Introduction

• The Hub-and-spoke (HS) network has been the focus of airline network studies since US airline deregulation.
Introduction

- Using linear marginal cost functions ($MC = 1 - \theta Q$), most theoretical work relies on a high value of returns-to-density parameter $\theta$ to guarantee optimality of the HS network ($Q$ is traffic) (Düedden 2006; Wojahn 2001a&b).

- Empirically, the existence of substantial economies of density has been confirmed in a number of papers (Caves et al. 1984, Brueckner et al. 1992 and Brueckner and Spiller 1994).

- Studies on dehubbing in the US and European airline industry have provided empirical support for the optimality of the single-hub solution (Burghouwt 2005; Dennis 1994; Redondi et al. 2010).

- However, much of the work is confined only to comparing hub-and-spoke (HS) and point-to-point or fully connected (FC) configurations.
Multi-Hub Network of Alitlia

Single-Hub Network of SAS

Multi-Hub Network of Delta
Introduction
A reality where multi-hub is popularly adopted

Geographical Reason
• Multi-hub networks with an effective geographical generate more profit and are more convenient for the passengers (Tretheway&Oum 1992; Geodeking 2010; O’Kelly 1998).

Congestion
• Bypass major hubs and divert traffic, hence forming secondary hub(s) at major cities (Swan 2002; Düedden 2006).

Offer Complementary Service in Connecting Market
• “Frequency Game”: Synchronizing flights to the same destination from both hubs, multi-hub system can be utilized to offer the same O&D with flights at different times (Geodeking 2010).

Other Reasons
• Consolidation, strategic positioning and entry deterrence, better aircraft utilization, bilateral restrictions, and the influence of unions are incentives for airlines to adopt multi-hub system (Burghouwt 2013; Dennis 2005).
Introduction
Theoretical Justification for Multi-hub Networks

• So far, theoretical settings with network of arbitrary size and structure have found no evidence for multi-hub networks existing as a result of cost-minimizing behavior under symmetric cost functions. (Hendricks et al. 1995, Wojahn 2001).

• Düedden (2006) used a simple theoretical model with exogenous price and demand, giving justification for the rationality of multi-hub networks with one large and one small hub.

Present Generalization
Introduction
Results preview

The Monopoly Case
• Economies of density do not guarantee optimality of the 1H network
• 2H network is more profitable if demand and economies of density are both low.

The Cournot Duopoly
• Network airline is competing with a low-cost carrier (LCC)
• It is more profitable for the network carriers to switch to 2H when confronted with an LCC challenge.
Model Setup
Network Structure

- Demand for travel exists between each pair of cities, yielding **six city-pair markets**.

- In a **1H network**, passengers in markets from a spoke city to the hub city can enjoy nonstop service, passengers flying from one spoke city to another must make a connecting trip.

- In a **2H network**, trips from spoke cities to either hub now have nonstop service, while passengers flying from one spoke city to another or from one hub to another can choose connecting flights.
Model Setup
Demand and Costs

Consumer utility: \[ u = C + B - G \]

Undertake travel if: \[ Y - p + B - G \geq Y, \quad \text{where } B \sim \text{Uniform } [\underline{B}, \overline{B}] \]

The number of consumers traveling is then found by integrating the density of \( B \) over the interval \([p + G, \overline{B}]\). The solution for \( p \) is given by:

\[ p = \alpha - \beta q \quad \text{where } \alpha = \overline{B} - G, \beta = \overline{B} - \underline{B} \]

Connecting travel through the hub will incur extra time cost. Denoting the extra connecting cost by \( \mu \), the intercept of the demand curve for connecting flights would be \( \alpha - \mu \) instead of \( \alpha \).
Model Setup
Demand and Costs

- Distance is assumed not to matter
- Quantities and prices will be the same in markets of the same type (i.e. direct markets and connecting markets). Hence we only distinguish between quantities (prices) in direct and connecting markets,
  - $q$ and $p$: traffic and prices in direct markets
  - $Q$ and $P$: traffic and prices in connecting markets.
  - the subscript $h(2h)$ denotes the 1H (2H) network.
  - $c(.)$ is the quadratic function $c(q) = q - \theta q^2$, incorporating the returns-to-density parameter $\theta$.
  - The marginal cost function is assumed to be linear ($MC = 1 - 2\theta q$)
The choice between 1H and 2H networks
Basic Model Simplest Case: n=4

<table>
<thead>
<tr>
<th>Structure</th>
<th>Total Traffic in:</th>
<th>Spoke Traffic Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A. 1H Network</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 spokes</td>
<td>Direct Markets : $3q_h$</td>
<td>Each spoke carries direct traffic in the market: $q_h$</td>
</tr>
<tr>
<td></td>
<td>Connecting Markets: $3Q_h$</td>
<td>Each spoke also carries connecting traffic from 2 connecting markets: $2Q_h$</td>
</tr>
</tbody>
</table>

$$
\pi_{1hub} = 3q_h[\alpha - \beta q_h] + 3Q_h[\alpha - \beta Q_h - \mu] - 3c(q_h + 2Q_h)
$$
The choice between 1H and 2H networks

Basic Model Simplest Case: n=4

Panel B. 2H Network

<table>
<thead>
<tr>
<th>4 spokes</th>
<th>Direct Markets: $4q_{2h}$</th>
<th>Each spoke carries direct traffic in the market: $q_{2h}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Connecting Markets involving non-hub cities: $Q_{2h}$</td>
<td>Each spoke also carries half of the connecting traffic from AC connecting markets involving non-hub cities: $\frac{1}{2} Q_{2h}$</td>
</tr>
<tr>
<td></td>
<td>Connecting Market involving two hub cities: $Q_{2h}$</td>
<td>Each spoke also carries $\frac{1}{2}$ of the connecting traffic involving hub cities: $\frac{1}{2} Q_{2h}$</td>
</tr>
</tbody>
</table>

$$
\pi_{2hub} = 4q_{2h}(\alpha - \beta q_{2h}) + 2Q_{2h}[\alpha - \beta Q_{2h} - \mu] - 4c(q_{2h} + Q_{2h})
$$
The choice between 1H and 2H networks

Basic Model

Consider \( n = 4 \), and normalize \( \beta \) to 1

Taking first order conditions and solving the equation systems, the quantities that maximize the two profit functions are:

\[
q_h = -\frac{-1+\alpha-2\alpha \theta-2\theta \mu}{2(-1+5\theta)} \\
q_{2h} = -\frac{-1+\alpha-\alpha \theta-\theta \mu}{2(-1+3\theta)}
\]

\[
Q_h = -\frac{-2+\alpha+\alpha \theta-\mu+\theta \mu}{2(-1+5\theta)} \\
Q_{2h} = -\frac{-2+\alpha+\alpha \theta-\mu+\theta \mu}{2(-1+3\theta)}
\]

For simplicity, assume that \( \mu = 0 \). The case where \( \mu \) does not equal 0 will be discussed later.
The choice between 1H and 2H networks

Basic Model

The feasible parameter space is defined by:

- second order condition for profit maximization \( \theta < \frac{1}{5} \)
- non-negative marginal costs and quantities in a 1H network \( \frac{2}{1+\theta} < \alpha < \frac{1}{3\theta} \)
The choice between 1H and 2H networks

**Basic Model**

**Profit indifference curve**
- After solving the 1H and 2H optimization problems, the airline must make a global choice of network type.
- Determine parameter combinations \((\theta, \alpha)\) that make the airline indifferent between the network types, with \(\pi_{1hub} = \pi_{2hub}\) holding.

\[
\Delta = \pi_{1hub}^* - \pi_{2hub}^* = 0
\]

Solving

\[
\alpha^* = \frac{-1 - 13\theta \pm \sqrt{1 - 7\theta + 7\theta^2 + 15\theta^3}}{-11\theta + \theta^2}
\]
The choice between 1H and 2H networks

Basic Model

**Proposition 1.** Given symmetric markets, linear marginal costs with 4 nodes and no connecting time cost, a 1H network is more profitable than a 2H network if

\[
\frac{-1 - 13\theta - \sqrt{1 - 7\theta + 7\theta^2 + 15\theta^3}}{-11\theta + \theta^2} < \alpha < \frac{1}{3\theta}, \quad \theta < \frac{5}{27}
\]

and 2H network is more profitable than a 1H network if

\[
\frac{2}{1+\theta} < \alpha < \frac{-1 - 13\theta - \sqrt{1 - 7\theta + 7\theta^2 + 15\theta^3}}{-11\theta + \theta^2}, \quad \theta < \frac{5}{27}
\]

or

\[
\frac{2}{1+\theta} < \alpha < \frac{1}{3\theta}, \quad \frac{5}{27} < \theta < \frac{1}{5}.
\]

Above figure shows that in a significant proportion of the parameter space, 2H is more profitable than the 1H network, thus justifying the existence of a multi-hub system.
The choice between 1H and 2H networks
Basic Model: Generalization

• Assumption that the connecting cost $\mu$ equals zero

  $\mu > 0 \quad \rightarrow \quad$ Demand for connecting flights decreases

  $\rightarrow \quad$ 1H requires more connecting flights

  $\rightarrow \quad$ The profit indifference curve move to the right

  $\rightarrow \quad$ Region where 2H preferred grows

• Introducing a fixed cost of operating a hub or a direct route

  $\rightarrow \quad$ 1H requires less hub and direct route

  $\rightarrow \quad$ The profit indifference curve move to the left

  $\rightarrow \quad$ Region where 1H preferred grows
The choice between 1H and 2H networks
Adding a direct inter-hub route
The choice between 1H and 2H networks
Adding cities to the network
The choice between 1H and 2H network after LCC entry

- LCC enters the market by connecting city A and C.
- Assume that the LCC and network carrier share the same cost function, with the same value of $\theta$.
- LCC creates asymmetry between the NC’s direct and connecting markets:
  - $q^N_h$: passengers in the NC direct markets HA and HC
  - $q^{N}_{HB_h}$: passengers in the NC direct market HB
  - $q^L_{AC_h}$: passengers in the LCC direct market AC
  - $Q^N_{AC_h}$: passengers in the NC connecting market AC
  - $Q^N_{-AC_h}$: passengers in the NC non-AC connecting markets
  - $q^N_{2h}$: passengers in the NC direct markets
  - $q^L_{AC_{2h}}$: passengers in the LCC market AC
  - $Q^N_{AC_{2h}}$: passengers in the NC market AC
  - $Q^N_{-AC_{2h}}$: passengers of the NC in non-AC connecting markets
The choice between 1H and 2H network after LCC entry

**Proposition 2.** Given symmetric markets, linear marginal costs with 4 nodes and no connecting time cost, LCC entry connecting one pair of the spoke cities shifts the profit indifference curve upward, and parameter combinations in between the two indifference curves switch from favoring the 1H network to favoring the 2H network.
The choice between 1H and 2H network after LCC entry

**Proposition 3.** Given symmetric markets, linear marginal costs with 4 nodes and no connecting time cost, LCC entry connecting one pair of the spoke cities shrinks area of the feasible parameter space and reduces the percentage of the feasible space favoring the 1H network from 45.4% to 43.5%. Hence, the network carrier is more likely to choose the 2H network after LCC entry.
Conclusions

The Monopoly Case

• Economies of density do not guarantee optimality of the 1H network
• 2H network is more profitable if demand and economies of density are both low.

The Cournot Duopoly

• Network airline is competing with a low-cost carrier (LCC)
• It is more profitable for the network carriers to switch to 2H when confronted with an LCC challenge.
Thank you!

how planes fly