A dynamic game of airline network competition: Hub-and-spoke networks and entry deterrence

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1. Introduction

An airline’s network is the set of city-pairs that the airline connects via non-stop flights. The choice of network structure is one of the most important strategic decisions of an airline. Two network structures that have received particular attention in studies of the airline industry are hub-and-spoke networks and point-to-point networks. In a hub-and-spoke network, an airline concentrates most of its operations in one airport, called the hub. All other cities in the network (i.e., the spokes) are connected to the hub by non-stop flights such that travelers between two spoke cities must take a connecting flight to the hub. In contrast, in a point-to-point network, all cities are connected with each other through non-stop flights. Pure hub-and-spoke and pure point-to-point networks are very rare. They represent the two extreme cases of the degree of concentration of an airline’s operations in a few airports.

Table 1 presents concentration ratios based on airline networks including the 55 largest US cities. While most airlines have some degree of concentration of their activity in a few airports, there is also very significant heterogeneity in their concentration ratios.

The relationship between network structure and airlines’ operating costs has received significant attention among IO economists in both theoretical and empirical work. Different studies have shown how a hub-and-spoke network can exploit significant economies of scope at the airport level and economies of traffic density. An argument for the use...
of hub-and-spoke networks that has received almost no empirical attention is the one that postulates that some airlines can use hub-and-spoke networks as a strategy to deter the entry of competitors. This argument was first established by Hendricks et al. (1997) using a sequential game of entry between an incumbent hub-and-spoke carrier and a point-to-point regional carrier. In a hub-and-spoke network, the profit function of an airline is supermodular with respect to its entry decisions for different city-pairs. This complementarity implies that a hub-and-spoke airline may be willing to operate non-stop flights for a city-pair even when profits are negative because operating between that city-pair can generate positive profits connected with other routes. Potential entrants are aware of this, and therefore, it may deter entry. This argument for entry deterrence does not suffer from several limitations that hinder other more standard arguments of predatory conduct. In particular, it does not require a sacrifice on the part of the incumbent (i.e., a reduction in current profits) that will be compensated for in the future only if competitors do not enter the market.

Furthermore, it is not subject to well-known criticisms of some arguments and models of spatial entry deterrence (see Judd, 1985). Furthermore, it does not require a sacrifice component of the argument. See the papers by Aguirregabiria and Ho (2009) that deal with this issue in the context of the US and American Airlines case.

3 See also Oum et al. (1995) and Hendricks et al. (1999).
4 It is difficult to generate this type of predatory conduct as a stationary Markov perfect equilibrium. Furthermore, in antitrust cases, it is typically quite difficult to find convincing empirical evidence regarding the sacrifice component of the argument. See the papers by Kim (2009) and Snider (2009) that deal with this issue in the context of the US and American Airlines case.
5 Judd (1985) notes that some models of entry and spatial location that generate entry deterrence as a subgame perfect equilibrium include strong assumptions regarding firms' level of commitment. Those papers assume that entry and location decisions are completely irreversible, with no possibility of exit or relocation. Judd shows that when there is strong enough substitutability among the stores of the same firm, allowing for exit may result in non-successful spatial preemption by the incumbent. Potential entrants know that the incumbent firm may prefer to have a monopoly in a single location rather than being a monopolist in one location and a duopolist in another nearby location. Therefore, spatial preemption and entry deterrence by the incumbent do not constitute a credible strategy. This type of argument does not apply to a hub-and-spoke airline because the profits from different city-pairs (different "stores") are not substitutes but are rather complements. This complementarity makes entry deterrence a credible strategy in equilibrium.

### Table 1

<table>
<thead>
<tr>
<th>Airline (code)</th>
<th>1st largest hub (# connections)</th>
<th>Concentration ratio CR1</th>
<th>2nd largest hub (# connections)</th>
<th>Concentration ratio CR2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southwest (WN)</td>
<td>Las Vegas (25)</td>
<td>9.3</td>
<td>Phoenix (33)</td>
<td>18.2</td>
</tr>
<tr>
<td>American (AA)</td>
<td>Dallas (52)</td>
<td>22.3</td>
<td>Chicago (46)</td>
<td>42.0</td>
</tr>
<tr>
<td>United (UA)</td>
<td>Chicago (50)</td>
<td>25.1</td>
<td>Denver (41)</td>
<td>45.7</td>
</tr>
<tr>
<td>Delta (DL)</td>
<td>Atlanta (53)</td>
<td>26.7</td>
<td>Cincinnati (42)</td>
<td>48.0</td>
</tr>
<tr>
<td>Continental (CO)</td>
<td>Houston (52)</td>
<td>36.6</td>
<td>New York (45)</td>
<td>68.3</td>
</tr>
<tr>
<td>Northwest (NW)</td>
<td>Minneapolis (47)</td>
<td>25.6</td>
<td>Detroit (43)</td>
<td>49.2</td>
</tr>
<tr>
<td>US Airways (US)</td>
<td>Charlotte (35)</td>
<td>23.3</td>
<td>Philadelphia (33)</td>
<td>45.3</td>
</tr>
<tr>
<td>America West (HP)</td>
<td>Phoenix (40)</td>
<td>35.4</td>
<td>Las Vegas (28)</td>
<td>60.2</td>
</tr>
<tr>
<td>Alaska (AS)</td>
<td>Seattle (18)</td>
<td>56.2</td>
<td>Portland (10)</td>
<td>87.5</td>
</tr>
<tr>
<td>ATA (TZ)</td>
<td>Chicago (16)</td>
<td>48.4</td>
<td>Indianapolis (6)</td>
<td>66.6</td>
</tr>
<tr>
<td>JetBlue (B6)</td>
<td>New York (13)</td>
<td>59.0</td>
<td>Long Beach (4)</td>
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<tr>
<td>Frontier (FL)</td>
<td>Denver (27)</td>
<td>56.2</td>
<td>Los Angeles (5)</td>
<td>66.6</td>
</tr>
<tr>
<td>AirTrans (FS)</td>
<td>Atlanta (24)</td>
<td>68.5</td>
<td>Dallas (4)</td>
<td>80.0</td>
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<tr>
<td>Trans States (AX)</td>
<td>St Louis (18)</td>
<td>62.0</td>
<td>Pittsburgh (7)</td>
<td>93.9</td>
</tr>
<tr>
<td>Reno Air (QX)</td>
<td>Portland (8)</td>
<td>53.3</td>
<td>Denver (7)</td>
<td>100.0</td>
</tr>
<tr>
<td>Sun Country (SY)</td>
<td>Minneapolis (11)</td>
<td>100.0</td>
<td>(0)</td>
<td>100.0</td>
</tr>
</tbody>
</table>


describe how the estimated model can be used to test for strategic entry deterrence. In a companion paper (Aguirregabiria and Ho, 2009), we estimate this model and use it to measure the contribution of demand, cost, and strategic factors to explaining hub-and-spoke networks. Here, we summarize the main empirical results of that paper, with particular attention to the empirical evidence regarding the entry deterrence motive.

### 2. Model

#### 2.1. Basic framework

The industry is configured by N airline companies and C cities. The network of an airline consists of the set of city-pairs that the airline connects with non-stop flights. Entry/exit for a city-pair is not directional—i.e., if an airline operates non-stop flights from city A to city B, then it should operate flights from B to A. Therefore, there are M ≡ (C − 1)/2 markets or city-pairs. We index time using t, markets using m, and airlines using i. An airline's network can be represented by a vector \( \mathbf{x}_i \equiv \{x_{im} \mid m = 1, 2, ..., M \} \), where \( x_{im} \in \{0, 1\} \) is the binary indicator of the event "airline i operates non-stop flights for city-pair m at period t." The whole industry network is represented by the vector \( \mathbf{x} \equiv \{x_{im} \mid m = 1, 2, ..., M \} \in \mathbb{X} \), where \( \mathbb{X} \equiv \{0, 1\}^M \). Travelers are concerned about the number of directions available for each route. A route is a directional round-trip between two cities, including possible stops. A network implicitly describes all of the routes for which an airline provides flights, either with stops or non-stop. In principle, we can construct routes with many stops. However, we consider only routes with zero, one, or two stops.\(^6\) \( \mathbb{I}(\mathbf{x}_i) \) is the set of these routes associated with network \( \mathbf{x}_i \). We index routes using r.

Every period (quarter) t, airlines take as given the current industry network \( \mathbf{x}_t \) and choose prices for all of the routes where they operate flights either non-stop or with stops.\(^7\) Price competition is static and determines variable profits for each airline and route.\(^8\) Airlines also decide their networks for the next quarter, \( \mathbf{x}_{t+1} \). We assume that it takes one quarter to build the inputs that are needed to start operating non-stop flights between a city-pair. Similarly, we assume that it takes one quarter to scrap the inputs to exit from servicing a city-pair. Fixed costs and entry

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\(^5\) Judd (1985) notes that some models of entry and spatial location that generate entry deterrence as a subgame perfect equilibrium include strong assumptions regarding firms' level of commitment. Those papers assume that entry and location decisions are completely irreversible, with no possibility of exit or relocation. Judd shows that when there is strong enough substitutability among the stores of the same firm, allowing for exit may result in non-successful spatial preemption by the incumbent. Potential entrants know that the incumbent firm may prefer to have a monopoly in a single location rather than being a monopolist in one location and a duopolist in another nearby location. Therefore, spatial preemption and entry deterrence by the incumbent do not constitute a credible strategy. This type of argument does not apply to a hub-and-spoke airline because the profits from different city-pairs (different "stores") are not substitutes but are rather complements. This complementarity makes entry deterrence a credible strategy in equilibrium.

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\(^6\) Routes with more than two stops represent less than 1% of all of the air tickets in the US Origin and Destination (DB1B) database.

\(^7\) The DB1B database has quarterly frequency.

\(^8\) Intertemporal price discrimination and plane capacity constraints can generate dynamic (forward-looking) pricing strategies at the level of individual flights (i.e., specific flight number and day). However, that type of pricing dynamics is short-run and flight-specific, and it plays a very minor role in the dynamics of network structure. For simplicity's sake, this model ignores dynamic pricing.
2.2. Demand and price competition

For notational simplicity, we omit the time subindex \( t \) from the description of the static model of demand and price competition. Let \( H_t \) be the number of potential travelers in route \( r \). For a given route, there are two forms of product differentiation: the airline (i.e., the indicator for non-stop flights \( n \)). Travelers decide which product \((i,n)\) to purchase, if any. The indirect utility for a consumer on route \( r \) is \( u_{ir}^{(0)}(b_{ir}-p_{ir})/[1+\sum_c \exp(b_{ir}-p_{ir})] \), where the sum \( \sum_c \) is over all products available for route \( r \). The variable profit of airline \( i \) on route \( r \) is \( \pi_{ir} = \pi_{ir}^{(0)}(b_{ir}-p_{ir})/[1+\sum_c \exp(b_{ir}-p_{ir})] \), where \( \pi_{ir}^{(0)} \) is the constant marginal cost of product \((i,n)\). The specification of this marginal cost is similar to that of product quality: \( \pi_{ir}^{(0)} = \omega_{ir}^{(0)} \cdot \omega_{ir}^{(0)} + \epsilon_{ir}^{(0)} \), where \( \omega_{ir}^{(0)} \) and \( \epsilon_{ir}^{(0)} \) represent the marginal costs of flights with stops and non-stop flights, respectively. Nash–Bertrand equilibrium prices depend on the quality and marginal costs of all the products that are active on the same route.

9. Note that, given our assumption that entry/exit decisions are made one period ahead (i.e., time-to-build), the assumption regarding the timing of the payment of the entry cost and fixed cost is really innocuous. Let \( \eta_{\alpha \beta} \) and \( \eta_{\alpha \beta}^{(0)} \) be the fixed cost and the entry cost in our model, respectively, under our assumption that these costs are paid in period \( t \) for operation during period \( t+1 \). Suppose that these costs were not actually paid in period \( t \) but were instead paid instead paid between periods \( t \) and \( t+1 \) — i.e., the fixed cost is paid at \( t+\delta \) for some values \( \delta \in [0,1) \) and \( \delta \in [0,1) \) that are unknown to us as researchers. This implies the following relationship between our "structural parameters", \( \eta_{\alpha \beta} \) and \( \eta_{\alpha \beta}^{(0)} \), and the actual values of the costs, \( \eta_{\alpha \beta} \) and \( \eta_{\alpha \beta}^{(0)} \), respectively. \( \eta_{\alpha \beta} = \eta_{\alpha \beta}^{(0)} - \delta \), and \( \eta_{\alpha \beta}^{(0)} = \eta_{\alpha \beta} + \delta \cdot \eta_{\alpha \beta}^{(0)} \) if \( \delta \) is the discount factor. That is, our "structural parameters" are discounted values of the actual current values of these costs. It is clear that not knowing the actual timing of the payments implies that we can only set-identify \( \eta_{\alpha \beta}^{(0)} \) and \( \eta_{\alpha \beta}^{(0)} \) from estimates of \( \eta_{\alpha \beta} \) and \( \eta_{\alpha \beta}^{(0)} \), i.e., all that we know is \( \eta_{\alpha \beta}^{(0)} \sim \eta_{\alpha \beta}^{(0)} \) and \( \eta_{\alpha \beta}^{(0)} \sim \eta_{\alpha \beta}^{(0)} \). Nevertheless, for most of the relevant empirical questions, all that we need to know about the fixed cost and entry cost are the discounted values \( \eta_{\alpha \beta} \) and \( \eta_{\alpha \beta}^{(0)} \) (i.e., \( \eta_{\alpha \beta}^{(0)} \) and \( \eta_{\alpha \beta}^{(0)} \)). We do not need to know the current values \( \eta_{\alpha \beta} \) and \( \eta_{\alpha \beta}^{(0)} \). Furthermore, given the quarterly frequency of our data and the value of the discount factor, \( \delta \approx 0.09 \), the difference between these values is smaller than 10%.

10. In Aguirregabiria and Ho (2009), we see a more general version of the model that includes exogenous state variables, \( z_t \), that affect demand and costs. In that model, the dynamics of the industry can be described using the endogenous Markov transition probability \( \pi_{ir}(x_t, x_{t-1}) \) and the exogenous transition probability of \( z_t \).

11. Aguirregabiria and Ho (2009) consider a richer specification of demand and variable costs that includes a nested logit structure for travelers’ idiosyncratic preferences, permanent airline and city heterogeneity, and hub-size effects on both demand and variable costs.

2.3. Supermodularity of variable profit

Let \( TR_i = \sum_{r \in R_i} \pi_{ir}(x_r) \) be the total variable profit function. For the main purpose of this paper, it is important to note that for an airline with a hub-and-spoke network this function is supermodular with respect to the airline’s own entry decisions for different city-pairs. To illustrate this point, consider an industry with three cities, A, B, and C. There are three city-pairs (AB, AC, and BC), and an airline’s network is described in terms of three binary indicators of non-stop flights: \( x_{AB}, x_{AC}, \) and \( x_{BC} \) — we omit the airline subindex for notational convenience. For the sake of simplicity, suppose that the three city-pairs are equivalent in terms of the variable profits that they generate. Let \( R^0 \) be the variable profit on one route if the airline operates only non-stop flights. Similarly, \( R^1 \) is the variable profit if the airline operates only flights with stops, and \( R^{0+1} \) is the profit when there are both non-stop flights and flights with stops. Consumer substitution between non-stop and stop flights on the same route implies that \( R^{0+1} = (R^0 + R^1) \). The total variable profit function is as follows:

\[
TR(x_{AB}, x_{AC}, x_{BC}) = (x_{AB} + x_{AC} + x_{BC})R^0 + (x_{AC}x_{BC} + x_{AB}x_{AC})R^1 + 3x_{AB}x_{AC}x_{BC}R^{0+1} + x_{AB}x_{AC}x_{BC}R^{0+2} \geq (R^0 + R^1)
\]

Suppose that the airline has a hub-and-spoke network with the hub at city \( A \) — i.e., \( x_{AB} = 1, x_{AC} = 1, \) and \( x_{BC} = 0 \). The profit of this airline is \( TR(1,1,0) = 2R^0 + R^1 \). The profit of operating in only one city-pair is \( TR(1,0,0) = R^0 \). Therefore, for a hub-and-spoke network the variable profit function is supermodular — i.e., \( [TR(1,1,0) - TR(0,1,0)] - [TR(1,0,0) - TR(0,0,0)] \geq R^1 \). This implies that the airline is willing to operate non-stop flights in a city-pair (say, AB) even if profits from that route are negative as long as this negative profit is more than compensated for the profit from the route B to C with a stop at A. It is straightforward to show that the degree of supermodularity in the variable profit function increases with the number of spoke cities in the hub-and-spoke network. That is, the larger the hub, the stronger the supermodularity and the more likely it is that an airline using a hub-and-spoke network will be willing to operate some spoke routes with negative profits. This is known by potential entrants into the spoke route and can deter them.

In contrast, in a point-to-point network, either there is no supermodularity or it is significantly weaker than in a hub-and-spoke network. The variable profit of a point-to-point network for this airline is \( TR(1,1,1) = 3R^{0+2} \), and we have that \( [TR(1,1,1) - TR(0,1,1)] - [TR(1,0,0) - TR(0,0,0)] = 3(R^{0+2} - R^0 - R^1) \). The term \( 3(R^{0+2} - R^0 - R^1) \) is negative because of the substitutability between non-stop flights and flights with stops within the same route. Therefore, it is clear that the complementarity between the entry decisions is weaker than in a hub-and-spoke network.

2.4. Fixed costs and start-up costs

The structure of the fixed cost is \( FC_{int} = (y_{FU}^{C0} - y_{FU}^{C1})HUB_{int} + \eta_{\alpha \beta}^{(0)} \), where \( y_{FU}^{C0} \geq 0 \) and \( y_{FU}^{C1} \geq 0 \). The component \( FC_{int} \) and \( FC_{int}^{(0)} \) is private information that the airline possesses on its own cost. This private information shock is assumed to be independently and identically distributed over firms and over time with zero mean. \( HUB_{int} \) represents the hub-size of airline \( i \) in the airports of city-pair \( m \) as measured by the total number of cities that airline \( i \) connects with non-stop flights from the origin and destination airports in city-pair \( m \): \( HUB_{int} \equiv \sum_{m \in C_i} x_{int} \), where \( C_i \) is the set of markets with a common city with market \( m \). The parameter \( y_{FU}^{C0} \) represents airline \( i \)'s fixed cost in a market where it does not have any other connections.

12. As in the case of variable profits, Aguirregabiria and Ho (2009) consider a richer specification of fixed costs and entry costs that includes permanent heterogeneity for both airlines and cities.
The parameter $\gamma^{FC(1)}$ measures how airline i's fixed costs decline with its hub-size in the city-pair. The start-up cost $SC_{imt}$ has the same structure as the fixed cost: $SC_{imt} = (G^{FC(0)}_i - G^{FC(1)}_i HUB_{imt}) + \epsilon_{imt}$, where $\epsilon_{imt}^{FC(0)} \geq 0$ and $\epsilon_{imt}^{FC(1)} \geq 0$ are the parameters.

When $\gamma^{FC(1)}$ or $\epsilon_{imt}^{FC(1)}$ are strictly positive, profits for different city-pairs are interconnected through the hub-size effects. This is the other source of complementarity between an airline's entry decisions for different city-pairs.

2.5. Markov perfect equilibrium

Airlines maximize intertemporal profits. They are forward-looking and take into account the implications of their entry and exit decisions for future profits and for the expected future reactions of their competitors. We assume that airlines' strategies depend only on payoff-relevant state variables — i.e., the Markov perfect equilibrium (MPE) assumption. An airline's payoff-relevant information at quarter t is $\{x_t, \epsilon_t\}$, where $\epsilon_t$ is the vector of airline-specific private information shocks $\epsilon_{imt}$, $G^{FC(0)}_{imt} = 1_{m=1,2,...,M}$. Let $\Omega = \{(x_t, \epsilon_t) ; t = 1, 2, ..., N\}$ be a set of strategy functions, one for each airline, such that $\sigma_t$ is a function from $X \times \mathbb{R}^{2M}$ into $[0,1]^M$. A MPE in this game is a set of strategy functions such that each airline's strategy maximizes its value for each possible state $(x_t, \epsilon_t)$ and taking as given other airlines' strategies.

Let $V^t(x_t, \epsilon_t)$ represent the value function for airline i given that the other airlines behave according to their respective strategies in $\sigma$, and given that airline i uses his best response/strategy. By the principle of optimality, this value function is implicitly defined as the unique solution to the following Bellman equation:

$$
V^t(x_t, \epsilon_t) = \max_{x_{t+1}} \left\{ \Pi_t(x_t, x_{t+1}) - \epsilon_t(x_{t+1}) + \beta E[V^{t+1}(x_{t+1}, \epsilon_{t+1}) | x_t, \epsilon_t] \right\}
$$

where $\beta \in (0,1)$ is the discount factor; $\Pi_t(x_t, x_{t+1})$ represents the common-knowledge part of the profit function, i.e.,

$$
\Pi_t(x_t, x_{t+1}) = \sum_{r\in R_t} \epsilon_t R_t(x_t) - \sum_{m=1}^M \epsilon_{imt} \left( G^{FC(0)}_i HUB_{imt} + \left(1 - \epsilon_{imt}\right) G^{FC(1)}_i HUB_{imt} \right);
$$

and the term $\epsilon_t(x_{t+1})$ contains the private information part of the profit function, i.e., $\epsilon_t(x_{t+1}) = \sum_{m=1}^M \epsilon_{imt} \left( G^{FC(0)}_i HUB_{imt} + \left(1 - \epsilon_{imt}\right) G^{FC(1)}_i HUB_{imt} \right)$. A set of strategies $\sigma_t$ is a MPE if, for every airline i and every state $(x_t, \epsilon_t)$, we have that:

$$
\sigma_t(x_t, \epsilon_t) = \arg\max_{x_{t+1}} \left\{ \Pi_t(x_t, x_{t+1}) - \epsilon_t(x_{t+1}) + \beta E[V^{t+1}(x_{t+1}, \epsilon_{t+1}) | x_t, \epsilon_t] \right\}.
$$

That is, every airline's strategy is a best response to the other airlines' strategies.

An equilibrium in this dynamic game provides a description of the joint dynamics of price, quantities, and airlines' incumbent status for every route between the C cities of the industry. To compute the equilibrium and perform the structural estimation of the model, one may define an MPE in terms of airlines' conditional choice probabilities (CCPs). Define the choice probability $P_i(x_{t+1} | x_t) = \int \{\sigma_t(x_t, \epsilon_t) = x_{t+1}\} dG_t(\epsilon_t)$, where $1{.}^t$ is the indicator function, and $G_t$ is the CDF of $\epsilon_t$. $P_i(x_{t+1} | x_t)$ is the probability that airline i operates a network $x_{t+1}$ at period t + 1 given that the industry network at period t is $x_t$. Let $P$ be the vector of CCPs associated with $\sigma$, i.e., $P = \{P_i(x_{t+1} | x_t) : i = 1, 2, ..., N, x_t \in \{0,1\}^M, x_t \in X\}$. Following Aguierregabiria and Mira (2007), a MPE in this dynamic game can be described as a vector of probabilities $P$ that solves the fixed point problem $P = \Psi(P)$, where $\Psi(P)$ is a vector-valued best-response probability function.

2.6. Entry deterrence and hub-and-spoke networks

The vector of structural parameters of the model, $\theta$, includes parameters in demand, $(\alpha^0, \alpha^1)$, variable costs, $(\alpha_0^0, \alpha_0^1)$, fixed costs, $(\gamma^{FC(0)}, \gamma^{FC(1)})$, and entry costs, $(\epsilon^{FC(0)}, \epsilon^{FC(1)})$. Aguierregabiria and Ho (2009) show that these parameters are identified using data on prices and quantities at the airline-route level (to identify demand and variable cost parameters) and longitudinal data on airline networks (to identify fixed costs and entry costs).

Given consistent estimates of the vector of structural parameters $\theta$ and of the equilibrium in the data as represented by the vector of choice probabilities $P$, we are interested in measuring the role of hub-and-spoke networks as a credible strategy for deterring the entry of point-to-point carriers. This entry deterrence argument is based on the supermodularity (complementarity) of the total variable profit function of a hub-and-spoke airline. The elimination of this supermodularity should also remove this potential source of entry deterrence. More specifically, if this supermodularity generates entry deterrence, then in eliminating it for a certain airline, we should find that the airline has both a lower tendency toward ‘hubbing’ (i.e., a lower concentration of its operations in a few airports as measured by concentration ratios $CRI$ and $CR2$) and a lower number of city-pairs for which it operates as a monopolist.

To implement this type of comparative statics exercise, we need to define a counterfactual scenario wherein we eliminate this source supermodularity from the variable profit of an airline. We consider the following approach. Suppose that we describe an airline as a group of local managers, one for each city-pair $m$. The double index $(i, m)$ represents the local manager of airline i in market m. This local manager decides whether to operate non-stop flights in city-pair $m$. In our model, the decision-making of the airline is centralized. Therefore, the model assumes that all local managers of an airline internalize the complementarities between their entry–exit decisions. To eliminate supermodularity from an airline’s variable profits, we consider the counterfactual scenario wherein the local managers of an airline are concerned with the maximization of its own city-pair profit, which includes only the variable profit from non-stop flights between two cities. This hypothetical local manager ignores that his city-pair is a segment in many other routes and that the operation of his city-pair can generate additional profits associated with these other routes.

To illustrate this, consider the example in Section 2.3 of an industry with three cities and a hub-and-spoke airline with a hub at city A and spokes at cities B and C. The total variable profit of this airline is $TR = (X_{AB} + X_{AC}) R^P + X_{AB} X_{AC} R^F$, which is a supermodular function in $(X_{AB}, X_{AC})$. However, in the counterfactual scenario, the local manager in city-pair AB is only concerned with its local variable profit $X_{AB} R^P$ (and the local manager AC is only concerned with profit $X_{AC} R^P$). Therefore, these “uncoordinated” local managers do not take into account the complementarity of their decisions in terms of the total profit of the airline. In this counterfactual model, we expect that the network of the airline will present a lower degree of ‘hubbing’. Furthermore, if the entry deterrence motive is significant in the factual equilibrium, we expect that in the counterfactual, the airline will be a monopolist in a smaller number of markets.

3. Empirical evidence

Aguierregabiria and Ho (2009) estimate the dynamic game described above using data from the Airline Origin and Destination Survey (DB1B) for the 55 largest cities in the US. Here we summarize the main empirical results presented in that paper, paying particular attention to those results related to strategic entry deterrence.

13 The estimated model in Aguierregabiria and Ho (2009) considers a certain degree of decentralization in local managers' decision-making. However, in that model, local managers still internalize the complementarities of their operation decisions.
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