Deregulation and Schedule Competition in Simple Airline Networks

Youdi Schipper   Peter Nijkamp
Piet Rietveld
Free University Amsterdam / Tinbergen Institute
email: yschipper@econ.vu.nl

38th Congress ERSA
Vienna, 28 August - 1 September 1998

1. Introduction[1]

In deregulated airline markets, carriers are free to choose the values of the variables affecting their profits. Out of the large number of decisions to be made in practice, the decisions on flight frequency and price on each route in an airlines network are of major importance. Frequency, or the number of flights offered per unit of time, determines consumer welfare by affecting not only the gap between desired departure times and actual departure times, but also the transfer time of passengers who are not on direct flights. Also, total flight frequency has a negative external effect on households suffering from noise and emission of pollutants. Interpreting frequency as quality of service, the frequency decision affects both the number of passengers and their willingness to pay. On the other hand, frequency clearly is a major determinant of airline costs, so that quality is costly to provide. Furthermore, frequency affects both quality of service and - given aircraft size - capacity at the same time and can thus be assumed to influence prices. A further basic aspect of airline markets is the small number of competitors, implying that competing carriers take the possible reactions of their opponents into account when making decisions, e.g., on frequencies and prices. Finally, it has been observed that prices in the airline industry are adjusted daily, whereas changes in frequency (schedules) can be assumed to be much less flexible.

The present paper wishes to model airline competition while taking into account the above observations. Consumer demand is affected by price, schedule delay and transfer time, while the latter two are determined by the airlines' frequency decisions. We consider airline behaviour in a small airline network, under monopoly and duopoly competition respectively and we restrict the analysis to situations where at least one of the firms in the market operates a hub-and-spoke (HS) system. The difference in decision flexibility between frequency and price is accounted for by modeling airline competition as a two stage game: in the first stage, airlines choose schedules, i.e. flight frequencies for each link in their network, while in the second stage, having observed the respective first stage choices, they choose prices. The equilibrium is thus computed as the subgame perfect Nash solution in schedules. A central policy issue addressed by the model is the welfare effect induced by airline deregulation, defined as the introduction of competition in (a part of) the network.

A number of articles in the large literature on airline (network) competition and deregulation are particularly relevant for this paper. The model has the same two stage structure as the network design model in Lederer (1993), but differs in two ways. Firstly, customer demand is distributed with respect to preferred departure times, so that there is not one least price 'path' per origin-destination (OD) market and more than one firm provide transport between OD markets in equilibrium. Secondly, demand in each market is elastic with respect to both frequency and price.[2] Brueckner and Spiller (1991) use a model of quantity setting duopoly competition in a network; they conclude that with returns to density or cost complementarities in a network, competition in a part of the network may result in an overall welfare decrease because of the negative externalities imposed on the other passengers in the system. Using a similar model Nero (1996) concludes that airline deregulation unambiguously improves welfare in the network when returns to density are absent. The present paper analyzes the introduction of competition in a simple network using the two-stage schedule competition model outlined above.

The paper is organized as follows. We introduce and calibrate the model in the next section, and discuss some of its properties. We then consider simulated market outcomes under monopoly and duopoly competition for two simple airline networks. Section 3 discusses monopoly and leg competition in a one-hub network. In section 4, monopoly and duopoly solutions in a network with two hubs are analyzed. The outcomes under monopoly and competition are compared in terms of welfare.

2. The model

2.1. Demand

A base assumption of the model is that at least one airline operates a hub-and-spoke (HS) system. Therefore, passengers fly either directly to their destination (local passengers) or have to transfer to a connecting flight (connecting passengers). Connecting passengers are assumed to use the services of one airline only during their trip. Furthermore, we do not consider demand for which more than

---

[2]Furthermore, passengers are assumed not to 'bundle' flights, i.e., not to switch between airlines when when making a transfer. Lederer (1993) shows that such bundling may lead to non-existence of the price equilibrium.

one transfer is necessary, so that connecting passengers are on two flights during their trip, passing through two spokes or legs s via a hub. Passengers make one-way trips between nodes (cities) in the network, so that the market m for transport between cities Y and Z represents two one-way markets $m_{Y \to Z}$ and $m_{Z \to Y}$.

A traveler derives gross utility ∇ from making a trip, and faces a price p. Furthermore, a consumer suffers a linear schedule delay cost $\mu_1 x$ when the flight leaves at a time distance $x = |t_{dep} - t_{pref}|$ from his or her preferred departure time,[3] and a linear travel time cost $\mu_2 d$, where d is the duration of the trip. Given the network layout, trip duration in the model is fixed for local passengers, whereas it depends on the departure frequency on the second spoke travelled during the trip for connecting passengers. When the gross valuation exceeds the sum of price, schedule delay cost and travel time cost, the traveler buys a ticket. We note that the schedule delay of a connecting passenger is determined by the departure time of the first of his two flights, whereas his travel time is partly determined by the departure time of the second flight.

Consumer preferences with respect to departure time are represented by a circle of (time) length L on which potential passengers are distributed uniformly. The departure times of flights on a particular leg of the network are also located on this time circle: we consider the departure times of flights i and $i + 1$, t_i and t_{i+1} respectively, which are separated by headway H. Flights are spaced equally on the circle. Therefore, the headway is determined endogenously as the time length of the circle divided by the total number of flights F offered by airlines on the particular leg, i.e.

$$H = \frac{L}{F} \tag{2.1}$$

Potential passengers who are 'located' at some preferred departure time $x \in (0; H)$ face a time distance x with respect to the departure time t_i of flight i and a distance $(H - x)$ with respect to t_{i+1}. These potential passengers derive the following net utilities or consumer surplus from the two options:

$$
\begin{aligned}
v_i &= \nabla - p_i - \mu_1 x - \mu_2 d \\
v_{i+1} &= \nabla - p_{i+1} - \mu(H - x) - \mu_2 d
\end{aligned}
\tag{2.2}
$$

---

[3]We thus make the assumption that the utility loss caused by taking a flight at a time distance x earlier than the preferred departure time is equal to the utility loss caused by taking a flight at x later than the preferred departure time. The term 'schedule delay cost' is meant to capture both types of utility loss.

Clearly, a consumer will choose the °ight belonging to the larger of the above expressions and buy a ticket if the net utility is positive. For the moment, we shall assume that the travel time of the two options is equal. We can now derive the distance x_b between t_i and the boundary between the market areas of the two °ights as that value of x for which $v_i = v_{i+1}$. This gives

$$x_{b+} = \frac{p_{i+1} \; i \; p_i + \mu_1 H}{2\mu_1} \tag{2.3}$$

All potential passengers located between t_i and x_{b+} will take °ight i, if they °y at all, and those located between x_{b+} and t_{i+1} will choose °ight $i + 1$, again, if they °y at all. The number of passengers with preferred departure time $x \; 2 \; (0; x_{b+})$ actually taking °ight i is calculated as the number of potential passengers with gross utilities $\overline{v_i} > p_i + \mu_1 x + \mu_2 d$; we represent this number by $D¢g\,(p_i + \mu_1 x + \mu_2 d)$, where D is a density parameter. Demand for °ight i from potential passengers with preferred departure times $x \; \; t_i$ can be obtained by adding the number of passengers over all preferred departure times x between t_i and x_{b+}. We include the demand from passengers with preferred departure times earlier than t_i, [4] giving

$$q_i = D \int_{x_{b_i}}^{x_{b+}} g\,(p_i + \mu_1 x + \mu_2 d)\, dx \tag{2.4}$$

Aggregate demand for °ight i is calculated as the sum of direct passengers and connecting passengers who choose the °ight on the ¯rst leg of their journey.

We now consider the demand for travel in one-way market $m_{Y!Z}$, which is either a direct market for local passengers on spoke s or a transfer market for which s is the ¯rst spoke to be travelled. Aggregate demand for market $m_{Y!Z}$ is found by summing $q_{m_{Y!Z};i}$ over all °ights. Thus, for an airline I operating a departure frequency $f_{I;s}$ in spoke s, demand $Q_{I;m_{Y!Z}}$ is

$$Q_{I;m_{Y!Z}} = \sum_{i=1}^{f_{I;s}} q_i\,(p_i; p_{i\,1}; p_{i+1}; H; d) \tag{2.5}$$

---

[4] The location x_{b_i} which marks the boundary between the market areas of °ight i and an earlier °ight $i \; 1$ departing at time $t_{i\,1}$ is found in the same way as x_{b+}, i.e.,

$$x_{b_i} = \frac{p_{i\,1} \; i \; p_i + \mu H_i}{2\mu}$$

5

Finally, total demand for city-pair market YZ is the sum of the demand in the two one-way markets $m_{Y \to Z}$ and $m_{Z \to Y}$ respectively.

2.2. Configurations

We proceed by analyzing the duopoly configuration of flights in a particular time period, represented by the circular 'time' market. For notational convenience, we consider a one-way non-stop duopoly market in the following. Consider a departure i operated by airline I. There are three possibilities: departure i may have either two, one or zero neighbouring departures offered by a competing airline $-I$; we refer to such departures as 'unfriendly neighbours', while we call two neighbouring flights operated by one and the same airline 'friendly neighbours'.

The expression for the market boundary x_b in the demand per flight function q depends on the configuration of the departures. With an interlaced configuration, for each departure i the price for both the earlier and the later departure ($i - 1$ and $i + 1$ respectively) is set non-cooperatively by a competing airline. Note that each airline sets one and the same price for all its tickets, i.e., there is no price differentiation between departures of one firm.[5] A departure i with two unfriendly neighbours faces market boundaries

$$
\begin{aligned}
x_{b-} &= \frac{p_{i-1} - p_i + \mu H}{2\mu} \\
x_{b+} &= \frac{p_{i+1} - p_i + \mu H}{2\mu}
\end{aligned}
\tag{2.6}
$$

from which demand for flight i is derived using equation (2.4). We refer to the demand for this type of flight as q_{cc} or completely competitive demand.

In the case of a non-competitive flight (with no unfriendly neighbours), demand is derived from the market boundaries

$$
x_{b-} = x_{b+} = \frac{H}{2}
\tag{2.7}
$$

because prices are the same for these flights. We refer to this type of demand as q_{nc}.[6] We note that for any specification of the demand function, completely competitive demand is more price sensitive than non-competitive demand.

---

[5] Therefore, in case of a duopoly the price of both competing departures is the same.

[6] An explicit analysis of demand for the intermediate case of a 'semi-competitive' flight i, i.e., a flight with only one unfriendly neighbour $i - 1$ and one friendly neighbour $i + 1$ is omitted.

For the market as a whole, we can now distinguish between two extremes. In a monopoly market, all departures are o®ered by the same airline; on the other hand, there is the completely interlaced equilibrium, in which all °ights have un-friendly neighbours. Of course, there are many possible con¯gurations between these extremes. The range of con¯gurations implies that with multiproduct competition, monopoly and oligopoly become relative rather than absolute concepts. We consider two con¯gurations in ¯gure 1.

(1a)

A symmetric completely
interlaced duopoly
configuration

(1b)

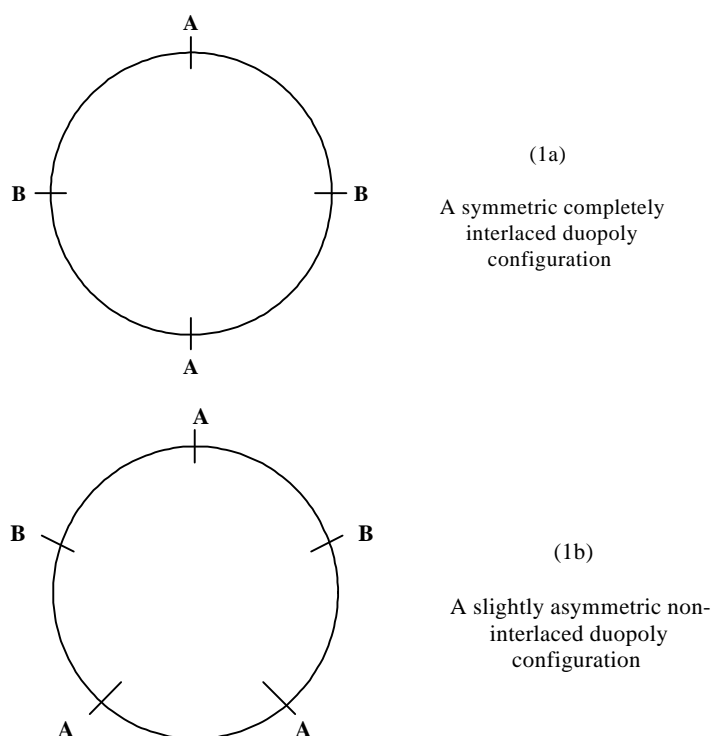A slightly asymmetric non-
interlaced duopoly
configuration

Figure 1: Multiproduct con¯gurations

Note that the number of such °ights is always a multiple of 2, and we therefore rewrite the demand for two 'semi-competitive' °ights as the demand for one competitive °ight q_{cc} and one non-competitive °ight q_{nc}.

The first configuration in figure 1 is a completely interlaced duopoly. When a duopolist analyzes the effect of a unit increase in departure frequency starting from a symmetric interlaced configuration, he necessarily considers a 'slightly asymmetric' configuration. As is illustrated in figure 1b, all non-symmetric duopoly configurations are non-interlaced. An implication of the model structure is that the form of the demand functions in an airline duopoly changes at $f_l = f_{-l}$.[7] Aggregate demand over all departures Q consists of two parts. For airline l, aggregate demand in the market is

$$Q_l = f_l q_{cc} \qquad\qquad\qquad \text{if} \quad f_l \cdot f_{-l} \qquad\qquad (2.8)$$

$$Q_l = (f_l - f_{-l}) q_{nc} + f_{-l} q_{cc} \quad \text{if} \quad f_l > f_{-l} \qquad\qquad (2.9)$$

Using equations (2.1), (2.3), (2.4) and (2.5), we note that

$$\frac{\partial Q_l}{\partial f_l} > 0$$

$$\frac{\partial Q_l}{\partial f_{-l}} > 0$$

$$\frac{\partial Q_l}{\partial p_l} < 0$$

$$\frac{\partial Q_l}{\partial p_{-l}} > 0$$

The demand and profit function of both duopoly airlines have the exact same form. Clearly, when the first line of the demand function is relevant for one airline, the second is relevant for the other. Only when $f_l = f_{-l}$, the two parts of the demand function give the same value.

2.3. Cost and profit

For each flight, the costs consist of a (major) fixed part FC and a marginal cost c per passenger. The model assumes that each airline l charges a single ticket price for each city-pair market $m; m = 1; ....; M_l$ it operates. Furthermore, airlines decide on the flight schedule, that is, the departure frequency for each spoke $s; s = 1; ....; S_l$ in their network. Thus, airline behaviour is represented by the

---

[7] Here and in the following, the subscript $-l$ refers to the competitor of airline l.

vectors $\vec{p}_l = \{p_1; ....; p_{M_l}\}$ and $\vec{f}_l = \{f_1; ....; f_{S_l}\}$. Using (2.5) and (2.1), profits of airline l facing a competitor $\neq l$ in one or more of the markets in its network are

$$\pi_l = \sum_{m=1}^{M_l} (p_m - c) Q_{l;m} \left(\vec{f}_l; \vec{p}_l; \vec{f}_{\neq l}; \vec{p}_{\neq l} \right) - 2 \sum_{s=1}^{S_l} f_{l;s} FC \qquad (2.10)$$

2.4. Calibration

For the calibration of the model we follow the procedure in Norman and Strandenes (1994), viz., solving for the demand parameters using price, frequency, cost and demand observations for a base monopoly situation in combination with the monopolist's first order conditions. Firstly, we impose a linear form on the point demand function $g(:)$ in (2.4):[8]

$$g(p + \mu_1 x + \mu_2 d) = \circledR - p - \mu_1 x - \mu_2 d \qquad (2.11)$$

Monopoly demand per flight is then derived as

$$q = D \int_{x_{b-}}^{x_{b+}} g(:)\, dx = 2Dx_b \left(\circledR - p - \mu_1 \frac{x_b}{2} - \mu_2 d \right) \qquad (2.12)$$

Data are available for a non-stop monopoly route only. We note that for such a trip, the monopolists first order conditions only refer to price and frequency on the leg. With the demand equation, we have a system of three equations, which allows solving for the three demand parameters D; $\bar{\circledR}$; and μ_1,[9] with $\bar{\circledR} = \circledR - \mu_2 d$. The data thus do not enable us to directly infer a value for μ_2, which represents the common value of travel time. Morrison and Winston (1989) report estimated values of travel and transfer time to be much higher (a factor 10 and 20, respectively) than the value of schedule delay. The relative values seem to depend on the type of traveler. As indicated by Morrison and Winston, business travelers are likely to have a much higher relative value of μ_1 than other travelers. Dobson and Lederer (1993), use a value of schedule delay higher than the value

---

[8] The demand specification ultimately depends on the assumed distribution of gross valuations ∇. A well known alternative is the negative exponential distribution, as used in e.g. Evans (1987). However, that specification does not allow one to solve the calibration equations for the parameters of the model. The specification used here is conform Greenhut et al. (1987).

[9] Data refer to the pre-deregulation Tel Aviv - Eilat monopoly, and consist of price, frequency and passenger observations. Furthermore, we dispose of passenger and per flight cost data.

of travel time in their simulation model, while Berechman and de Wit (1996) use a single value of time to calculate utility as a function of flight frequency for local and connecting passengers.[10] Given the scarcity of evidence and the difficulty of comparing parameter values between rather different models, we do not assign a fixed value to μ_2 here. Rather, we investigate the sensitivity of the results to changes in the relative value, and look for restrictions on the parameter value in the next section.

As indicated above, for local passengers, the utility loss caused by the time involved in the trip is represented by the parameter $\tilde{\alpha} = \alpha - \mu_2 d$. For connecting passengers, the calculation differs on three accounts. Firstly, the trip consists of two leg flights. Secondly, the connecting passengers have to wait for a connecting flight. Thirdly, the gross trip valuation may differ between non-stop and on-stop travel. In order to simplify the calculations, we have assumed the following. For connecting passengers', gross trip valuation is higher than for local passengers, e.g., because of the larger travel distance. However, the difference in trip valuation is exactly matched by the utility loss derived from the incremental travel time. Therefore, the parameter $\tilde{\alpha}$ has the same value for both passenger types. The difference between the demand functions, however, stems from the waiting time of the connecting passengers, which depends on the frequency of the airline on the second leg of the trip. We thus have, for connecting passengers

$$d_c = {}^{1}H_{leg2} = {}^{1}\frac{L}{F_{leg2}} \tag{2.13}$$

where ^{1} is a parameter indicating proportion of the headway time on the second leg which the passenger has to wait, with $0 \cdot {}^{1} \cdot 1$. Thus, even at a low frequency on the second leg, the waiting time can be small when arrival and departure times of connecting flights are close. We have chosen an arbitrary value of $^{1} = 0.5$ in the calculations. The base set of parameters is presented in Table 1, with all monetary equivalents in US$.

---

[10]They do, however, distinguish between business and non-business passengers.

Table 1:
base simulation coe±cients

calibrated parameters	
D	0:49
β ($)	174:47
μ_1 ($)	131:58
imposed parameter	
1	0:5
cost parameters ($)	
c	5
F C	1500

Using these parameter values, we simulated frequency and price decisions in network markets. The simulation results are presented and discussed in the next sections.

3. A one-hub network

In this section, we consider the e®ects of introducing competition in a simple network consisting of one hub and two spokes, as depicted in Figure 2. We assume that the network is symmetric in the sense that legs 1 and 2 have the same length, and that all markets have the same density. Using the same type of aircraft on both legs, the demand and cost characteristics are equal on non-stop °ights.
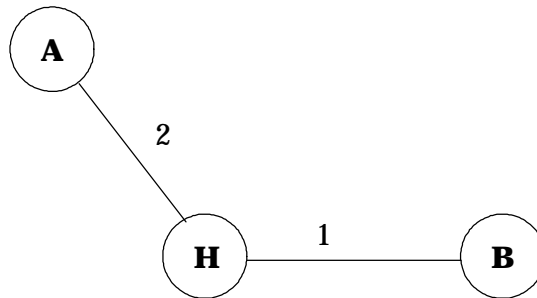
Figure 2

3.1. Monopoly

We ¯rst consider the schedule choice of a monopolist, who operates a HS system in the above network. As the monopolist does not have to take into account the

possible actions of an opponent, the problem is simply

$$\max_{f^1;\vec{p}} \pi = \sum_{m=1}^{M} (p_m - c) Q_m \left(f^1;\vec{p}\right) - 2\sum_{s=1}^{S} f_s FC \tag{3.1}$$

where M is the number of markets, and S the numebr of spokes. Clearly, the number of spokes is two, so that $f^1 = \{f_1; f_2\}$. We distinguish three city-pair markets, viz., the local markets AH and HB, and the connecting market AB, so that $\vec{p} = \{p_{AH}; p_{HB}; p_{AB}\}$.

We start by considering the price solution of the monopolist. Using (2.12), we derive as the monopoly price solution for a given market

$$p_{mon}^{\pi} = \frac{c + \circledR - \mu_1 \frac{x_h}{2} - \mu_2 d}{2} \tag{3.2}$$

We may conclude that, for given °ight frequency, the pro¯t maximizing monopoly price decreases in both μ_1 and μ_2, and so, given (2.12), revenues decrease in both parameters. Similarly, we can derive a expression for the frequency decision of the monopolist. Considering a non-stop market for simplicity, we have

$$F_{mon}^{\pi} = \sqrt{\frac{(p - c)\mu_1 L}{4FC}} \tag{3.3}$$

Next, we analyze the simultaneous solution to the monopoly network problem (3.1). Using the parameters from Table 1, we solve for f^1 and $\vec{p}$ for varying μ_2, we have calculated pro¯t maximizing frequencies and prices for a range of values of μ_2. The results are presented in Figure 3, which only shows results for one of the two identical local markets and legs.
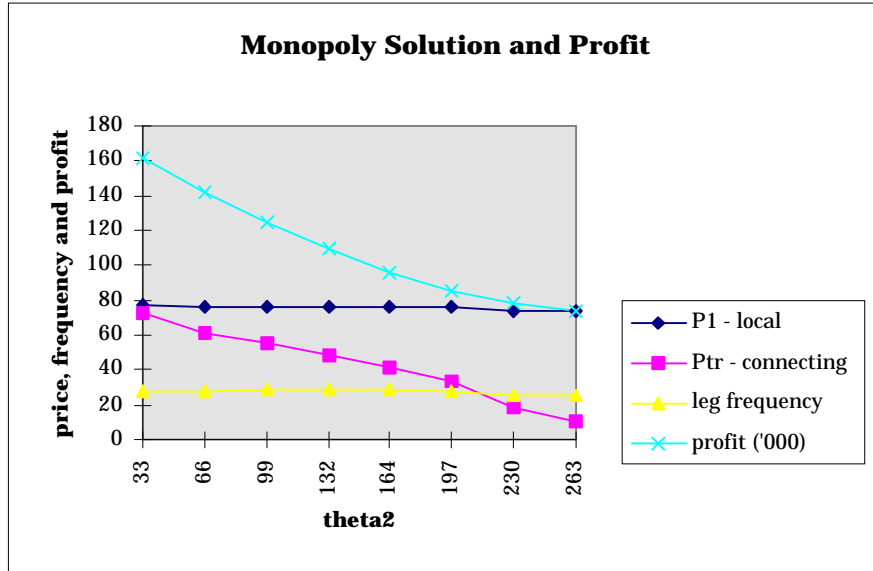
Monopoly Solution and Profit

Figure 3

As Figure 3 illustrates, the price in the connecting market decreases in μ_2, as the travel time costs increase. The monopolist can counteract the negative demand e®ect by increasing the departure frequency in the legs (which has a small positive e®ect on the price in the direct market). The pro¯t maximizing frequency is concave in μ_2. Clearly, the overall e®ect of an increase in μ_2 on pro¯t is negative. From this conclusion, we can derive a restriction on the value of μ_2. From the calibration data, we know the pro¯t of a single leg market. A monopolist will choose a HS network, whenever the pro¯t of such a network is larger than the pro¯t in a fully-connected (FC) network. Therefore, from the assumption that the monopolist operates a HS network, a maximum value for μ_2 follows, viz., the value of $\mu_2 = \bar{\mu}_2$ for which the pro¯t of both network types are equal. Put di®erently, values of μ_2 have to be consistent with the choice of the network type. In the following simulations, we use the maximum value of μ_2 consistent with the HS network type, viz., $\mu_2 = 0.8 \times \mu_1$.

3.2. Leg competition

We now consider the introduction of competition in leg 1 of the network in Figure 2, e.g., after entry of a small airline only serving the local market between H and B. An important asymmetry is thus present in the competition in market 1. The

13

incumbent, airline 1, carries both local and connecting passengers on leg 1, while the entrant, airline 2, only carries local passengers.

We consider the outcome of the following two-stage frequency and price game. Both airlines face the proﬁt function

$$\pi_l = \sum_{m=1}^{M_l} (p_m - c) Q_m \left(f_l; p_l; f_{-l}; p_{-l} \right) - 2 \sum_{s=1}^{S_l} f_{l;s} FC \tag{3.4}$$

with $M_1 = 3; M_2 = 1$ and $S_1 = 2; S_2 = 1$. The equilibrium is found by solving the game backwards: for each pair of schedules $\{f_1; f_2\}$ the Nash equilibrium in prices $\{p_1^*; p_2^*\}$ is calculated as the set of prices at which

$$\pi_l \left(p_l^*; p_{-l}^*; f_l; f_{-l} \right) > \pi_l \left(p_l; p_{-l}^*; f_l; f_{-l} \right); \quad l = 1; 2 \tag{3.5}$$

(Note that for airline 2, the problem is conﬁned to ﬁnding a single departure frequency and a single price). Given the second stage price equilibria, the ﬁrst stage Nash equilibrium in ﬂight schedules is calculated as the set of schedules for which

$$\pi_l \left(f_l^*; f_{-l}^*; p_l^*; p_{-l}^* \right) > \pi_l \left(f_l; f_{-l}^*; p_l^*; p_{-l}^* \right); \quad l = 1; 2 \tag{3.6}$$

The ﬁrst stage equilibrium choices and market outcomes are compared with the monopoly solution in Table 2 below.

Table 2
Market equilibria: 1 hub network

	Monopoly	Leg competition	
		airline 1	airline 2
schedules	{29; 29}	{26; 29}	13
prices	{76; 76; 54}	{66; 76; 52}	57
passengers	{1673; 1673; 1161}	{1330; 1673; 1113}	820
proﬁt	121221	87410	16944
CS ('000) per market	{62:4; 62:4; 31:5}	{99:9; 62:4; 29:6}	
CS total	156326	191952	
welfare	277547	296307	

We note a few interesting characteristics of the equilibrium. As explained in section 2, asymmetric frequency choices result in non-interlaced conﬁgurations

14

of departures. This confers the monopoly power to the airline with the higher number of departures, which explains the asymmetry in pricing. Clearly, the schedule asymmetry is determined by the network asymmetry: for airline 1, the marginal °ight has a higher pro¯tability because it serves both the local duopoly market and the monopoly market for connecting passengers.

The overall conclusion is that leg competition raises welfare. Not surprisingly, a reallocation of surplus from producers to consumers takes place. Aggregate consumer surplus increases by some 23%, which represents a gain for local travelers in market 1 (60%), a loss for connecting passengers (-6%), while nothing changes for local passengers in market 2. Note that the welfare loss for connecting passengers caused by airline 1's frequency decrease in leg 1 is partly compensated by the lower ticket price. This conclusion is partly in line with the conclusion by Brueckner and Spiller (1991). In their model, leg competition raises welfare for local passengers in market 1 and hurts connecting passengers too. The reason for the latter welfare e®ect is, however, the existence of negative cost externalities between markets, which also causes a welfare reduction for local passengers in market 2. In our model, connecting passengers are a®ected through the higher costs of schedule delay and travel time, not through an increase in price (marginal cost). Therefore, local passengers in market 2 are not a®ected, while local passengers in market 1 bene¯t from both higher °ight frequencies and lower prices. Note that the two-stage character of the model gives both airlines an incentive not to choose symmetric frequencies: with a symmetric, interlaced con¯guration of departures, price competition is more intense and second stage prices are lower than in a non-symmetric equilibrium. Finally, we note that the model outcomes represent a slight S-curve e®ect, that is, airline 1, carries a share of the passengers traveling on leg 1 that is higher than it's share of departures. The e®ect is a result of the connecting travel carried by airline 1 while having a lower than proportional share of the local tra±c, as a result of the high price in market 1.

4. A two-hub network

In this section, we investigate the solution of ¯rms to the network frequency-price problem for a slightly more complex network under regimes of monopoly and competition. The network under consideration now consists of 2 hubs and three spokes or legs, as depicted in Figure 4.
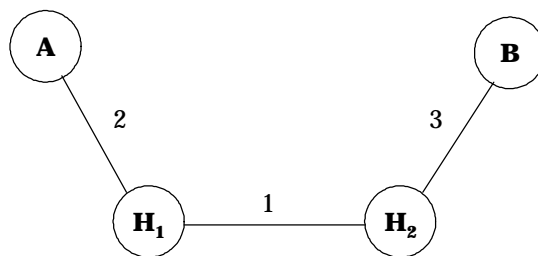
Figure 4

4.1. Monopoly

The monopoly network problem has the same general form as for the one-hub network presented in (3.1). In this case, however, $S = 3$ and we distinguish $M = 5$ city pair markets, viz., three markets for local passengers AH_1, H_1H_2, H_2B and two markets for connecting passengers AH_2 and H_1B.[11] The monopoly network problem can be interpreted either as the scheduling problem of a single airline operating two hubs or a as the problem of two airlines maximizing joint profits. In the latter interpretation, local market H_1H_2 may represent a route market between hubs of flag carriers before deregulation in the European Union, which until recently were governed by restrictive bilaterals, while the other markets can be thought of as hinterland monopoly markets in the absence of cabotage, e.g., as in Nero (1996).

Using the same parameters as in the one-hub system, the (base) solution to the monopoly scheduling problem is $\bar{f} = \{f_1; f_2; f_3\} = \{36; 29; 29\}$ and $\bar{p} = \{p_{H_1H_2}; p_{AH_1}; p_{H_2B}; p_{AH_2}; p_{H_1B}\} = \{79; 76; 76; 58; 58\}$. As before, $\mu_2 = 0.8 \cdot \mu_1$, a value at which the HS system is slightly more profitable than the FC system. As before, equilibrium profit decreases in μ_2.

4.2. Hub competition

We now consider the case of competition on the local market H_1H_2. The situation can be interpreted as an example of partial deregulation, in the sense that a collusive bilateral, containing capacity and fare restrictions is abolished for the international route H_1H_2, while carriers continue to operate monopoly routes

---

[11]As indicated before, we do not consider trips for which more than one transfer is necessary.

within their respective countries. The model assumes that two identical airlines with identical hinterland markets compete on H_1H_2. In the following, airline 1 operates the monopoly markets AH_1 and AH_2, and airline 2 operates monopoly markets H_2B and H_1B.

The results of the base simulation are compared with the monopoly regime in Table 3.

<div align="center">

Table 3
Market equilibria: 2 hub network

</div>

	Monopoly	Hub competition	
		airline 1	airline 2
schedule	f36; 29; 29g	f24; 28g	f21; 28g
prices	f79; 76; 76; 58; 58g	f54; 76; 50g	f52; 76; 47g
passengers	f1735; 1673; 1673; 1242; 1242g	f1265; 1661; 1059g	f1171; 1661; 987g

A basic characteristic of the equilibrium is the asymmetric frequency choice on leg 1. This result is due to the second stage price competition: airlines have an incentive to avoid symmetry, as this results in lower equilibrium prices.[12] In equilibrium, airline 1 operates 3 monopoly °ights, which enables it to charge a higher price in the duopoly market H_1H_2. The higher frequency of airline 1 in leg 1 also lowers schedule delay and travel time for its transfer passengers relative to those of airline 2, so that the price in market AH_2 is higher than in airline 2's transfer market H_1B.

A comparison of the monopoly and hub competition regime shows that the individual duopoly airlines have a lower °ight frequency on each leg than the monopolist. On legs 2 and 3, the di®erence is quite small. On leg 1, however, the individual °ight frequencies are much lower with competition, while the combined °ight frequency on this leg is much higher. As we have assumed that connecting passengers never transfer to a °ight operated by an other airline, the connecting passengers su®er from higher travel times as a result from the decrease in airline °ight frequency. This decrease in utility is re°ected by the lower transfer demand

---

[12]Although the model is di®erent, the results are close the those obtained in two-stage quality-price competition (Shaked and Sutton, 1982) , where ¯rms di®erentiate in order to avoid price competition. In fact, there are two pure strategy asymmetric equilibria with identical ¯rms, only one of which is presented. Furthermore, we do not consider mixed strategies here.

and the much lower prices in the transfer markets of both airlines. The local passengers in duopoly market H_1H_2 do bene¯t, both from increased °ight frequency and lower prices because of price competition. In this market, there is a signi¯cant increase in passengers.

In Table 4 below, welfare results of both regimes are compared, where the welfare total is de¯ned as the sum of consumer surplus in all markets plus industry pro¯t. A ¯rst result of deregulation in market H_1H_2 is a dramatic decrease in industry pro¯t. Secondly, there is an increase in total consumer surplus. The table shows that the aggregate increase is the sum of a gain for local passengers (in market H_1H_2) and losses for connecting passengers. The result of these opposing changes is a net decrease in the welfare sum.[13]

Table 4
Welfare results: 2 hub model

	Monopoly	Hub competition
industry pro¯t	215016	138545
CS ('000) per market	f66; 62; 62; 40; 40g	f127; 62; 62; 28; 31g
CS total	269875	309454
welfare	484891	447999

The general welfare result above is qualitatively in line with earlier work on the e®ect of deregulation in network markets. Nero (1996), using a similar HS network, concludes that for particular parameter combinations in his model, welfare (the sum of consumer surplus and pro¯ts) over all markets in the network is higher under monopoly (after an airline merger) than under competition. Brueckner and Spiller (1991) reach a similar conclusion for leg competition. In these papers, the form of the cost function drives the results. In particular, the cost function re°ects increasing returns to tra±c density, that is, marginal passenger costs are decreasing.

In our model, marginal passenger costs are constant, so that network externalities take the form of demand rather than cost complementarities. This di®erence, which follows from the model speci¯cation, has a number of implications. As indicated in the previous section (leg competition), the introduction of competition in

---

[13] In a number of simulations, the sensitivity of the welfare results with respect to the value of travel time parameter μ_2 has been investigated for parameters in the range $0:2\mu_1 \cdot \mu_2 \cdot \mu_1$. As is to be expected, the negative welfare e®ect of deregulation increases in μ_2; the qualitative conclusions remain, however, unchanged.

a local market does not result in higher marginal costs and prices for connecting passengers in our model. Rather, prices decrease for connecting passengers, as their net trip utility decreases in travel time. However, consumer surplus for connecting passengers still decreases, as the price decrease does not compensate the travel time increase. Similarly, the marginal passenger cost of local passengers, e.g. in market AH_1, is constant, so that demand, price and consumer surplus changes, if any, are due to changes in the °ight frequency on leg 2. The consumer surplus change is still positive, but is smaller than the pro¯t decrease, so that the overall welfare e®ect is negative in the two hub model.

Finally, we note that external costs have not been taken into account in the analysis. However, one can expect increased environmental costs in the network, e.g. taking the form of noise and emissions, after deregulation. The e®ects are not evenly spread over the network. Whereas there is a slight decrease in aircraft movements at airports A and B, there a signi¯cant net increase at the hub airports. Clearly, including the external cost to the analysis would only add to the negative welfare result for the hub competition model.

5. Conclusion

This paper presents a model of schedule competition in simple airline networks. We model airline competition in frequencies and prices as a two stage game: in the ¯rst stage, airlines choose frequencies on the legs in their network, in the second stage they choose prices for direct and connecting markets. The two-stage setup of the model allows airlines to choose asymmetric frequency equilibria such that price competition is avoided. We consider pro¯t maximizing schedule solutions for two types of networks, and compare monopoly solutions with competition in part of the network.

The numerical results indicate that for both types of networks, the introduction of competition, deregulation, in part of the network has a positive e®ect on aggregate consumer welfare. However, consumers in transfer markets lose because, under the assumption that they do not transfer to a competing airline's °ight, their schedule delay and travel time costs increase. Furthermore, industry pro¯t decreases after deregulation.

In the case of leg competition in a one hub model, the positive consumer surplus e®ect dominates the pro¯t loss, resulting in an increase in overall consumer surplus. In the case of hub competition, the pro¯t loss dominates, so that there

is a net welfare decrease.

6. References

Berechman, J. and J. de Wit (1996), An Analysis of the E®ects of European Aviation Deregulation on an Airline's Network Structure and Choice of a Primary West European Hub Airport. Journal of Transport Economics and Policy, 30(3), 251-274.

Brueckner, J.K. and P.T. Spiller (1991), Competition and Mergers in Airline Networks. International Journal of Industrial Organization, 9, 323-342.

Dobson, G. and P.J. Lederer (1993), Airline Scheduling and Routing in a Hub-and-Spoke System. Transportation Science, 27(3), 281-297.

Evans, A. (1987), A Theoretical Comparison of Competition with other Economic Regimes for Bus Services. Journal of Transport Economics and Policy, 21(1), 7-36.

Greenhut, M.L., G. Norman and Chao-Shun Hung (1987), The Economics of Imperfect Competition: A Spatial Approach. Cambridge University Press.

P.J. Lederer (1993), A Competitive Network Design Problem with Pricing. Transportation Science, 27(1), 25-38.

Morrison, S.A., and C. Winston (1989), Enhancing the Performance of the Deregulated Air Transportation System. Brookings Papers on Economic Activity; Microeconomics, 61-123. Brookings Institution, Washington, D.C.

Nero, G. (1996), A Structural Model of Intra European Union Duopoly Airline Competition. Journal of Transport Economics and Policy, 30(2), 137-155.

Norman, V.D., and S.P. Strandenes (1994), Deregulation of Scandinavian Airlines: A Case Study of the Oslo-Stockholm Route, in P. Krugman and A. Smith (eds., 1994), Empirical Studies of Strategic Trade Policy. NBER / CEPR, The University of Chicago Press, Chicago.

Osborne, M. and A. Rubinstein (1994), A Course in Game Theory. The MIT Press, Cambridge, MA.

Shaked, A. and J. Sutton (1982), Relaxing Price Competition through Product Di®erentiation. Review of Economic Studies, 49, 3-13.