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A dynamic oligopoly game of the US airline industry: Estimation and policy experiments

Victor Aguirregabiria [a,*], Chun-Yu Ho [b]

[a] University of Toronto, Canada

[b] School of Economics, Antai College of Economics and Management, Shanghai Jiao Tong University, Shanghai, China

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ABSTRACT

This paper studies the contribution of demand, costs, and strategic factors to the adoption of hub-and-spoke networks in the US airline industry. Our results are based on the estimation of a dynamic game of network competition using data from the *Airline Origin and Destination Survey* with information on quantities, prices, and entry and exit decisions for every airline company in the routes between the 55 largest US cities. As methodological contributions of the paper, we propose and apply a method to reduce the dimension of the state space in dynamic games, and a procedure to deal with the problem of multiple equilibria when implementing counterfactual experiments. Our empirical results show that the most important factor to explain the adoption of hub-and-spoke networks is that the sunk cost of entry in a route declines importantly with the number of cities that the airline connects from the origin and destination airports of the route. For some carriers, the entry deterrence motive is the second most important factor to explain hub-and-spoke networks.

1. Introduction

The US airline industry has undergone important transformations since the 1978 deregulation that removed restrictions on the routes that airlines could operate and on the fares they could charge.[1] Soon after deregulation, most airline companies adopted hub-and-spoke networks to organize their routes. In a hub-and-spoke network, an airline concentrates most of its operations in an airport called the *hub* such that all the other cities in the network (the *spokes*) have non-stop flights only to the hub. Different hypotheses have been suggested to explain airlines' adoption of hub-and-spoke networks. According to demand-side explanations, some travelers value the services associated with the scale of operation of an airline in the hub airport, e.g., more convenient check-in and landing facilities, higher flight frequency.[2] According to cost-side explanations, an airline can exploit economies of scale and scope by concentrating most of its operations in a hub airport. For instance, larger planes are cheaper to fly, on a per-passenger basis, and airlines can exploit these economies of scale by seating in a single plane, flying to the hub city, passengers with different final destinations.[3] There may be also economies of scope. Some costs of operating a route, such as aircraft maintenance and labor costs, may be common for different routes in the same airport.[4] Another hypothesis that has been suggested to explain hub-and-spoke networks is that it can be an effective strategy to deter the entry of competitors (see Hendricks et al., 1997). The main argument is that a hub-and-spoke airline is willing to operate non-stop flights between two cities even if profits from this city-pair are negative, as

* Correspondence to: 150 St. George Street, Toronto, ON, M5S 3G7, Canada. Tel.: +1 416 978 4358.

E-mail address: victor.aguirregabiria@utoronto.ca (V. Aguirregabiria).

1 Borenstein (1992), Morrison and Winston (1995), and Borenstein and Rose (2007) provide excellent overviews of the US airline industry. For studies that evaluate the effects of the deregulation, see Alam and Sickles (2000), Morrison and Winston (2000), Kahn (2004), and Färe et al. (2007).

2 The willingness to pay for these services can be offset by consumers' preference of non-stop flights over stop-flights.

3 These economies of scale can be offset by the larger distance traveled with the hub-and-spoke system.

4 Some of these cost savings may not be only technological but they may be linked to contractual arrangements between airports and airlines. Airports' fees may include discounts to those airlines that operate many routes in the airport.

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long as these losses are compensated by the positive profits from other routes that have this city-pair as a segment. This willingness to operate in a city-pair with negative profits may deter the entry of airlines that do not have hub-and-spoke networks or that have smaller networks.[5]

This paper develops an estimable dynamic game of airlines network competition that incorporates the demand, cost, and strategic factors described above. We estimate this model and use it to measure the contribution of each of these factors to explain hub-and-spoke networks. To our knowledge, this is the first study that estimates a dynamic game of network competition. In our model, airline companies decide every period the city-pairs where they operate non-stop flights, and the fares for each route-product they serve. The structure of our model is similar to the one in a well-known class of models of industry dynamics studied by Ericson and Pakes (1995). In particular, we have that: (i) direct strategic interactions between firms occur only through the effect of prices on demand; (ii) price competition is static; and (iii) a firm's entry decisions in city-pairs is dynamic or forward looking and it affects other firms' profits only indirectly through its effect on equilibrium prices.

The model is estimated using data from the *Airline Origin and Destination Survey* of the US Bureau of Transportation Statistics (BTS). We use information on quantities, prices, and route entry and exit decisions for every airline company in the routes between the 55 largest US cities (1485 city-pairs). To answer our empirical questions on the sources of hub-and-spoke networks, we need to measure airline costs at the route level. Though there is plenty of public information available on the balance sheets and costs of airline companies, this information is not at the airline–route level or even at the airline–airport level. Our approach to estimate the demand and cost parameters of the model is based on the *principle of revealed preference*. Under the assumption that airlines maximize expected profits, an airline's decision to operate or not in a route *reveals* information on costs at the airline–route level. We use information on airlines entry–exit decisions in city-pairs to estimate these costs.

This paper builds on and extends two important papers in the Industrial Organization of the airlines industry: the theoretical literature on airline network competition, especially the work of Hendricks et al. (1995, 1997, 1999); and the empirical literature on structural models of competition in the airline industry, in particular the work of Reiss and Spiller (1989), Berry (1990, 1992), Berry et al. (2006), and Ciliberto and Tamer (2009). We extend the static duopoly game of network competition in Hendricks et al. (1999) to a dynamic framework with incomplete information, and N firms. Berry (1990) and Berry et al. (2006) estimate structural models of demand and price competition with a differentiated product and obtain estimates of the effects of hubs on marginal costs and consumers' demand. Berry (1992) and Ciliberto and Tamer (2009) estimate static models of entry that provide measures of the effects of hubs on fixed operating costs. Our paper extends this previous literature in two important aspects. First, our model endogenizes the existence of hubs and, more generally, the structure of airlines' networks. Treating hub size as a variable that is endogenously determined in the equilibrium of the model is important for some predictions and counterfactual experiments using these structural models. Second, our model is dynamic. A dynamic model is necessary to distinguish between fixed costs and sunk entry costs (which have different implications on market structure), and to study the hypothesis that hub-and-spoke networks deter entry of competitors.

The paper presents also two methodological contributions to the recent literature on the econometrics of dynamic discrete games.[6] First, we propose a method to reduce the dimension of the state space in dynamic games. Our method extends to dynamic games the inclusive-values approach in Hendel and Nevo (2006) and Nevo and Rossi (2008). The main contribution of our approach to model inclusive-values is that we endogenize the transition probabilities of the inclusive-values such that we can use the estimated model to make counterfactual experiments that take into account how these transition probabilities depend on the strategies of all the players, and therefore how they change in the counterfactual scenario. Second, we implement the procedure proposed in Aguirregabiria (in press) to deal with multiple equilibria when conducting counterfactual experiments with the estimated model. Under the assumption that the equilibrium selection mechanism is a smooth function of the structural parameters, we show how to obtain an approximation to the counterfactual equilibrium.

Our empirical results show that an airline's scale of operation in an airport (as measured by the number of cities that the airline connects from that airport) has a statistically significant effect on travelers' willingness to pay, on unit (per-passenger) costs, on fixed operating costs, and on the cost of starting a new route (i.e., route entry costs). Nevertheless, the most substantial impact is on the cost of entry in a route. Given the estimated model, we implement counterfactual experiments to decompose the contribution of demand, costs, and strategic interactions to each airline's propensity to use a hub-and-spoke network. These experiments show that eliminating the effect of the number of connections in an airport on route entry costs would reduce very substantially airlines' propensity to hubbing. We also find that, for some of the larger carriers, strategic entry deterrence is the second most important factor to explain hub-and-spoke networks.

The rest of the paper is organized as follows. Section 2 presents our model and assumptions, as well as our approach to reduce the state space of the dynamic game. The data set and the construction of our working sample are described in Section 3. Section 4 discusses the estimation procedure and presents the estimation results. Section 5 describes our procedure to implement counterfactual experiments and our results from these experiments. We summarize and conclude in Section 6.

2. Model

2.1. Framework

The industry is configured by N airline companies and C cities or metropolitan areas. We assume that each city has only one airport. Airlines and airports are exogenously given in our model. An airline's *network* is the set of city-pairs that the airline connects via non-stop flights. From the point of view of an airline's entry and exit decisions, a market in this industry is a *not directional city-pair*, i.e., if an airline operates flights from A to B, then it should operate flights from B to A. Therefore, there are $M \equiv C(C-1)/2$

[5] Consider a hub airline who is a monopolist in the market-route between its hub-city and a spoke-city. A non-hub carrier is considering to enter in this route. Suppose that the size of this market-route is such that a monopolist gets positive profits but under duopoly both firms suffer losses. For the hub carrier, conceding this market to the new entrant implies that it will also stop operating in other connecting markets and, as a consequence of that, its profits will fall. The hub operator's optimal response to the opponent's entry is to stay in the spoke market. Therefore, the (subgame perfect) equilibrium strategy of the potential entrant is not to enter. Hendricks et al. (1999) extend this model to endogenize the choice of hub versus non-hub carrier. See also Oum et al. (1995) for a similar type of argument that can explain the choice of a hub–spoke network for strategic reasons.

[6] See Aguirregabiria and Mira (2007), Bajari et al. (2007), and Pakes et al. (2007) for recent contributions to this literature.