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Modeling the selection of airline network structure in a competitive environment

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ABSTRACT

This paper deals with modeling the selection of airline network structures for airlines operating in a competitive environment. In order to capture interactions between competing airlines when choosing the structure of their networks, the effects of product differentiation based on prices, flight frequencies, seat accessibility and route length have been considered. Competing airlines are supposed to be able to choose either point-to-point (PP) or hub-and-spoke (HS) network structure. Each choice is expected to have different implications on their profitability (i.e. costs and revenues) strongly influenced by different products offered to passengers. The main results indicate that there are direct benefits to users/passengers due to the simultaneous increase of flight frequencies and unchanging prices, which leads to the socially-optimal choices of prices and flight frequencies. In addition, modeling which includes route lengths opens new perspectives on coexistence between the two different business models. Integration of these parameters results in selecting an airline network structure model in a competitive environment which enables passengers to differentiate among the offered transport services.

1. Introduction

Deregulation of air transport industry significantly changed market conditions all over the world and permanently affected airline competition (Morrison and Winston, 1986; Burghouwt and Hakfoort, 2001). Since market forces did not affect airline service during the period of regulation, airline service was shaped by bilateral agreements negotiated between the countries involved. Nowadays, in most parts of the world air transport policy and regulation programs aim to provide that prices and capacities are set by market forces of supply and demand. However, sustainability of airline business models was questioned once the market became open and competition began to strengthen. Only those airlines that were able to react promptly and adjust to the emerging conditions had a chance to sustain profitably and retain their market position.

Through adequate network structure and pricing policy, airlines can gain higher profit and still increase/maintain their market share. Given the freedom to manage traffic and price more proactively, airlines are able to influence the demand by maximizing the value provided to consumers and to charge prices which are most rewarding in relation to its goals. This added value is reflected in better scheduled times, better connectivity, higher frequencies, higher probability of booking a seat on a flight, etc.

Network designing implies that an airline has to make decisions about markets that will be served and the routing policy between those markets. From passengers' point of view, it would be ideal if the airline offers the nonstop services between any points that correspond to O & D demand matrix. In reality, many markets do not have sufficient demand to support nonstop service or high frequency nonstop service. Making these decisions means finding a good balance between serving different market segments and meeting economic interests of the airline. However, the impact of the competition should not be neglected either.

On the other hand, pricing policy denotes how an airline sets the price of its service regarding costs, demand, quality of service and competition. It allows airlines to examine the effects that changing the prices has on the accomplishment of their goals. Integrating pricing policy into network strategy development enables airlines to set sustainable, profitable prices in the market or to discard services that cannot be produced cost-effectively. Achieving efficiency in operating costs is one of the most important requirements for air carriers in order to be competitive. It is noteworthy that almost all carriers significantly reduced their costs compared to the period twenty years ago (Oum and Yu, 1995; Tsoukalas et al., 2008). Strong competition from low cost carriers (LCCs) has forced traditional carriers to change their former way of business performance, or to withdraw from the market. However, achieving efficiency in operating costs does not mean that the carrier has the lowest operating costs, it is more important that the level of costs reflects the level of quality offered to passengers.

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This research aims at finding an appropriate choice for network structure that would enable an airline to position itself in the market and to offer a service required to sustain the chosen position. In this paper, we study whether and how price, frequency, load factor and route length affect optimal network structure chosen by airlines. In particular, we attempt to gain some insight about network structure equilibrium when an airline creates more value to its customers by increasing the service quality. Moreover, we analyze how inclusion of load factor and route length affects network efficiency. This paper is organized as follows. In Section 2 the background of this research is provided. In Section 3, three mathematical sub-models with formulations are proposed. The results obtained from the sub-models are then used in Section 4 to study the equilibrium in airline networks. Section 5 provides welfare analysis and network efficiency analysis. Finally, the outcomes and conclusions are summarized in Section 6.

2. Literature review

In the academic literature, one could find many research papers related to the network optimization problem in airline industry and solutions proposed could be divided into two groups: analytical models with economic approach and transportation models with heuristic approach in network designing. This paper belongs to the first group of publications, thus our focus will be only on those publications that deal with analytical models. Oum et al. (1995) analyze the effects of strategic interaction between deregulated airlines on their network choice and establish that demand-side network effects of HS network together with reduced costs make it a dominant strategy for airlines. Hendricks et al. (1995, 1999) provide a general approach by considering the characteristics of airline's behavior when choosing a HS or a PP network. Berechman and Shy (1996) consider the effects of network structure on the scheduling and fare choices of a monopoly airline and assume that passengers gain an extra benefit when flying PP because of shorter time. Brueckner and Zhang (2001) show that HS network leads to lower cost per passenger and excessive flight frequency relative to the social optimum. Brueckner (2004) also analyzes the effects of network structure on the scheduling and aircraft size choices of a monopoly airline adding a disutility parameter into travelers' utility when trips are HS. Brueckner and Flores-Fillol (2007) consider a duopoly market where airlines compete in prices and schedules, adopting the PP structure. Pels (2009) considers the effects of the Open Atlantic Aviation Area on airline networks and shows the mechanism of airlines' behavior. Flores-Fillol (2009) modeled an airline's selection of network structure in a duopoly market where airlines compete in prices and schedule while adopting symmetric and asymmetric network structures.

Pai (2010) provides an analysis of aircraft size and frequency with regard to market demographics, characteristics of the airport and airline characteristics. Li et al. (2010) developed a model for network structure optimization by distributing new routes within the network, in a liberalized market, by taking into account capacity limitation at airports. Takebayashi (2013) applies a bi-level air transport market model in order to show the selected airline network structure considering the demand–supply interaction. Silva et al. (2014) analyze selection of optimal airline network structure in the presence of congestion externalities. Dae Ko (2016) uses the game theory to study management strategies of a full service carrier, its subsidiary LCC and a rival LCC taking into account the demand leakage between the airlines.

In order to improve airline products as perceived by passengers and to reflect that improvement on its choice of network structure, in this paper we use a duopoly model that accounts for passenger benefits from increased frequency (frequency and stochastic[1] delay), passenger loyalty and route length. By incorporating these realities we focus on product differentiation and cost efficiency resulting from variation in flight frequency, load factor and route length. By introducing stochastic delay, it is possible to manage seat accessibility[2] by controlling load factor and to have direct influence upon service quality. Increase in seat accessibility will cause an increase in market size. As Oum et al. (1995) pointed out, the airline management can manage load factors by adjusting flight frequency and aircraft size to changing demand. The higher the average load factor on a flight is, the lower the seat accessibility is likely to be. Therefore, with higher load factor there would be more passengers who want to but are unable to book a desired flight. As a consequence, these passengers spill to the airline's competitor(s), which means a revenue loss for the airline.[3] Moreover, load factor has direct influence upon airline costs, too, in a way that higher load factor generates lower cost per passenger. However, this could be acceptable in the short-run, but this will lead to unacceptable demand spill, (Holloway, 2003). On the other hand, 100% full flight could mean that the potential is not completely used, e.g. the airline charged its service too low. Models found in the literature assume that all seats offered are sold. However, what can be observed from the practice is that airlines always had excess capacity (load factor < 100%) that, *inter alia*, could occur as a result of a competitive strategy to achieve high scheduled frequency on each important route.

The importance of introducing the route length as a parameter that drives the network strategy is seen in its impact upon airline operating costs (unit costs generally fall as route length increases). In some previous papers (Brueckner, 2004; Brueckner and Flores-Fillol, 2007; Flores-Fillol research, 2009; Silva et al., 2014) the authors also assume that the network configuration is symmetrical and all routes have the same length. However, the route length is neglected and its impact on setting price, frequency and network configuration is not considered.

To summarize our contribution, the parameters defined ensure that the chosen network structure attains two goals - profit maximization and targeted level of service. This research demonstrates that the load factor is an important determinant when selecting airline network structure, defined by passengers' preferences from the stochastic delay. Specifically, there is a direct benefit (to passengers) of increasing frequency, with unchanged price, all leading to socially optimal choices of price and frequency. Moreover, the importance of load factor in network cost efficiency is demonstrated, as well. Finally, integration of route length into the model leads to results that open new perspectives when it comes to the coexistence between two different business models.

3. Model setup

Nomenclature

q	Passenger demand on direct routes
Q	Passenger demand on indirect route
C	Passenger disutility function
p	Ticket price on a direct flight
P	Ticket price on an indirect flight
f	Frequency on AH and BH routes
F	Frequency on AB route
FD	Frequency delay
SD	Stochastic delay

[1] Stochastic delay measures passenger delay in time caused by inability to book a seat on the preferred flight, because all seats are booked.

[2] Seat accessibility represents the measure of probability that booking of a seat on the desired flight can be made any time before the departure.

[3] The motivation can be found in Brenner (1982), who provides the relationship between load factor and service convenience. When average load factor is only 60%, 6% of flights will be fully booked; for 70% of average load factors, this jumps to 21% of fully booked flights and at 80% load factor the percentage of fully booked flights jumps to 64%.