HOW BIG IS TOO BIG FOR HUBS:

MARGINAL PROFITABILITY IN HUB-AND-SPOKE NETWORKS

by

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ABSTRACT Increasing the scale of hub operations at major airports has led to concerns about congestion at excessively large hubs. In this paper we estimate the marginal cost of adding spokes to an existing hub network. We observe entry/non-entry decisions on potential spokes from existing hubs, and estimate both a variable profit function for providing service in markets using that spoke as well as the fixed costs of providing service to the spoke. We let the fixed costs depend upon the scale of operations at the hub, and find the hub size at which spoke service costs are minimized.

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1. INTRODUCTION

One legacy of airline deregulation has been an increased reliance upon hub-and-spoke networks among national carriers. By drastically reducing the number of flights required to accommodate a set of endpoints, hubs have been the source of massive scale and scope economies. A benefit of the hub-and-spoke system is service to smaller markets where direct service to a variety of destinations is cost prohibitive, yet exclusive service to a nearby hub is not; this service enables travelers from small markets to access a carrier's entire network. While consumers benefit from spacial accessibility resulting from large networks, most national carriers reported excessive losses during the early 1990s. These losses threaten service to numerous small markets. Given the proliferation of hubs and the recent losses incurred within the airline industry, it is timely and appropriate to identify the minimum and maximum efficiency scales of both hubs and their associated networks.

We focus on identifying the incremental costs of increasing the number of spokes served by a single hub. This structure may be determined by examining the additional profits gained from offering service to smaller airports and connecting those airports to an entire network via a central hub. We do not measure profits explicitly. Rather, we use entry and exit decisions as a signal of profitability. Our approach is innovative in inferring spoke-level fixed costs from entry and exit decisions.

The optimal structure for an air carrier depends on both the incremental costs associated with each spoke and the fixed costs of operating a hub. Two extreme cases may be considered. If carrying traffic over long spokes is costly, or if the average "cost-minimizing" hub contains only a small number of spokes, then the efficient network structure involves many small hubs. This type of network would more likely evolve when congestion costs are high. Conversely, if the fixed costs associated with hubs are high, or if carrying spoke traffic is inexpensive, then an efficient network will involve a few large hubs with numerous spokes. Some anecdotal evidence suggests that moving toward larger hubs is the more efficient network structure for airline markets.[1] However, a fundamental issue in building an assessment of the relative efficiency of large and small hubs lies in the determination of costs.

We use entry and exit decisions as a signal of profitability, since it is not straightforward to measure operating costs with cost data.[2] First, we infer both the profits earned by carrying traffic along the network as well as the fixed costs associated with providing the entire network. The use of entry decisions to infer fixed costs was pioneered by Bresnahan and Reiss (1987) and has been applied to airlines by Reiss and Spiller (1989),

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[1] This conclusion is based upon the recent consolidation of American Airlines.

[2] An entire literature has evolved with respect to allocating costs among routes, spokes, etc. For details see Caves, Christianson and Tretheway (1984), Cornwell, Schmidt and Sickles. (1990) etc.

Berry (1992), and Brueckner and Spiller (1994). Second, we combine the use of entry as a signal of costs and profitability with the cost disaggregation of Brueckner and Spiller, to directly measure the costs associated with adding a spoke to an existing hub-and-spoke network. This second innovative step is crucial in identifying the optimal network structure.

Our model of entry, unlike previous models, recognizes that demand is based on city-pair markets, not on service along spokes. We incorporate the many four-segment markets (or routes) a carrier simultaneously enters when adding a spoke. Adding a flight along a spoke between two cities enables the carrier to enter any four segment city-pair market that is accessible from either endpoint. Demand for any route depends upon the total distance, competition, and demographic factors. Costs depend on both the variable costs associated with providing service in the relevant city-pair markets, plus the fixed costs of adding the additional spoke to the hub airport. Thus choice of entry or exit depends on the variable profits for the change in a network versus the associated fixed costs of operating that particular spoke.

Like Brueckner and Spiller (1994) we measure costs as a function of flights between city pairs. Because the choice of entry or exit depends upon the incremental revenue of entry versus the associated incremental cost of offering service on a particular spoke, we measure the total effect of entry or exit on the carrier's network-wide profits. We combine three data sets (route variables, route-carrier variables, and spoke variables) into a maximum likelihood specification where entry/non-entry is the dependent variable. From our model, we recover a cost specification for operating spokes through hub cities, and test that specification for scale economies.

The remainder of paper is organized as follows: The next section contains a description of the hub-and-spoke system and provides motivation for our research. Our methodology, including a description of our technique and our data, comprises the third section. Results from our model and concluding remarks are included in the fourth and fifth sections, respectively.

2. THE HUB-AND-SPOKE SYSTEM

During airline economic regulation, tight government control over route entry resulted in a "linear" structure for national carriers. Airlines were required to petition the Civil Aeronautics Board (CAB) if they desired entry into a given route and often had to justify the need for additional service to gain such entry. Conversely, carriers were required to provide service to many smaller, less lucrative markets. While the CAB was effective in providing service to small markets, travel to and from these airports often involved numerous stops and inter-line connections.[3] Proponents of regulation expected small airports to suffer a loss of

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[3] When making an inter-line connection, the passenger changes airlines at some point during the trip and recheck in himself and his luggage.

service without government protection. This prediction was based on the linear route structure imposed by regulation.

Since deregulation, we have observed a curiously different outcome. The linear route structure imposed by the CAB was quickly abandoned by national carriers in favor of a hub-and-spoke (H&S) system.[4] The H&S system has been used in other modes of transportation, such as busing, rail, and subway; it was a natural progression for airlines. A noted advantage in H&S is the cost savings generated from more efficient aircraft utilization. These savings generally offset the cost increases that are associated with additional ascents and descents, and circuitous routing. These cost savings have allowed many small markets to maintain a profitable niche in airline networks and driven carriers to extend their networks even further.[5]

The dominance of the H&S system has revolutionized the way carriers offer service. Two key aspects of this revolution are in flight composition and frequency of service. Because H&S systems allow passengers, from a variety of origins, travel to the entire network of destinations via a hub, a spoke is used by all passengers originating at the spoke regardless of their intended destination.[6] Given this increased spoke usage, airlines offer more frequent service to accommodate passengers requiring connecting service at various times. Increased frequency implies a greater dependence on smaller aircraft and better utilization of larger aircraft between hubs and other large markets. The end result is larger, non-uniform fleets of aircraft.

The economic consequences of H&S paradoxically include both heightened competition and the market power associated with hub dominance. Competition has increased on a network scale. Prior to deregulation, carriers were restricted in the markets they could enter; since deregulation, entry is easier, although not free, and carriers are able to use their H&S networks to link all entered markets to all others. Given the increased variety in routes offered by all carriers, it is inevitable that carriers will begin to compete for customers on previously monopolized routes. Conversely, Borenstein (1989) has shown significant market power associated with hub dominance. A case in point is the Charlotte, NC hub dominated by USAir. USAir uses its USAir express service to provide spoke service to several dozen small markets within a few hundred miles of Charlotte. For most

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[4] Under H&S airplanes from several points of origin arrive at a central hub where passengers change planes to travel to their intended destinations.

[5] For extensive details on the transition from linear to hub-and-spoke systems in the airline industry, see Oum and Tretheway (1990).

[6] This implies an absolute increase in spacial accessibility due to the availability of network service from their local airports.

of these markets, USAir express is the only local link to a national network.[7] American Airlines attempted to introduce competition from a "mini-hub" at Raleigh/Durham (RDU). However, after several years of poor response American left these smaller markets and sold much of its RDU business to Midway Airlines. Therefore, although the H&S system has led to intense competition among national carriers for heavily traveled routes, monopolized pockets have become an important factor in maintaining profitable service to smaller markets and the entire network.[8]

3. METHODOLOGY

In the following subsection, we use various terms to describe network configurations for supply and demand purposes. A hub is a centrally located airport serving as an intermediate point between numerous outlying cities. A spoke is a connection between a hub city and an endpoint city. Airlines fly along spokes, connected to their hubs, to feed traffic into their networks. A route is a connection between one outlying city and another reached via a hub; that is, each route contains two spokes attached to the same hub. Passengers fly along routes; the routes an airline can serve depend on the spokes it flies. A market is a pair of endpoint cities; each market contains one route for each possible hub by which a passenger can travel between the outlying cities.

3.1. Model

In order to provide service to a market, an airline must operate two spokes connecting the origin city and destination city to its network via one of its hub cities. We specifically define a route as two endpoints connected by a hub. Following Brueckner and Spiller (1994), we disaggregate the costs into two components--the fixed costs of providing the hub, and the incremental cost of providing service along each spoke. We then break down the incremental costs of serving each spoke into a fixed cost of serving the spoke, and the variable costs of carrying passengers along that spoke. Brueckner and Spiller examine the marginal costs of carrying passengers to test for economies of density; in contrast, we focus on the fixed (with regard to network traffic) costs of adding the spoke into the hub. We define spoke costs between an outlying city and the hub as

$$C_i = X_i * \beta ,$$ (1)

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[7] Access to other national networks would require travel to other mid-sized airports such as Raleigh/Durham, Nashville, or Norfolk.

[8] An alternative representation of this point may be found in Hayes and Ross (1996). Hayes and Ross note that the financially viable national carriers tend to offer an extensive network of service, but carefully protect dominated routes.

where C_i represents the cost of operating spoke i, X is a set of exogenous variables describing cost conditions at the outlying city and at the hub, and β is a vector of parameters. If a carrier does not provide spoke service to some outlying city, it cannot provide route service between that city and any other city on the airline's network. However, providing spoke service, allows service on any four-leg routes in the network (as well as the two-leg route between the outlying city and the hub).

When the airline incurs the fixed costs of providing the sppoke, it gains the ability to provide service to four-segment routes that connect to the network along that spoke. In serving the network of routes, the airline will incur traffic costs but will also earn revenue from additional traffic. Profits earned by serving a given route are

$$\Pi_{ij} = Z_{ij}{}^*\gamma + \varepsilon_{ij}, \tag{2}$$

where Π is the airline's profitability from route j via spoke i. Z_{ij} is a set of exogenous variables describing cost conditions and demand for tickets between the two endpoints; γ is a vector of parameters; and ε is an error term whose distribution is described below. The airline will choose to serve those routes for which profits are positive. For any spoke i, let S_i be the set of all routes for which such profits are positive. Then the airline's incremental profits for serving spoke i are given by

$$\Pi_i = \Sigma_{Si} \Pi_{ij} - C_i.\,{}^9 \tag{3}$$

If incremental spoke profits are positive, then the airline will choose to provide service in spoke i and will serve those routes in the set S_i. The carrier will not serve those routes for which incremental route profits are negative, even after the costs of providing spoke i are paid; that is, the routes outside the set S_i. If incremental spoke profits are negative, then the carrier will not provide service on the spoke nor any of the routes which include that spoke.

The incremental profit from serving a route depends upon the extent of competition from other airlines serving the same market, and on the level of product differentiation between them. This issue was addressed by Berry (1992). Following his approach, we decompose the error term in the profit equation (2).

$$\varepsilon_{ij} = h(N, W, \alpha)_{ij} + \upsilon_{ij} \tag{4}$$

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[9] This is similar to Brueckner and Spiller, p. 396.

N is the number of airlines serving the market; W is a set of variables describing the product differentiation between those airlines which affect this airline's share of the market; α is a vector of parameters; and the error υ is independent of N and distributed Normal(0,1).[10]

After substituting, the final form of the incremental route profit function is

$$\Pi_{ij} = Z_{ij}*\gamma + h_{ij}(N,W,\alpha) + \upsilon_{ij}. \tag{5}$$

After rearranging to collect error terms, the incremental spoke profit function is given by

$$\Pi_i = (\Sigma_{Si} Z_{ij}*\gamma + h_{ij}(N,W,\alpha)) - X_i*\beta + (\Sigma_{Si} \upsilon_{ij}). \tag{6}$$

The airline enters the spoke if Π_i is positive and does not enter if it is negative. [11]

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[10] Berry allows for the possibility that there is product differentiation which is observed by airlines and customers, but unobserved by econometricians. He thus allows the $h()$ function to contain a second, carrier-specific error term whose distribution may be firm-specific and may be correlated with ε. The identification of the model is made complicated by the presence of two error terms, possibly correlated, whose joint distribution depends on the number of carriers already serving the market. Berry suggests four different strategies for identifying the model.
1) Assume that profits are constant with respect to N, thus removing the correlation between e and N from the model.
2) Berry himself restricts consideration to markets served by two or fewer carriers, and reduces the problem of the joint distribution of error terms to one which is computationally tractable. This solution is not suitable to our problem. In order to consider the effect of spoke costs on entry we must consider all routes served along that spoke, regardless of the number of carriers which serve the relevant markets.
3) Suppress the carrier-specific error requiring the addition of sufficient W variables to explicitly account for product differentiation. While airlines are product differentiated in many ways, we believe that the variables we include in W are sufficient to measure the effect of product differentiation on profitability. We adopt this method. As a result, the entry game between the carriers serving this market uniquely determines the number of firms serving the market, but not their identities (see Berry for details). We therefore condition our draws for ε on the equilbrium having the proper number of firms, since that is what can be inferred from the distribution of ε, not whether any specific firm enters or not.
4) Assume that firms enter in order of decreasing profitability, and that entry decisions are binding. Then one need consider the firm-specific error of the last firm, rather than one for every potential entrant. An alternative representation of this point may be found in Hayes and Ross (1996). Hayes and Ross note that the financially viable national carriers tend to offer an extensive network of service, but carefully protect dominated routes.

[11] The above description may not apply to some markets where alternate hubs are available for serving the markets in question. In that case, the airline serving the spoke may be able to make some profits in some of the affected markets even if it chooses not to serve the spoke in question; adding service to the spoke in question may cause the airline to forego profits on passengers that are currently flying between the

3.2. Estimation Strategy

As in a probit model, we maximize the likelihood of observed entry and non-entry decisions as a function of our parameters. However, our estimation is complicated by two distinguishing features. First, the distribution depends of ε upon the number of competitors in each of the markets served by a particular spoke. Second, when an airline does enter a spoke, we know which routes it chooses to serve and which routes it chooses not to serve. This entry decision provides useful information regarding the γ parameters.

To address the peculiarities of our model, we use numerical integration to estimate its parameters. For every spoke in the data set, we estimate the likelihood that the airline chooses the entry/no entry decision we observe by the following procedure:

1) In each route served by that spoke, we draw a value, e_{ij}, for ε_{ij} which is consistent with the known information about how many other carriers serve the market, and with the airline's actual decision to serve that route if we observe it (that is, if the airline did enter the spoke in question).

2) Based upon e_{ij}, we calculate the airline's profit on that route from equation (5). If the airline did enter the spoke, we know for which routes the airline chose to provide service. Our calculated route profits will be positive if they did and negative if they did not (due to the conditioning in step 1). If the route profit is negative, we set it to zero, since the airline will not enter this route even if they do enter the spoke. If the airline did not enter the spoke, then our random draws can produce either positive route variable profits (route entry) or negative route variable profits (route non-entry), since we do not observe whether the airline chooses to serve that route or not if it had entered the spoke. Since the airline would not serve a route predicted to offer negative variable profits, we set zero profits in that case also.

3) We add the profits on each route together and subtract the additional costs of serving the spoke. We predict entry if the total spoke profits are positive, and non-entry if they are negative.

4) We repeat steps 1 to 3 a large number of times for each spoke, and take the fraction in which we predict entry as the probability of entry in that spoke.

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endpoint cities by means of a different hub. In such case the entry decision should be conditioned on marginal profit earned by serving the spoke, rather than the total. For the current version of the paper we have restricted ourselves to airlines and spokes where no alternative hub is available and therefore the profits the airline will earn, in the relevant markets, by not entering the given spoke is known to be zero. We may expand the data sample to include other markets in which the marginal profit characterization will be relevant in a future version of this paper.

When entry is not observed, we do not know which routes the airline would serve if it chose to serve the spoke. However, we surmise profits for the whole spoke to be negative, and accordingly, the likelihood for the spoke is $\Pr(\Pi_i < 0)$. Conversely, when a spoke is served, we do know which routes the airline serves and which it does not serve. In the case of entry, the likelihood for the spoke is $\Pr(\Pi_i > 0, \Pi_i > 0$ over $S_i, \Pi_{ij} < 0$ over $\sim S_i)$. We calculate the former likelihood by numeric integration without complication. Since the probability of any one trial having the correct pattern of routes served and not served is low, the latter likelihood is computationally intensive; therefore, numerous draws are required to accurately estimate the probability. A more efficient procedure is to decompose the probability of entry into $\Pr(\Pi_i > 0 \mid \Pi_{ij} > 0$ over $S_i, \Pi_{ij} < 0$ over $\sim S_i) * \Pr(\Pi_{ij} > 0$ over $S_i, \Pi_{ij} < 0$ over $\sim S_i)$. The first term, a conditional probability of the decomposition, is computed numerically by drawing values of ε_{ij} that are conditioned on $\Pi_{ij} > 0$ for routes where entry is observed, and on $\Pi_{ij} < 0$ for routes where entry is not observed, as discussed above. The second term, a marginal probability, is computed using the normal distribution function. We multiply these two probabilities together to condition properly the likelihood estimates.

3.3. Airline Data

Adapting our empirical model to available airline data presents many challenges. We use airline presence data from the Department of Transportation's Origin and Destination Survey (DB1A) and the T100 Domestic Segment Data for 1992 (T100).[12] The DB1A provides revenue and number of passengers flying from ticket sales, leg by leg itinerary records for each ticket, and hub utilization information. The T100 provides plane usage, frequency of service, and fleet composition information. In addition to the data from the Department of Transportation, we incorporate gate information and demographics to describe hub dominance and demand, respectively.[13]

We chose the entire year of 1992 for several reasons. First, 1978 through 1988 was a period of massive restructuring in the airline industry with some 41 mergers (27 alone occurring between 1985 and 1988) and numerous bankruptcies. Such activity could easily complicate the identification of entry, non-entry, and competition. Therefore, we want to be (chronologically) as far away from this activity as our available data allow. Second, the T100 is a valuable source of information which began in 1990.[14] Third, we chose to utilize

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[12] The former data comprises a 10% sample of all domestic passenger itineraries and provides us with detailed information on routes of travel, hub utilization and revenue. The latter data source includes data from all non-stop flights and provides information on plane size and utilization, and flight frequency.

[13] We are indebted to Robin C. Sickles for demand characteristics and to Richard Butler for gate information. The demand characteristics are not included in this draft.

[14] Another data source (Service Segment Data) provides similar information for earlier years.

an entire year to avoid seasonal fluctuations. Finally, much of the financial distress that rocked the airline industry in the very early 1990s led carriers to abandon unprofitable routes and discontinue service to small markets. By catching the tail end of this era, we hope to correctly label these abandoned routes as non-entry.

A central issue to our estimation procedure is a comparison between entry and non-entry spokes. While collecting revenue and flight information about entry spokes is a straightforward process, the same is not true for the non-entry spokes. A non-entry spoke is the combination of a hub and an outlying airport that is not served through the hub. Our task is to find the potentially fruitful outlying airport. We find the fruitful airports by watching the behavior of (a) other carriers hubbing at the same hub, (b) other carriers hubbing near by, or (c) the same carrier hubbing near by. Table 1 contains a list of our carrier/hub combinations and the alternative carrier/hubs we utilize to identify and infer revenue and flight information for non-entry routes. Table 2, showing summary statistics, exhibits an average value of .87 to the entry indicator. The low percentage of non-entry routes demonstrates that airline carriers have a tendency to "blanket the market" and, therefore, non-entry spokes are rare.

The set of independent variables is composed of three subsets. The first subset of variables is spoke-carrier based. We include the total revenue associated with entry into a spoke, spoke distance, flight frequency and enplanement data, and the number of endpoints accessible from the hub. The second subset of variables is route-carrier based and provides information regarding overall flight distance, route revenue, and market share. The third subset is composed of route information focusing on endpoint demographics and the competitive environment of the route. Summary statistics for these variables are contained in Table 2 and detailed descriptions may be found in the Data Appendix.

4. RESULTS

Our preliminary results are based upon a limited number of variables and a 10% sample of our data set. In the spoke fixed costs $X_i*\beta$ (equation 1) we use two independent variables, TOTGATES, the total number of gates at the hub, and CARRGATES, the number of gates under the control of the carrier in question. In the route profits $Z_{ij}*\gamma$ (equation 6) we use ROUTDIST, the distance along the route; we hope to add demographic information on demand in the near future. In the $h_{ij}(N,W,a)$ function, we include log N, the number of carriers serving the route, NDEST, the number of destinations each carrier may reach from a spoke, and DISTRATIO, the ratio of distance of each carrier on the route to the distance of the competitor with the shortest path between the two endpoints.[15] The latter two variables capture heterogeneity in service between airlines. Airlines which serve more destinations are more attractive for frequent flyer programs, and should be more profitable;

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[15] We include observations for all carriers flying a route in question.

airlines which take passengers far out of their way will have longer travel times and should be less demanded, hence less profitable.

The results of the estimation are:

Route profits = -0.730 - 0.210e-4 * DISTRATIO + 3.26e-4 * NDEST
- 0.044 * CARRDIST - 1.85 * log N

and

Spoke costs = -0.208 + 2.726 * TOTGATES + 0.136 * CARRGATES

Log likelihood = -6612.973633

We have not yet been able to calculate standard errors for these estimates, so we cannot determine their significance, but we can still draw some preliminary conclusions based on the signs of the estimates as long as the tentative nature of those conclusions is clear. First, we note that while spoke fixed costs are substantially higher at larger airports (those with more total gates), it does not make a great deal of difference how large the operations of the hubbing carrier are (because the coefficient on CARRGATES is considerably smaller than that on TOTGATES). This suggests that most of the incremental costs of adding a spoke to a hub are the physical costs of making the airport larger; if a spoke is added by switching gates from a non-hubbing airline to the hubbing airline, the incremental costs are quite small in relative terms. Indeed, they may be zero if the estimated coefficient turns out to be insignificant. This result suggests that there are decreasing returns (rising incremental costs) in making hubs larger, although the returns decrease more slowly, perhaps not at all, if the increase is achieved by giving the hubbing carrier a larger share of the existing gates at the airport rather than by making the airport larger.

Second, the coefficient on ROUTDIST is negative. This is reasonable, since the costs of serving long routes, particularly fuel and the opportunity cost of pilot and crew time, are higher than those of serving short routes. Our current specification for distance is linear; however, if airlines have economies of hauling distance, the true relationship may be quadratic, with the $ROUTDIST^2$ term being positive. We hope to test for this in future regressions. Third, the airline heterogeneity measures are taking the expected signs; NDEST is positive and DISTRATIO is negative. This gives us reason to believe that we have correctly controlled for demand heterogeneity between carriers in the profit function.

Our next step is to add more variables to $X_i^*\beta$, specifically the number of spokes served by the airline, and to use a quadratic functional form to allow for the possibility that incremental spoke costs might fall, then rise as the size of the network increases.

5. CONCLUDING REMARKS

As airlines continue to rely on hub and spoke networks to compete in an increasingly global market, economists and other researchers must weigh the costs and benefits associated with these networks. We add to a literature addressing these issues by evaluating the marginal

profitability of spokes within these networks. Our approach was innovative in several ways. First, we used entry as a signal of costs and profitability as did Berry. Second, we disaggregated costs as did Brueckner and Spiller, by directly measuring the fixed costs associated with adding a marginal spoke to an existing hub-and-spoke network. The combination of these two methods is an important first step towards identifying the optimal network structure.

Our data comprised three sets: a set of spoke-carrier observations, a set of route-carrier observations and a set of market-carrier observations. These data included demand characteristics, congestion indicators,[16] spoke cost variables, network cost variables and network characteristics. We restricted our sample to a small number of mid-sized hubs and data from the calender year 1992.

We presented some preliminary results that are both consistent with the literature and puzzling. Our results indicated slightly increasing, possibly constant returns to scale in airport presence and economies of scope in destination alternative. Both constant returns to scale and scope economies are consistent with the literature and suggest benefits to larger hubs and economies in network size. As we continue to include additional observations and variables to the model, and obtain standard errors, we hope to improve the reliability of these findings.

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[16] To be added in a later draft.

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Data Appendix

Spoke Carrier Variables. These variables are based upon information regarding a particular carrier/spoke. In the case of non-entry, the data is reflective of the alternate carrier/spoke.

SUMPASS - The total number of passengers traveling with the carrier through the spoke regardless of the origin or destination of travel. (Source: DB1A and author's calculations).

SUMDOLL - The total revenue generated from passengers traveling with the carrier through the spoke regardless of the origin or destination of travel. (Source: DB1A and author's calculations).

ENTRY - A 0/1 variable indicating that the carrier in question has or has not entered the spoke in question. (Source: DB1A and author's calculations.)

TSCHED - The total number of flights that the carrier has scheduled throughout the year. (Source: T100)

TPERF - The total number of flights that the carrier has performed throughout the year. (Source: T100)

TSEATS - The total number of seats that the carrier has made available throughout the year. (Source: T100)

TPASS - The total number of seats that the carrier has filled throughout the year. (Source: T100)

VPLANE - The variance in plane size (as measured by total number of seats per plane) for the carrier on performed flights throughout the year. (Source: T100)

DIST - The great circle distance between the outlying airport and the hub. (Source: T100)

TOTGATES - The total number of gates at the hub airport.

CARRGATES - The number of gates the carrier controls at the hub airport.

Route Carrier Variables. These variables are based upon information regarding a particular carrier/route. The route includes the spoke in question as one of its "legs" and the hub-

endpoint as the other "leg." In the case of non-entry, the data is reflective of the alternate carrier/spoke and the endpoint.

ENDPASS - The total number of passengers traveling with the carrier through the spoke to the endpoint in question. (Source: DB1A and author's calculations).

ENDDOLL - The total revenue generated from passengers traveling with the carrier through the spoke to the endpoint in question. (Source: DB1A and author's calculations).

ENTRY - A 0/1 variable indicating that the carrier in question has or has not entered the spoke in question. (Source: DB1A and author's calculations.)

ROUTDIST - The great circle distance from the outlying airport to the hub in question and then from the hub in question to the endpoint. (Source: DB1A and author's calculations.)

ENDPTSHR - The share of the carrier at the endpoint reached via the spoke. (Source: DB1A.)

NSMLSAPT - The non-stop miles from the outlying airport.

TNPXAPT - The total number of passengers using the outlying airport.

INCMAPT - The average income in the SMSA of the outlying airport.

POPAPT - The population in the SMSA of the outlying airport.

WKFCAPT - The workforce in the SMSA of the outlying airport.

UNEMPAPT - The unemployment rate in the SMSA of the outlying airport.

NSMLSEND - The non-stop miles from the endpoint.

TNPXEND - The total number of passengers using the endpoint.

INCMEND - The average income in the SMSA of the endpoint.

POPEND - The population in the SMSA of the endpoint.

WKFCEND - The workforce in the SMSA of the endpoint.

UNEMPEND - The unemployment rate in the SMSA of the endpoint.

Market Carrier Variables. These variables are based upon information regarding a particular carrier/market. The market include all possible routes that could be used travel between the outlying airport on the spoke and the endpoint on our sample or routes. For each market we have observations for all carriers offering service between the endpoints.

N - The number of competitors in the market.

NDEST - The number of destinations available from the outlying airport in the market.

CARRDIST - The minimum distance traveled by the carrier in the market to connect the outlying airport and the endpoint.

Table 1
Spokes and Alternatives

Hub and Carrier In Question		Alternate Hub and Carrier	
Hub	Carrier	Hub	Carrier
Cleveland, OH	USAir	Cleveland, OH	Continental
		Dayton, OH	USAir
Memphis, TN	Northwest	Nashville, TN	American
Nashville, TN	American	Memphis, TN	Northwest
		Chicago, IL*	American
Cincinnati, OH	Delta	Cleveland, OH	USAir
		Cleveland, OH	Continental
		Dayton, OH	USAir
Philadelphia, PA	USAir	Baltimore, MD	USAir
		Pittsburgh, PA	USAir
		Washington, DC**	USAir
Pittsburgh, PA	USAir	Philadelphia, PA	USAir
		Baltimore, MD	USAir
		Indianapolis, IN	USAir
Dayton, OH	USAir	Cleveland, OH	USAir
		Indianapolis, IN	USAir
Denver, CO	United	Denver, CO	Continental
Washington, DC**	USAir	Baltimore, MD	USAir
		Washington, DC***	United
Detroit, MI	Northwest	Cleveland, OH	USAir
		Cleveland, OH	Continental

Table 1 (cont'd)
Spokes and Alternatives

Salt Lake City, UT	Delta	Las Vegas, NV	America West
Las Vegas, NV	America West	Salt Lake City, UT	Delta
St. Louis, MO	TWA	Chicago, IL*	United
		Chicago, IL*	American

* O'Hare International Airport
** Washington National Airport
*** International Airport at Dulles

Table 2
Some Summary Statistics

Spoke Carrier Variables					
Variable	N	Mean	Std Dev	Minimum	Maximum
SUMPASS	765	2575.68	2199.60	11.00	11899.00
SUMDOLL	765	805374.36	703166.18	2347.00	3713978.00
ENTRY	765	0.87	0.34	0.00	1.00
TSCHED	765	1408.74	1177.49	0.00	8205.00
TPERF	765	1388.87	1159.66	1.00	8127.00
TSEATS	765	197580.26	177157.87	97.00	1084548.00
TPASS	765	118927.13	116826.77	0.00	705672.00
VPLANE	765	1002.69	1844.18	0.00	15140.66
DIST	765	804.66	659.11	30.00	4129.00

Route Carrier Variables					
Variable	N	Mean	Std Dev	Minimum	Maximum
ENDPASS	39797	58.16	89.01	1.00	1245.00
ENDDOLL	39797	17727.40	28248.12	0.00	582041.00
ENTRY	39797	0.83	0.37	0.00	1.00
ROUTDIST	39797	1332.69	772.60	107.00	6975.00
ENDPTSHR	39797	0.17	0.23	0.00	1.00