Approaching an Airline Network Model of Competitive Strategy in International Aviation: A Conceptual Framework

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Abstract:

This paper presents a framework for analysis of international aviation at the network level. The relationships between the competitive variables are determined suing structural equation modelling before generic competitive strategies and network strategy are formally linked Game theory is used to model competition. The specified output is a set of international airline frequencies that define a state a state of non-cooperative Nash equilibria The set of frequencies is such that each airline maximises its profit or some other objective function A method of comparative statics is proposed for comparing the profit performances of the airlines with the hypothesised optimal network configuration The approach adopted is conceptual although the model could be empirically tested with data obtained from airlines in the Asia-Pacific region and official aviation sources

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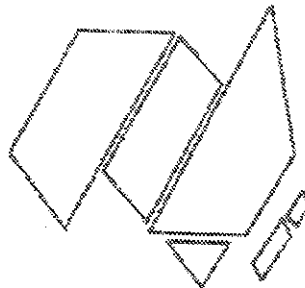
A working definition of an airline network

An airline network is the integration of separate routes into a geographical pattern. Demand for travel between a pair of communities represents a potential market. If a market has sufficient revenue potential or if a route between a city-pair would provide an essential link in the system, an airline is likely to begin scheduled flights between the city-pair. The way the airline links various routes (the spatial dimension) and coordinates schedules (the temporal dimension) defines the firm's network.

Networks exist in a variety of configurations. At the simplest level, it is a single city-pair. They can also be complex - characterised by indirect routing and multiple city-pairs. The possibility of indirect routing enables the airline to establish a network which can help protect critical markets from competition, control costs and to differentiate its service.

In the international aviation context, Oum et al. (1993) extend the definition of network to include strategic alliances between airlines of different nations. In what they call 'global airline networks', a group of affiliated airlines offer seamless services to consumers through joint use of computer reservation systems, throughfares and ticketing, automatic baggage transfers, coordinated flight schedules, code sharing of flights, joint marketing, sharing of frequent flier programs, joint purchasing of aircraft and fuel. For all practical purposes, to consumers, it is like using a single airline company. Strategic alliances, therefore can be viewed as an instrument of increasing both network size (market coverage) and sprucing up network structure (optimal route configuration and connectivity). Network size represents the number of nodes that an airline serves. It relates to geographical market coverage. An extensive nodal coverage does not necessarily confer network economies - there are at best constant returns to scale associated with network size. Route configuration and connectivity refer to the manner in which the airline *links* the various nodes in its network. The airline might elect (subject to constraints such as bilateral terms) to use the hub-and-spoke system or some other system such as the turnaround route system. Optimal route configuration and connectivity are also closely linked with scheduling. The scheduling regime in a hub-and-spoke system for instance, will be substantially different from that in a tournaround system. In a hub-and-spoke system the airline may have banks or complexes but these are not possible in the turnaround route system.

An overriding theme here is that airline networks represent both the product of the firm and also the production plan: each segment may be seen as an asset of the firm, contributing the production of flights not only on that route, but also adjoining routes, since connecting passengers are 'by-products' in the process. Airline networks can be viewed as multi-product.

There are three generic types of networks in the airline industry; the linear network, the hub-and-spoke network and the turnaround route system (Sorenson, 1990). Figure 1 illustrates the three.
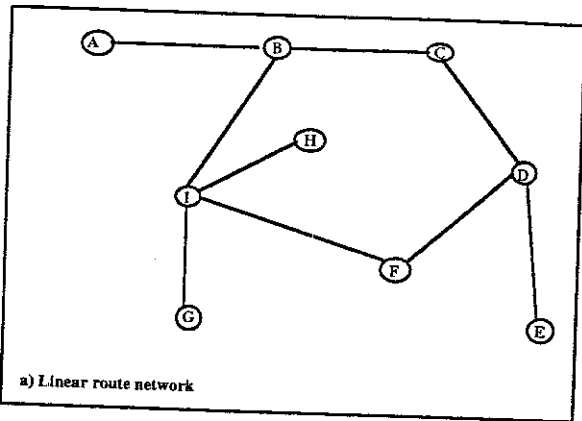
a) Linear route network
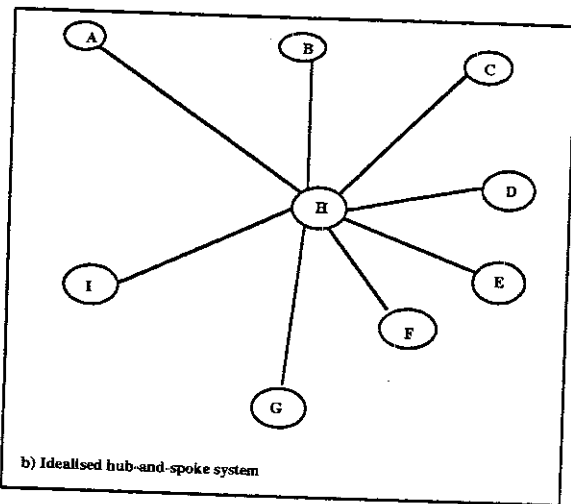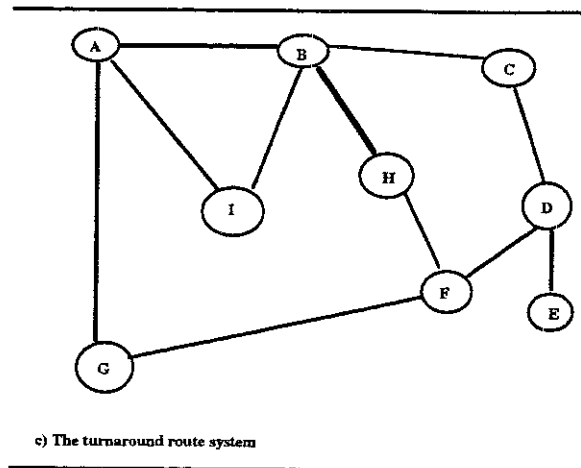

b) Idealised hub-and-spoke system

c) The turnaround route system

Figure 1 The three generic route systems

In the linear network, the airline, makes several stops in order to gather enough passengers. In the hub-and-spoke system airlines build their networks by combining features from non-stop and multi-stop routing patterns. Airlines coordinate schedules of in-bound and out-bound flights. The turn-around system uses the 'high density approach' where there is little economy to be gained in expanding the geographical scale of links between nodes that have a large demand for interacting with each other. Airlines in international aviation may be constrained by bilaterals as to their network structure, but where the bilaterals are liberal, airlines may use a combination of all three, but will tend to emphasise one of them.

The link between competitive strategy and networking

There has been much controversy and discussion in the literature relating to industrial organisation about whether the firm or industry or some other intra-industry group stratification is the appropriate unit of analysis. Recent developments in oligopoly theory have done much to resurrect interest in analysis at the firm level by concentrating on interactions in markets where one firm's actions affect its rivals (see McGee and Thomas, 1986).

The approach taken in this paper is to concentrate on the aviation industry at the firm level. A game theory approach, where firms take strategic manuvoures against each other in an attempt to gain competitive advantage is adopted (see Fisk, 1984). The link between competitive strategy and networking has not been clearly identified in the literature, yet the airline network represents both the production plan of the airline and its product. The strategy of an organisation is the course of action it selects to ensure that it achieves its goals and enhances its chances of long term viability in the face of changing circumstances and an uncertain future. The strategy gives the organisation a direction - that is a set of guidelines used to commit resources. By committing resources, an organisation binds itself to the course it has chosen. Porter (1985) suggests that the firm's strategy is related to advancing or maintaining its position. The strategy can be defined as the determination of long term goals and the objectives of an enterprise, and the adoption of courses of action and the allocation of resources for carrying out these goals. For most businesses, the objective is to achieve targets of profitability. Profitability must be achieved in an environment that comprises other organisations also vying to raise their competitive advantage. The groups, organisations, and individuals in the competitive environment consist of rivals, potential entrants, substitutes, buyers and suppliers.

There are general courses of action available to firms which they can vary and combine to suit their perception of the competitive situation. Each course of action is based on constructing barriers designed to restrict the courses of action available to rivals and other entrants in the environment. In non-transportation industries, there are basically two generic strategies - cost leadership and product/service differentiation. In transportation, it is also possible for a firm to base its strategy on its ability to deny other firms access to a geographic market area. Barriers created by firms employing strategies based on cost leadership or differentiation are built by presenting the potential entrant with an unacceptably high cost of entering a market. In aviation, an alternative strategy is based on controlling access to transportation facilities such as airports or terminal facilities or landing slots in a region.

Because of their high fixed costs, and relatively low variable costs, transportation firms have a strong motivation to seek monopolistic control over some of their territory. The idea is to eliminate competition in parts of its system in order to cross-subsidise routes where competition drives rates and fares below the break-even point. A firm's power to set prices derives in part from its ability to assign consumers to different markets and its ability to attain at least local monopoly power over a group of these separate consumer groups. This is a strategy that Sorenson (1990) terms area

monopoly. In the deregulated and liberalising airline industry, airlines have gained significant level of control of traffic generating in the airport's air travel hinterland due to such factors as the slot allocation system and the nature of the hub-and-spoke system.

The ability of a firm to vary its strategy by targeting a group of consumers or a geographic region, increases a firm's strategic options to the point that Porter (1985) considers a focus to be a separate strategy.

In summary, the two broad courses of action for an airline would be to employ the generic aspatial strategies - cost leadership or differentiation. And since it serves a spatial market, it can employ an area monopoly strategy. In either case, the airline uses aspects of its network as an element in its strategy.

Cost leadership

There is no indication that increasing the scale of an airline network will reduce the unit cost of production. There are generally constant returns to scale associated with airline network size, that is, economies of scale are minor or non existent. There are, however, economies of scope and density that are brought about by a well configured network.

While an airline cannot substantially reduce the cost of providing available seat kilometres (ASK) by increasing the size of its network, it can reduce unit cost by increasing the density of its operations in the existing network. Increasing density means making more seats available by increasing the seating capacity of aircraft or higher frequency, and it requires less than proportional increases in labour and other operating costs, thus allowing the airline to increase seat kilometres performed at a decreased seat - kilometre cost.

While an airline can increase density and reduce unit costs or switch to a hub-and-spoke network to increase network efficiency, these strategic pursuits do not necessarily build lasting cost barriers to protect the firm in the competitive environment. There are no substantial cost penalties preventing another firm switching to a more efficient network configuration.

Differentiation

Carriers that offer wide service through comprehensive networks potentially could erect product differentiation entry barriers by developing a perceived service advantage - witness the mega carriers. In the US after deregulation, the major network strategies observed were hub strengthening, establishing longer and stronger routes, network extension through entry into new markets, network extension through merger or acquisition and network changes to emphasise regional identity. In international aviation, strategic alliances (in the form of equity swaps, seat swaps, code-sharing etc) more or less fulfil the same objectives.

Hub-and-spoke networks allow airlines to focus on selected markets with frequent flights and still achieve large market coverage. In addition to frequency and traffic generation, hub systems can be used to monopolise a major market area. Once a carrier establishes itself with a network of spokes at a particular hub, it becomes difficult for any other carrier to challenge it competitively, unless the other carrier has

resources to develop a similar feed network. To attempt to compete on just one or two of the individual segments into that hub becomes difficult, because the challenging carrier in this situation must rely mainly on the local origin-destination traffic on those few segments while the hub dominant carrier can support a much better pattern of service with the support of all the feed (flow) traffic.

The barriers which protect a firm that has managed to gain domination at a hub airport are its contractual rights at the majority of airport gates. Secondary strategies are also possible, for example, service differentiation (convenient times and destinations) and frequent flyer programmes (FFPs) and interlining and strategic alliances.

From the foregoing, it is desirable that transportation research should move into a different modelling mode of international aviation networks and competitive strategy. The next section proposes the procedures that should be followed. The approach is influenced by the work of Gillen et al. (1990) and Hansen and Kanafani (1985).

The proposed modelling approach

The modelling approach adopted begins with specifying and subsequently verifying the structural relationships between the variables to be included in the profit sub-model and the airline game theory model. Previous approaches looking at the network variable have incorporated it in single equation ordinary least squares cost model as a technology factor without verifying its functional relationship with other variables.

Much of economic theory is built upon sets of systems of relationships. Structural equation modelling is premised on the concept that the variables of interest are part of an overall economic system, but their interaction is not exactly known. There are three sub-models; the measurement sub-model, the structural sub-model and the complete model system. Since we make the *a priori* assumption of market equilibrium in our model of airline network competition, it is instructive that the structural relationship be scientifically tested, and tests of variable endogeneity or exogeneity be undertaken.

The model of market equilibrium for instance is a system of structural equations consisting of the following equations:

Demand equation: $q_d = \alpha_1 \rho + \alpha_2 y$

Supply equation: $q_s = \beta_1 \rho$

Equilibrium equation: $q_d = q_s = q_e$

where: q_d q_s, and q_e are the quantiies demanded, supplied, and equilibrium quantities respectively. The αs and the β are coefficients to be estimated, ρ is the price and y is a vector of factors such as substitutes, complements that affect the quantity demanded.

These are structural equations in that they are derived from a theory that purports to describe the state of airline competition at any snap shot in time. Since the model is one of joint determination of price and quantity, they are labelled jointly dependent or endogenous variables.

The cobweb model of market equilibrium, for example, to be used in obtaining the profit maximising network size and type may be written in the structural equation form:-

$$Q_t = \alpha_0 + \alpha_{t-1} + \varepsilon_{1t} \quad \text{(supply)}$$

$$P_t = \beta_0 + \beta_1 Q_t + \varepsilon_{2t} \quad \text{(inverse demand)}$$

The quantity supplied to the market (Q_t) is determined by the previous period's price. Supply in the current period is inelastic. Demand (P_t) responds to the usual forces and determines an equilibrium price. The αs and βs are coefficients to be estimated and the ε is the error term for the relevant time period. It is imperative therefore, that the structural relationship be determined before the full model is estimated.

A useful presentation of the network problem in structural equation form can be specified by using Golob's framework (1993). The structural equations have a measurement sub-model and a structural sub-model. The output of these models is the specification of what constitute endogenous and exogenous variables. The strength of the relationships between the variables is also specified. The structural relationships will also assist in the specification of the data types required and the specification of the functional form of the model. The functional form that has been predominantly adopted is the linear additive form, where network structure and size have been included in linear ordinary least squares equations as a technology variable. Whilst this might be in order, the literature does not reveal any evidence of testing the linear additive specification.

The approach adopted here begins with an examination of the causal relationships in an international airline network. The a priori assumption being made is that there are some linear structural relationships that will be exposed. The question of what are the exogenous and endogenous variables will be handled by the modelling process using appropriate software such as LISREL. Sorenson (1990) has used a similar approach in isolating the network variable from other variables in domestic airline competition in the US after deregulation. He, however, limits his inquiry to factor analysis (the measurement component of structural equation modelling).

The measurement sub-models

On the endogenous variable side it is assumed that the observed variables can be expressed or captured by a set of unobserved latent constructs (factors):

$$y = \Lambda \eta + \varepsilon \tag{1}$$

where y = observed endogenous variable

ε = error term

η = exogenous latent variable

Λ = coefficient to be estimated

It is necessary for unbiased estimation that ε is uncorrelated with η.

On the exogenous variable side, often called predictors, covariates or input variables, we have:

$$x = \Lambda_x \zeta + \delta \qquad (2)$$

where x = exogenous variable(predictors)

ζ = latent variable

δ = error term

For unbiased estimation it is a necessary condition that δ is uncorrelated with ζ.

The structural sub-model

The structural sub-model captures the structural relationships of the variables and is of the form:

$$\eta = B\eta + \Gamma \xi + \zeta \qquad (3)$$

Unbiased estimation requires that

$$E(\zeta\xi) = 0 \text{ ie } \zeta \text{ is uncorrelated with } \xi$$

The complete model system

The complete model system is a combination of the measurement sub-models and the structural sub-model systems. The general system is given by:

$$y = \Lambda_y\eta + \varepsilon$$
$$x = \Lambda_x \zeta + \delta$$
$$\eta = B\eta + \Gamma\xi + \zeta \qquad (4)$$

where: **B** = causal links between the endogenous latent variables.

Γ = causal links (regression effects) of the exogenous variables on the endogenous variables.

Λ_y = measurement model (factors on the endogenous variable size).

The structural parameters are the elements of the $\mathbf{B}$ Γ, Λ_y, Λ_x vectors. The remaining parameters are error variances and covariances. For unbiased estimation using maximum likelihood, it is assumed that:

ε is uncorrelated with η

δ is uncorrelated with ξ

ζ is uncorrelated with ξ

and for simultaneous estimation of all sub-models, ζ, ε, and δ are all mutually uncorrelated (Golob, 1993).

The full structural equation models are summed up in Figure 2. The arrows represent the expected causal effects of the relationships.
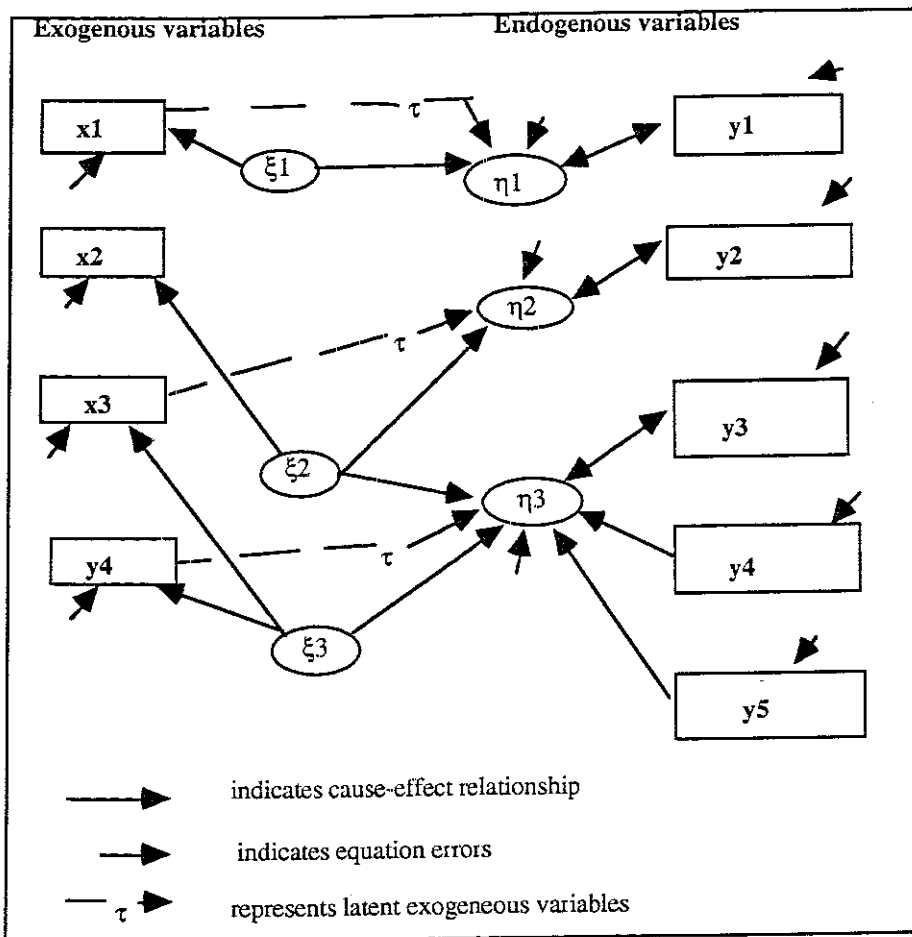
Figure 2   The full structural equation model (illustrative)

The principles espoused in structural equation modelling can be applied to networks in international aviation. Figure 3 shows the causal relationships in an international airline network.
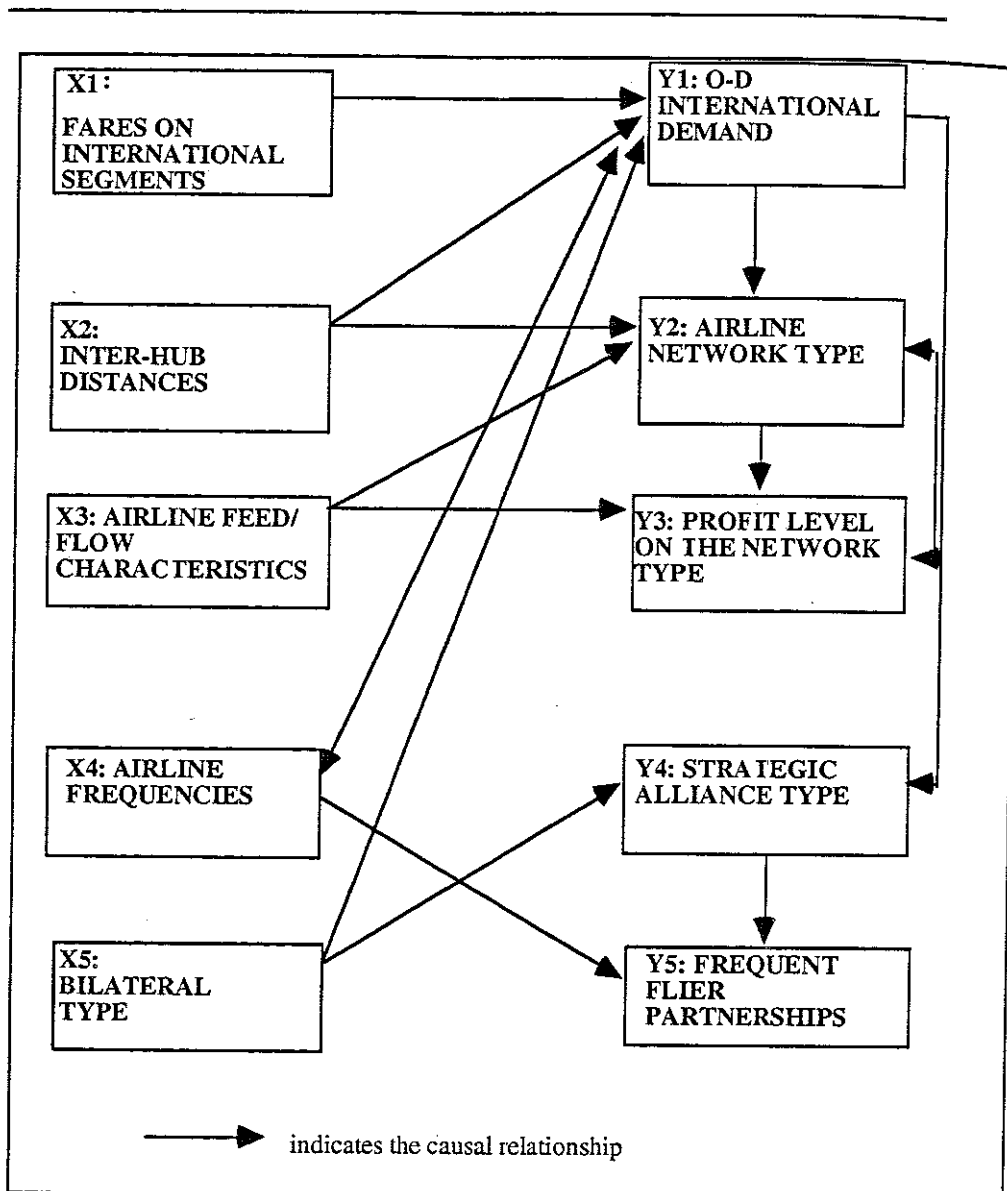
Figure 3   Causal relationships in an international airline network

       It is important to note that the directions of the arrows in the flow diagram are *a priori* assumptions of the causal relationships. Once the model is estimated the direction of the arrows may change. Secondly, what might at first be considered to be exogenous variables may turn out to be otherwise. The primary specification is thus a flexible one and the software package LISREL (Version 8) has the versatility to indicate whether the specification is flawed or not.

The game theory approach

Game theory provides a framework for modelling interactions between airlines when their individual actions jointly determine the outcome. Concepts from the theory first appeared in transportation models in the form of a behavioural hypothesis of route choice, (Wardrop's (1952) first principle), being a Nash non-cooperative game. Network competition is portrayed as an n-player non cooperative game in which the airlines are assumed to be profit maximising.

The determination of what are competitively significant variables is complex. An airline is a multi-product firm, producing flights over a large number of routes in its network - hence the complexity. Production of flight services on one route influences production of services on other routes by generating increased passenger flows between routes. Each route in the airline's network represents a different product and the characteristics of the route need to be incorporated in the modelling process.
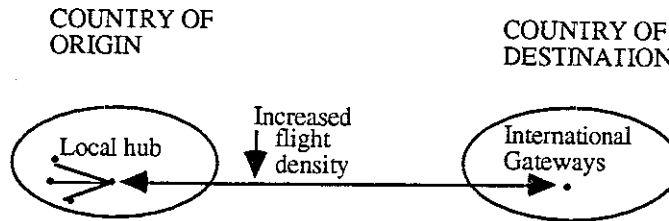
The joint-product nature of the airline production process implies that there exists a dependence between potentially all routes in the network system. Reynolds-Feighan (1992) has captured this interdependence by estimating a spatial autoregressive model, where the connection rate of passengers between different routes is used as a measure of system inter-connectivity. This is a significant and perhaps more plausible approach from the earlier graph theoretic measures first propounded by Kansky (1963). Its major drawback, however, is that there is no recognition that demand data must reflect the true O-Ds rather than mere segment flows.
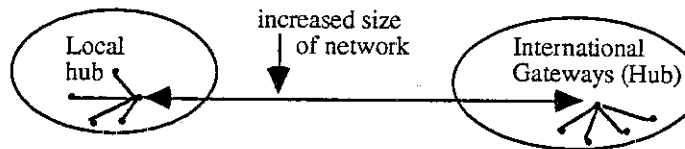
The methodology

The model of airline network competition simulates the behaviour of profit maximising airlines with different network types and hubbing locations by finding states of Nash equilibria. In international airline network competition, two variables are competitively significant; the first is access to routes and the second is access to hubs (airports) (Hansen and Kanafani, 1985).

The model inputs will be specified airline network type and hub locations, airline feed/flow characteristics, aircraft operating characteristics ie type and operating costs, international origin-destination (O-D) demand, average fares on international routes, inter-city/hub distances (stage lengths) and an airline route choice model of the logit model including the type of routing - non-stop, one stop, multi stop. The airlines to be specified in the model will have three types of networks, the turnaround route system, the hub-and-spoke route system, and the linear network as shown in Figure 4 below.

(a) The turn-around route system

COUNTRY OF
ORIGIN

COUNTRY OF
DESTINATION

Local hub — Increased flight density — International Gateways

(b) The hub-and-spoke system

Local hub — increased size of network — International Gateways (Hub)

(c) The linear network system

Originating hub — multi-stop to increase load factors — International Gateway
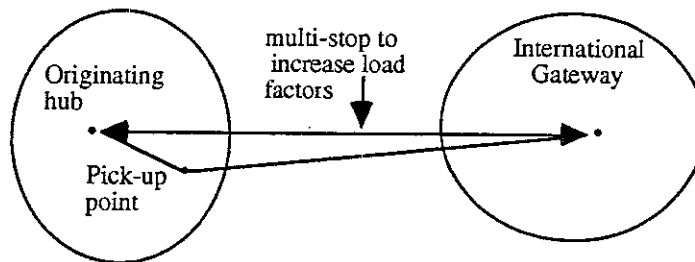
Pick-up point

Figure 4   Causal relationships in an international airline network

In the turnaround route system the airline attempts to serve those markets where there are opportunities of higher load factors due to the traffic density of the routes. The service is invariably a direct one from the local hub to the designated international

gateway. Frequency has to be high on these routes so as to further stimulate demand. The hub-and-spoke system is most plausible between countries that have liberal bilaterals or where a single aviation market exist, such as the Australia-New Zealand one. The airline is able to obtain feed traffic from the hinterland in its home country and flow traffic from the destination country. The linear network is characterised by several stops by the airline in its home country in order to gather enough passengers. There could be other stops in countries which have third or fourth freedom rights with the airline's home country. Its distinguishing characteristic is that the density on the segments is relatively low compared to the turnaround route system.

The proposed model determines the profit maximising set of frequencies for each airline compared to the frequencies of its competitors. A cobweb algorithm is used to search for states of competitive equilibria in which airlines have profit-maximising frequency vectors. Ideally, a full profit model should be specified in which other competitive variables such as fares, service quality and comfort, seat availability are included. We, however, take frequency to be a hedonic aggregator of these variables. Airlines decide on the level of frequency after taking into account the demand potential of a particular route, and demand itself is partly determined by the above variables. Besides, airline frequency is closely related to the hubbing phenomenon in hub-and-spoke, turnaround and linear route networks. Gillen et al. (1990) endorse this approach in their study of proposals to liberalise the US-Canada air transport bilateral.

Put more formally, the model can be expressed by assuming a set $\mathbf{P}$ of nodes with np the number of nodes in the set. Demand is given by the matrix Qij. The competitive game will be defined by identifying a set of players in the Asia-Pacific in terms of their network strategy and performance (profit) functions. Each airline is contained in one of np classes $(1; \ldots np)$. The airlines in class k, are airlines with a particular network type and they have a strategy defined as an np dimensional vector of frequencies $f(f_1, \ldots, f_{k-1}, f_k + 1, \ldots, f_{np})$. The ith element in the vector matrix in the set $\{0, [f^i min., f^i max]\}$ where $f^i min.$ is the base frequency necessary to preserve market presence and $f^i max.$ is the maximum frequency permissible under a bilateral agreement of type b_i. The airline profit functions in class k for a frequency f^i will be:-

$$p^k(f^i) = \sum_{\substack{i=1 \\ i\neq k}}^{np} \sum_{\substack{j=1 \\ j\neq i}}^{np} \left[\{\delta_{kj} \cdot S^{ns/ms}(f_j, L_{ij}) + (1 - \delta_{kj}) \cdot S^{hs/nh}(f_j, f_i, D_{jk} + \right.$$

$$D_{ik} - D_{ij}, L_{ij})\} \cdot F_{ij} \cdot Q_{ij} - 2 \sum_{i=1}^{np} C(f_i, \sum_{j=1}^{np} \{\delta_{kj}$$

$$\cdot S^{ns/ms}(f_j, L_{ij}) + (1 - \delta_{kj}) \cdot S^{hs/nh}(f_j, f_i, D_{jk}$$

$$\left. + D_{ik} - D_{ij}, L_{ij})] \cdot Q_{ij} D_{ij}\right) \right]$$

where:

$p^k(f^i)$ is profit function for a given frequency f^i

f_{ij} is the frequency between city-pairs i and j

F_{ij} is the average fare in the market ij

$S^{ns/ms}$ ($\bullet$) is the market share of either a non-stop or multi-stop service in ij, and is a function of service frequency f_{ij} and the level of frequency competition from other airlines, L_{ij}

Q_{ij} is the demand in market ij

C ($\bullet$) is the cost, a function of frequency (f_{ij}), passenger numbers (pax) and stage length (D_{ij})

$\delta_{kj} = 1$ if k = j and 0 otherwise

$S^{hs/nh}$ ($\bullet$) are the market shares of hubbed and non-hubbed services a function of circuity, $D_{jk} + D_{ik} - Di$) and frequency competition, L_{ij}.

(see Gillen et al. 1990 and Hansen and Kanafani, 1985).

Requisite data

The data necessary to implement the procedure outlined above are:

- international O-D demand data. This could be obtained from ICAO publications, Jane's Airline World or individual airlines

- fares on international routes. This could be obtained from the airlines' published fares or travel agents

- inter-city distance data could be obtained from Jane's Airline World or ABC World Airlines

- cost data for different aircraft types could be obtained from the BTCE's Aerocost model or other similar models

- revealed preference data (the actual routes chosen subject to bilaterals) for the logit model of airline route choice will be obtained from the airlines' publications of their networks. The route choice probability for traffic between a given city-pair is given by:

$$P_{(r,j)} = \frac{\exp\,(V\,(r,j))}{\sum\limits_{r} \exp\,(V_{r,j})}$$

Model output

The output will be a set of international service frequencies that define a state of non-cooperative Nash equilibria, that is, the set of frequencies is such that each airline is maximising its own profit, given the frequencies of other airlines - (the typical S-shaped frequency-market share curve). Using a cobweb algorithm, involving sequential maximisation of each profit function, an equilibrium is reached.

$S^{ns/ms}$ (Υ) is the market share of either a non-stop or multi-stop service in ij, and is a function of service frequency f_{ij} and the level of frequency competition from other airlines, L_{ij}

Q_{ij} is the demand in market ij

C (Υ) is the cost, a function of frequency (f_{ij}), passenger numbers (pax) and stage length (D_{ij})

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The next step would be to use a method of comparative statics to compare the profit performance of the airlines with the hypothesised network configuration. A set of airlines in the Asia-Pacific region will be defined with an intention of portraying a set of generic network strategies and how these can be used to gain a competitive advantage.

Conclusion

The changes that are taking place in international aviation call for a new econometric modelling paradigm as far as competition on networks is concerned. There is a need to incorporate the spatial and temporal components of the airline firm's network into an analysis of the economic issues surrounding such a system. As obvious as this requirement may seem, its implementation is difficult. The network-based models must not only be realistic, they must also be useful and useable. These requirements, along with the problems involved in integrating network models with competitive strategy ones, should be the driving forces behind efforts to find new modelling paradigms in international aviation.

This paper has proposed a network model of competition in international aviation. The applicability of the model is yet to be tested with appropriate data. It is conceivable, however, that the model proposed will be more applicable to single aviation markets and liberal bilateral regimes. There is some evidence of a shift towards these regimes. It is envisaged that the model may analyse competition on international airline networks better than the traditional theories of trade in services, such as comparative factor advantage.

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