Impact of Landing Fee Policy on Airlines' Service Decisions, Financial Performance and Airport Congestion

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ABSTRACT

The airline industry has been changed significantly after the September 11th of 2001, while delay and congestion at airport have been consistently a problem to passengers, airlines and airports since the last decade of the 20th century. Most of previous methods to reduce airport delay and congestion mainly focus on airport capacity expansion through building new runways, which incurs billions of dollars. Due to the complexity and dynamics in the aviation system, there is little study, theoretically or practically, on applying administrative and economic polices to reduce airport congestion and delays without huge investment in building more runways.

In this paper, we study how airport landing fee policy could influence airlines' service decisions and affect airlines' financial performance and airport congestion. This research is based on our previous studies of the cost economics of aircraft size and of market share modeling for airlines using different aircraft size and service frequency in a competitive environment. In this paper, we propose a one-shot simultaneous game-theoretic model for two airlines competing in a non-cooperative duopoly market. We assume that airlines are profit maximizers – they make their own best operation decisions in order to achieve the maximum profit. Specifically, we study how the changes of airport landing fee policy could influence airlines' decisions on aircraft size and service frequency in their operations, and how the changes could influence airlines' profit, as well as congestions and delays at airport.

Our researches find that, due to the properties of cost function and market share model, airlines' optimal aircraft size and service frequency depend on the landing fees charged by the airport, and higher landing fee will force airlines to use larger aircraft and less frequency for the same number of passengers in service. We find that airlines' load factor will be increased if higher landing fee policy is employed. We also find that, very interestingly, airlines will be better off if some of the extra landing fees are returned to airlines as a bonus for airlines using larger aircraft and consequently reducing airport congestion. Since airport capacity depends on the size of aircraft in operations, using larger aircraft and less frequency to serve the same number of passengers will significantly reduce airport congestion and delays.

We also propose further researches in this area by applying cost model, market share model and game-theoretic models to understand how government policy could affect airlines' behavior and airport performance in different demand and market scenarios.

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INTRODUCTION

The airline industry has been changed significantly after the September 11th of 2001, while delay and congestion at airport have been consistently a problem to passengers, airlines and airports since the last decade of the 20th century. Most of previous methods to reduce airport delay and congestion mainly focus on airport capacity expansion through building new runways, which incurs billions of dollars. Due to the complexity and dynamics in the aviation system, there is little study, theoretically or practically, on applying administrative and economic polices to reduce airport congestion and delays without huge investment in building more runways.

In this paper, we are interested in how airport landing fee policy could influence airlines' decisions on aircraft size and service frequency and affect airlines' financial performance and airport congestion.

We assume that airlines are profit maximizers – they make their own best operation decisions in order to achieve the maximum profit. And this research is based on previous studies of the cost economics of aircraft size and of market share modeling for airlines using different aircraft size and service frequency in a competitive environment. In the cost side, Wei and Hansen (2003) study the relationship between aircraft cost and size for large commercial passenger jets. Based on a translog model, they develop an econometric cost function for aircraft operating cost and find that economies of aircraft size and stage length exist at the sample mean of their data set, and that for any given stage length there is an optimal size, which increases with stage length. The scale properties of the cost function are changed considerably if pilot unit cost is treated as endogenous, since it is correlated with size. The cost-minimizing aircraft size is therefore considerably smaller, particularly at short stage lengths, when pilot cost is treated as endogenous, and this helps to explain why US airlines expect to accommodate future traffic growth with more flights instead of larger planes. In the demand side, Wei and Hansen (2004) build a nested logit model to study the roles of aircraft size, service frequency, seat availability and fare in airlines' market share and total air travel demand in non-stop duopoly markets. They find that airlines can obtain higher returns in market share from increasing service frequency than from increasing aircraft size, and their study confirms an S-curve effect of service frequency on airlines' market share. They conclude that airlines have no economic incentives to use aircraft larger than the least-cost aircraft, since for the same capacity provided in the market, increase of frequency can attract more passengers than increase of aircraft size.

In general, if there is more than one airline in the market, one carrier's market share and revenue depend not only on its own service but also on the services provided by all other airlines in the market, therefore, in this paper, we propose a one-shot simultaneous game-theoretic model for two airlines competing in a non-cooperative duopoly market to systematically study airlines' competition behavior. Specifically, we study how the changes of airport landing fee policy could influence airlines' decisions on aircraft size and service frequency in their operations, and how the changes could influence airlines' profit, as well as congestions and delays at airport.

The next section of this paper describes a game-theoretic model for studying airlines' competition in choices of aircraft size and service frequency. The third section shows how the model can be applied in practice through a case study. This section includes analysis of how the differences in landing fees could influence airlines' decisions on aircraft size and service frequency, and how the changes of land fees could influence airlines' profit, as well as congestions and delays at airport. At last, we will summarize our analysis, research results and implications, and also direct further studies.

GAME-THEORETICAL COMPETITION ANALYSIS

In this study, we apply a non-cooperative non-zero sum game-theoretic model to study airlines' competitive behavior, especially airlines' strategic choices of aircraft size and service frequency. While emphasizing the environment of competition, we concentrate on airlines' long-term behavior on the level of market (a city-pair), in particular a duopoly market, where all the local passengers are served by direct non-stop flights. Further, while there could be some connecting passengers in these flights, the number of such passengers is assumed to be exogenous for each carrier. Thus we only consider competition for local market share.

There are two players in the game; we term them airline 1 and airline 2. Each player selects an aircraft size and a service frequency. Each airline's objective is to maximize its profit. We assume that the fare charged to passengers by each airline is exogenous to their decisions on aircraft size and service frequency, i.e., fare is not strategic decision variable in the game. On the one hand, despite the occasional "fare war", airlines are generally unwilling to use pricing as a competitive variable. On the other hand, the simple average fare variable in our applied demand model (Wei and Hansen (2004)) can not capture the complex airlines' yield management process, although it is not too hard to incorporate a fare variable in the formulated game.

The two bases for our research are: a) airline cost function and b) airline demand and market share functions. These functions capture the roles of aircraft size and service frequency in airlines' cost, demand, market and profit. In this research, we directly apply the cost function specified in Wei and Hansen (2003) and demand and market share functions specified in Wei and Hansen (2004).

In this research, we concentrate on the pure strategy of the game, i.e., uncertainty is not taken into consideration here, and we assume that each airline will choose only one type of aircraft and one frequency. We also keep the assumption of "complete information" in our games, i.e., we assume that each player knows the other's payoffs, available actions and other information; moreover, each player knows that the other player has such complete information, and this "knowing" is also known to each other, and so on. All the games are formulated for one period.

A central concept in game theory is the equilibrium property of the game. The most fundamental equilibrium is called Nash Equilibrium (NE), which is defined as a set of strategies chosen by each player in the game, where no player has the incentive to change their own strategy when given the other players' strategy. More detailed concepts in game theory can be found in such references as Bierman and Fernandez (1993) and Gibbons (1992).

The purpose of applying models of game theory is to help us understand and predict the actual decisions of airlines, the processes leading to which are generally very diverse and complex. Since we are interested in airlines' interactive behaviors and their long term strategies in the choices of aircraft size and service frequency, there are two basic questions that need to be answered in order to analyze airlines' decisions in a duopoly market: 1. Does each airline make decisions on the choice of aircraft size and on service frequency sequentially or simultaneously? 2. Do the two airlines in the market make decisions at the same time, or does one airline have an advantage over the other and make decisions before the other?

Based on the answers to these two questions, we can use three different games to formulate the competition between the two airlines. These three games are: a one-shot simultaneous game, a leader-and-follower Stackelberg game, and a two-level hierarchical game. In this research, we focus on the application of one-shot simultaneous game to study the role of landing fees on airlines' choices of aircraft size and service frequency. More analysis of applying other game-theoretical models in this study can be found in Wei (2000).

In the one-shot simultaneous game model, the two airlines in the market choose aircraft size and service frequency at the same time, each assuming that the other airline will have a fixed choice once the choice is made. According to the "complete information" assumption mentioned above, both airlines know all the available choices of each other as well as the payoffs from each combination of choices. In this simultaneous game, when each airline makes a choice, they assume that the other airline will make an optimal choice for its own benefit**,** and each airline's optimal choice depends on its competitor's choice.

Mathematically, in this case, there are two optimization problems facing the airlines, and aircraft size and service frequency are decision variables for each airline. We use the notations S_1, F_1 , S_2 and F_2 as variables to represent the size and frequency used by the first and the second airlines. S_1^*, F_1^*, S_2^* and F_2^* denote the Nash Equilibrium choices for corresponding variables, and $\text{Profit}\,1(S_1, F_1, S_2, F_2)$ and $\text{Profit}\,2(S_2, F_2, S_1, F_1)$ denote the profit functions for airline 1 and airline 2 respectively when airline 1 chooses S_1 and F_1, and airline 2 chooses S_2 and F_2. Finally, we use the symbol $\arg\max \text{Profit}(\bullet)$ to denote the argument (or arguments) that makes function $\text{Profit}(\bullet)$ achieve maximum. Then the two airlines' decision problem, under the one-shot simultaneous game, can be formulated through the following two simultaneous optimization models.

$$\begin{cases} \underset{S_1,F_1}{Maximize}\ \text{Profit}\,1(S_1, F_1, S_2, F_2) \\ \underset{S_2,F_2}{Maximize}\ \text{Profit}\,2(S_2, F_2, S_1, F_1) \end{cases} \tag{1}$$

The solutions for this problem can be denoted as:

$$(S_1^*, F_1^*) = \text{argmax}_{(S_1,F_1)}\ \text{Profit}\,1(S_1, F_1, S_2^*, F_2^*) \tag{2}$$

$$(S_2^*, F_2^*) = \text{argmax}_{(S_2,F_2)}\ \text{Profit}\,2(S_2, F_2, S_1^*, F_1^*) \tag{3}$$

If we use $[(S_1, F_1), (S_2, F_2)]$ to represent a general strategy for the two airlines in this game, where airline 1 chooses aircraft size and service frequency (S_1, F_1), and airline 2 chooses (S_2, F_2), then the Nash Equilibrium (NE) strategy can be represented as $[(S_1^*, F_1^*), (S_2^*, F_2^*)]$, in which airline 1's optimal choice of aircraft size and frequency is (S_1^*, F_1^*), given airline 2's optimal choice of (S_2^*, F_2^*), and vice versa.

In the next section, we apply the formulated model in a case study to see how the competition models can be used to analyze airlines' decisions on aircraft size and service frequency, and how the land fee policy may change airlines' decisions.

CASE STUDY

Case Description

The competitive environment for our case study can be described as follows:

(1): There is a hypothetical market with a 1000-mile flight distance.

(2): There are two identical airlines operating in the market. Their operating characteristics are assumed the same as in Wei and Hansen (2004).

(3): The fares charged by the two airlines are the same, fixed at 100 dollars (one-way).

(4): The total demand in this market is assumed to be inelastic with airlines' service decisions.

(5): Both airlines will choose one of 18 available sizes of aircraft: from 60 to 400 seats, increasing in step of 20 seats.

(6): Both airlines will choose one of 16 service frequencies per day: from 1 to 31, increasing in step of 2.

(7): The flights in this market only serve local passengers.

Following the notations of S_1, F_1, S_2 and F_2, which are introduced in the last section as variables to represent airline 1's and airline 2's general choices of aircraft size and service frequency**,** we use $s_{1,i}$, $f_{1,j}$, $s_{2,k}$ and $f_{2,l}$ to represent the specific choice of aircraft size i by airline 1, service frequency j by airline 1, aircraft size k by airline 2, and service frequency l by airline 2 respectively.

Results without Charging Additional Landing Fees

For the case described above, we apply the one-shot simultaneous game model to see what airlines' choices of aircraft size and service frequency, if the airport doesn't charge any additional fee to airlines, assuming the airlines are only charged with the basic land fees as what was included in Wei and Hansen (2003).

In the last section we denote the general airlines' strategy as [(S_1, F_1), (S_2, F_2)]; then a specific strategy in this section can be represented as [($s_{1,i}$, $f_{1,j}$), ($s_{2,k}$, $f_{2,l}$)], which consists of both airlines' choices of aircraft size and service frequency. Therefore, there are totally 18*16*18*16, i.e., 82944, possible strategies available in this game.

A Nash Equilibrium strategy $[(s_1^*, f_1^*), (s_2^*, f_2^*)]$, in this one-shot simultaneous game, is one in which airline 1 chooses aircraft size and service frequency (s_1^*, f_1^*) and airline 2 chooses (s_2^*, f_2^*), and neither airline has the incentive to change its choices when given the other's choices. Mathematically, we want to find combinations of (s_1^*, f_1^*) and (s_2^*, f_2^*) from all 82944 possible combinations that will solve the optimization problem (1), although there is no guarantee that there exists a solution or the solution is unique, due to the non-zero-sum property of the game and the discreteness of choices available for each airline. In this case study, we find that there are unique Nash Equilibrium solution strategies for this market. The solution is $[(s_1^* = 160, f_1^* = 7), (s_2^* = 160, f_2^* = 7)]$. That is to say, under the Nash Equilibrium condition, both airlines will choose aircraft of 160 seats and operate 7 times per day. The load factor is 58%. The cost, revenue and profit for each airline are described in Table 1.

Additional Charge ($/flight)	0	1000	3000
Aircraft Size (seats)	160	200	260
Service Frequency (daily)	7	5	3
Load Factor (%)	58.2	65.2	83.6
Demand (# of local passengers, in thousands)	60	60	60
Cost ($,in millions)	2.76	2.94	3.32
Revenue ($, in millions)	6	6	6
Profit ($, in millions)	3.24	3.06	2.68

Table 1 Indices of Airlines' Operations Resulted from Different Additional Landing Fees

Results with Charging Additional Landing Fees

We have found the airlines' choices in the base case above, assuming airport will not charge any additional fee to airlines. Now we assume that airport would charge airlines additional landing fees so that airlines may use larger aircraft and reduce daily service frequency, we apply the same cost model, market share model and the one-shot simultaneous game model to obtain new equilibrium solutions.

We find that if airlines are charged $1000 per flight extra landing fees, then both airlines will use 200-seat aircraft and operate 5 times per day; and if airlines are charged with $3000 per flight extra landing fees, then both airlines will use 260-seat aircraft and operate 3 times per day. The load factors are 65% and 84% respectively. The cost, revenue and profit for each airline under these two circumstances are described in Table 1.

Comparing these results with the result when airlines are not charged any additional landing fee, we first notice that additional airport charges change the game equilibrium, and airlines' choices of aircraft size and service frequency are different when airlines were charged different landing fees. This is due to the properties of the cost function and market share model applied in this research. Airlines have different optimal choices when the operations costs are different.

Secondly, we notice that airlines use larger aircraft and less frequency if charged higher airport fees. Being charged $1000 extra landing fees, airlines use larger aircraft and less service frequency than without being charged any additional landing fee; and being charged $3000 extra landing fees, airlines use larger aircraft and less frequency than being charged $1000 extra landing fees. Due to the cost economies of aircraft size, higher landing fees will force airlines to use larger aircraft and less frequency for the same number of passengers in service. Therefore, airlines' load factor will be increased if higher landing fee policy is employed.

Thirdly, since airport capacity depends on the size of aircraft in operations, using larger aircraft and less frequency to serve the same number of passengers will significantly reduce airport congestion and delays. Therefore, higher landing fees will provide incentives for airlines to use larger aircraft and less frequency and then reduce the number of aircraft operations at the airport, and thus reduce airport congestion and delays.

Fourthly, we also find that, very interestingly, airlines will be better off if some of the extra landing fees are returned to airlines as a bonus for airlines using larger aircraft and consequently reducing airport congestion. From Table 1, we find that airlines cost will go up and profit will go down if they are charged with higher landing fees. But if part of the higher landing fees collected by the airport are given back to airlines, airline will not lose any profit comparing with the base case when airlines are not charged with any additional landing fee. For example, if 40% of $1000 additional landing fees are returned to airlines, or 69% of $3000 additional landing fees are returned to airlines, then airlines will make the same profit as the base case. Obviously, if more than 40% or 69% of the additional landing fees under these two cases respectively are returned to airlines, airlines will get better off than the base case when airlines are not charged extra landing fee.

SUMMARY AND FURTHER STUDIES

In this paper, we study how airport landing fee policy could influence airlines' service decisions and affect airlines' financial performance and airport congestion. We propose a one-shot simultaneous game-theoretic model for two airlines competing in a non-cooperative duopoly market. Specifically, we study how the changes of airport landing fee policy could influence airlines' decisions on aircraft size and service frequency in their operations, and how the changes could influence airlines' profit, as well as congestions and delays at airport.

Our researches find that, due to the properties of cost function and market share model, airlines' optimal aircraft size and service frequency depend on the landing fees charged by the airport, and higher landing fee will force airlines to use larger aircraft and less frequency for the same number of passengers in service. We find that airlines' load factor will be increased if higher landing fee policy is employed. We also find that, very interestingly, airlines will be better off if some of the extra landing fees are returned to airlines as a bonus for airlines using larger aircraft and consequently reducing airport congestion. Since airport capacity depends on the size of aircraft in operations, using larger aircraft and less frequency to serve the same number of passengers will significantly reduce airport congestion and delays.

While the government investments in increasing airport capacity, such as runway expansion, will allow airlines to increase service frequency, alleviate airport congestion and reduce flight delays, they may send a wrong signal to aircraft manufacturers that the increasing air travel demand will be accommodated by continually increasing service frequency. On the contrary, more incentives should be offered to aircraft manufacturers to make new, larger and more cost-efficient aircraft, especially to be used in the short-haul markets. And government should investigate more administrative and economic measures so that airlines may use larger aircraft and less service frequency in their operations, and airport congestion and delay can be alleviated.

This research shows a promising beginning towards applying cost model, market share model and game-theoretic models to understand how government policy could affect airlines' behavior and airport performance. We are currently expanding our research in the following areas:

1) apply more realistic demand and cost coefficients in case studies;
2) allow total demand to be elastic with airlines' service variables, considering airport competitions in multi-airport regions;
3) apply other slot-related landing fee policies;
4) apply two other game models described in this paper;
5) compare and analyze airlines' profit, airport's revenue, impact on airport delay, passengers' and social welfare under different market scenarios.

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