is flatter than the one it would have had was it a single-market Cournot game. Given a flatter reaction function the point at which the Direct carrier's reaction function crosses that of the Hub carrier's is now down and to the right on the graph. (See the left graph of Figure A.1).

Now allow the Direct carrier to serve more than one market. As before, when the Direct carrier adds capacity to any specific market, the large Hub carrier will respond by pulling some quantity out of that market and into its other markets. Unlike before, the Direct carrier serves some of these markets as well. Internalizing this effect, the Direct carrier is now not as aggressive and its reaction curve is flatter than that of a simple single-market Cournot game. Nevertheless, the new equilibrium is still down and to the right of the single-market Cournot equilibrium: the Direct carrier is more aggressive in terms of quantity relative to the single-market Cournot game. The amount by which the Direct carrier's other markets are affected depends on the size of its network relative to the large Hub carrier's network. Specifically, when the large Hub carrier has a very extensive network, the effect is insignificant as the large carrier splits the removed quantity over all its markets.

²⁸As the Hub carrier has no strategic effect, ($S_i^H = 0$), balancing marginal revenue across all markets results in maintaining marginal revenue in all markets equal to marginal cost for the Hub carrier. However, the discussion here considers second stage reactions, given first stage quantities and so marginal revenues deviate from marginal costs.

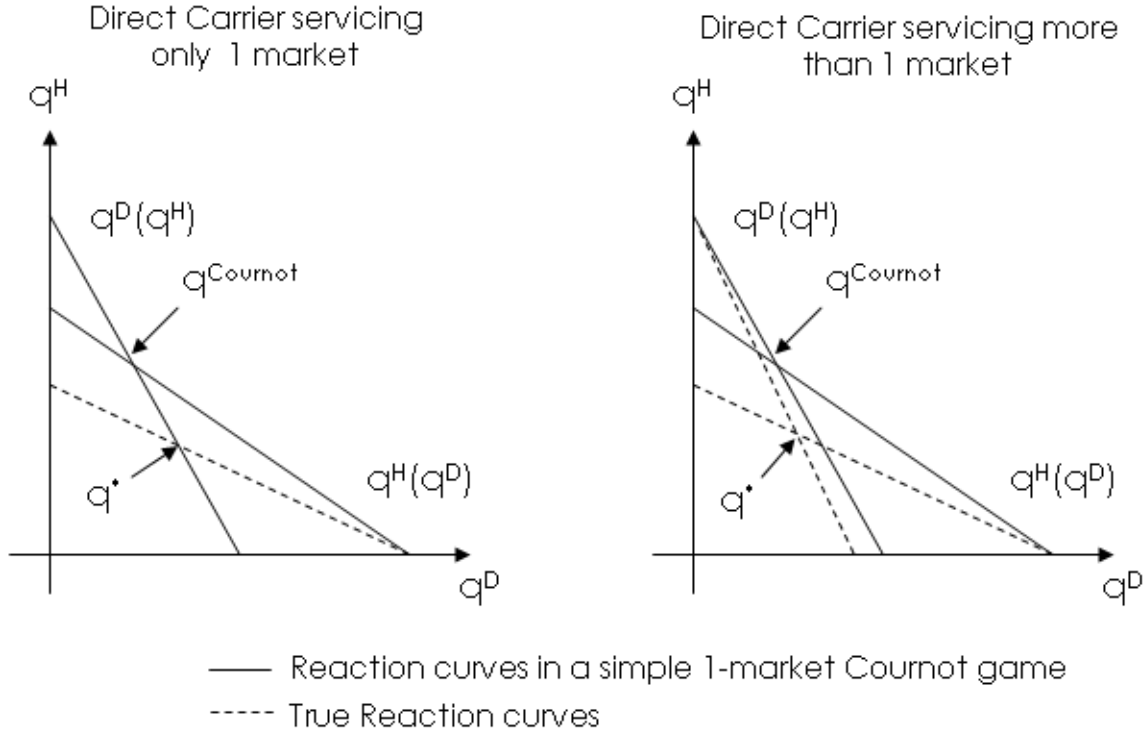


FIGURE A.1. Reaction Curves when a small carrier (D) services a single market (left) and few markets (right). The larger carrier's reaction curve is $q^H(q^D)$

For small carriers, most of the effect of any rival's excess capacity is spread across markets the carrier does not serve. The larger the carrier, the more it internalizes the negative effect of an increase in its capacity. Consequently, p

APPENDIX B. PROOFS AND DERIVATIONS

B.1. Deriving the First Stage Solution. We show for a hub carrier. The development for a direct carrier is immediate.

The Hub carrier's problem is

$$\Pi^H = \max_{\{k_m^H\}_{m \in M^H}} \sum_{n \in \Gamma^H} [q_n^H(k) P_n(q_n(k))] - \sum_{m \in M^H} c_m^H \cdot k_m^H$$

Taking first order condition w.r.t. k_m^H is :

$$\sum_{n \in \Gamma^H} \frac{dq_n^H}{dk_m^H} P_n + \sum_{n \in \Gamma^H} q_n^H P'_n \left(\frac{dq_n^H}{dk_m^H} + \frac{dq_n^-}{dk_m^H} \right) = c_m^H$$

Rearranging

$$\sum_{n \in \Gamma^H} \frac{dq_n^H}{dk_m^H} (P_n + q_n^H P'_n) + \sum_{n \in \Gamma^H} q_n^H P'_n \frac{dq_n^-}{dk_m^H} = c_m^H$$

Placing $S_m^H = \sum_{n \in \Gamma^H} q_n^H P'_n \frac{dq_n^-}{dk_m^H}$ and $MR_n^H = q_n^H P'_n + P_n$

$$\sum_{n \in \Gamma^H} \frac{dq_n^H}{dk_m^H} MR_n^H + S_m^H = c_m^H$$

For the first element we use the second stage result $MR_{\langle m_1, m_2 \rangle} = MR_{m_1}^H + MR_{m_2}^H$ for a two spoke route and $MR_{m_1}^H$ if m_2 is the hub.

Any change in quantities on a route $\langle m_1, m_2 \rangle$ such that $m_1 \neq m$ and $m_2 \neq m$ must be compensated by an opposite change on those routes. Therefore, all such changes cancel out. We can focus on routes that include the leg with a changed capacity $\langle m, m_1 \rangle$. Any change on a route other than from m to the hub must be compensated by a change in some other routes to balance the quantities again. Without loss of generality (following $MR_{\langle m_1, m_2 \rangle} = MR_{m_1}^H + MR_{m_2}^H$) can assume that all the compensation is done on the route between m_1 to the route. Therefore, the added revenue is $\frac{dq_{\langle m, m_1 \rangle}}{dk_m} \left(MR_m + MR_{m_1} - MR_{m_1} = \frac{dq_{\langle m, m_1 \rangle}}{dk_m} MR_m \right)$. The interior solution guarantees that $\sum_{m_1 \in M^H \setminus m} \frac{dq_{\langle m, m_1 \rangle}}{dk} = 1$ and so the desired result is obtained

$$MR_m^H + S_m^H = c_m^H$$

B.2. Proof for proposition 4. If all carriers serve all markets and markets are symmetric $S_l^j = 0$ for all carriers j and all legs l . If one carrier is a direct carrier and the other a hub carrier and markets are asymmetric, $S_l^j \neq 0$ for the direct carrier in some markets and thus quantities will differ from the Cournot quantities. The Direct carrier's profits are higher than the Hub's and than the Cournot profits.

Proof. $S_l^j = 0$ for all carriers in all markets if and only if the Cournot equilibrium is played in all markets. Starting in the cournot equilibrium let q_n^c denote the single firm quantity and Q_n^c the total market quantity in market n . If all markets are symmetric, $q_n^c = q^c$ for spoke-to-spoke markets and $q_n^c = \frac{q^c}{2}$ at the Cournot equilibrium in all markets. The strategic effect can then be written as

$$S_l^j = q^c P'(Q^c) \cdot \sum_{n \in N^{S-S}} \frac{dq_n^H}{dk_l^j} + \frac{q^c}{2} P'(Q^c) \cdot \sum_{n \in N^{H-S}} \frac{dq_n^H}{dk_l^j}$$

Each carrier $i \neq j$ has

$$\sum_{n \in N^{S-S}} \frac{q_n^i}{2} + \sum_{n \in N^{H-S}} q_n^i = \sum_l k_l^i$$

If $\sum_{n \in N^{S-S}} \frac{dq_n^H}{dk_l^j} = a \neq 0$ then from the capacity constraint $\sum_{n \in N^{H-S}} \frac{dq_n^H}{dk_l^j} = -2a$ and therefore

$$S_l^j = q^c P'(Q^c) \cdot a + \frac{q^c}{2} P'(Q^c) \cdot (-2a) = 0$$

If markets are asymmetric, the total change for a Hub carrier is still zero but the coefficient on each specific $\frac{dq_n^H}{dk_l^D}$ is different. Moreover, because $q_l^D = k_l^D$, the hub carrier will react ($\frac{dq_l^H}{dk_l^D} < 0$). Thus, S_l^D is generically non-zero. In contrast, $S_l^H = 0$ because $\frac{dq_n^D}{dk_l^H} = 0$.

The effect on profits follows from the fact that setting the Cournot quantities and the Hub's reaction quantities are both in the Direct carrier's feasible set. \square

B.3. Proof for proposition 6.

Proposition. *In a two carrier competition, if all markets are symmetric*

- (1) *If both carriers (A and B) are Hub carriers and $M^A \subset M^B$ then $S_l^A > 0$ for all legs in carrier A's network. In equilibrium, carrier A's quantities exceed the Cournot quantities, and carrier B's quantities, in markets where it competes with carrier A, are below the Cournot quantities.*
- (2) *If two Hub carriers' networks overlap only partially ($M^A \setminus M^B \neq \emptyset$ and $M^B \setminus M^A \neq \emptyset$) then $S_l^A > 0$ and $S_l^B > 0$ for $l \in M^A \cap M^B$*
- (3) *If markets n and n' are served by two carriers, A and B. Let $\rho(n)$ denote the fraction of markets connected to market n that both carriers serve. If $\rho(n) > \rho(n')$ the carriers will compete softer in n than in n' .*

Proof. All markets are symmetric so we can start from the Cournot equilibrium (see the previous proof).

For part 1

$$S_l^A = q^c P'(Q^c) \cdot \sum_{n \in N^{S-S} \cap N^A} \frac{dq_n^B}{dk_l^j} + \frac{q^c}{2} P'(Q^c) \cdot \sum_{n \in N^{H-S} \cap N^A} \frac{dq_n^H}{dk_l^j}$$

$S_l^A > 0$ if and only if $\sum_{n \in N^{S-S} \cap N^A} \frac{dq_n^B}{dk_l^j} + \frac{1}{2} \cdot \sum_{n \in N^{H-S} \cap N^A} \frac{dq_n^H}{dk_l^j} < 0$. Suppose the converse. Then by $\sum_{n \in N^{S-S} \cap N^A} \frac{dq_n^B}{dk_l^j} + \frac{1}{2} \cdot \sum_{n \in N^{H-S} \cap N^A} \frac{dq_n^H}{dk_l^j} = 0$ we get that the effect of A adding capacity on leg l is a net decrease in capacity by carrier B on the independent routes.

TO BE COMPLETED \square

B.4. Proof for proposition 7.

Proof. Let \bar{S}_n denote the sum of the strategic effects on market n . Solving for q_n^j in equation 2.1 and adding over all carriers players we have:

$$(B.1) \quad Q = -\frac{1}{P'_n} [\bar{S}_n + J(P_n - c)]$$

Solving for \bar{S}_n gives $-(\bar{S}_n) = QP'_n + J(P_n - c)$. When \bar{S}_n is zero then aggregate quantity in the market is the Cournot outcome. For a slightly positive \bar{S}_n the aggregate quantity in the market will be larger than the Cournot outcome. To prove the proposition for a large \bar{S}_n it is sufficient to look at the curvature of the demand function: if $\frac{d}{dQ}(QP'_n + J(P_n - c))$ is always positive the sign of \bar{S}_n will be sufficient to determine if the aggregate quantity in the market is larger (smaller) than the Cournot outcome. The derivative is always positive if $P'' < \frac{(J+1)P'}{-Q}$. Using the FOCs of the firms the condition simplifies to

$$P'' < \frac{(J+1)(P')^2}{J(P-c) + \bar{S}_n}$$

Log concavity of $P(\cdot)$ is sufficient to assert that the above always holds: log concavity implies $P'' < \frac{(P')^2}{P}$. The LHS of the above relation is larger than $\frac{(P')^2}{P}$ as long as \bar{S}_n is not too positive ($\bar{S}_n < P + J \cdot c$). This is always the case since $S^X = c - MR^X$ and $MR^X \geq 0$ from the subgame equilibrium conditions. Thus $\bar{S}_n < J \cdot c$, which completes the proof. \square

APPENDIX C. DATA AND ESTIMATION

To ease notation we let $ECH_{ijct} = \sum_{j \in R} \sum_{a \in C \setminus c} \varphi_{ijat} \kappa_{ij} (\eta_{jat}^{entry} - \eta_{jat}^{exit})$ be the net number of carriers that entered route j (total entry minus total exit) where routes i and j are connected and are both served by carrier c with connecting service through the same hub city. We also interact ECH with a dummy variable equal to one if carrier c (carrier of the unit of observation) uses non-stop service on this route. The dummy variable is also included non-interacted. To identify the effect of ECH properly we include, as base controls, $EH = \sum_{j \in R} \sum_{a \in C \setminus c} \varphi_{ijat} (\eta_{jat}^{entry} - \eta_{jat}^{exit})$ and $EC = \sum_{j \in R} \sum_{a \in C \setminus c} \rho_{ijct} \kappa_{ij} (\eta_{jat}^{entry} - \eta_{jat}^{exit})$. EH will capture the response by competitors to entry/exit on both connected and unconnected markets. Our model predicts that the effect on ECH should be negative after controlling for EH . That is, the response on connected and unconnected markets differ precisely because of the ability of the hub carrier to shift seat allocation across routes. Our model does not have precise predictions on the sign of EH , so we expect it could go both ways. EC captures the response by competitors to entry/exit on connected routes, regardless if the connected route and the route in question are served through the same hub, or with connecting flights at all. EC will be an important control as it will capture changes in market power by competitors' on the origin or destination cities. Finally,

for the sake of completeness, we include $E = \sum_{j \in R} \sum_{a \in C \setminus c} \rho_{ijct} (\eta_{jat}^{entry} - \eta_{jat}^{exit})$, $C = \sum_{j \in R} \sum_{a \in C \setminus c} \rho_{ijct} K_{ij}$ and $H = \sum_{j \in R} \sum_{a \in C \setminus c} \varphi_{ijct}$.