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An airline's management strategies in a competitive air transport market

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ABSTRACT

Over the last decade, the demand for domestic and international flights in Korea has increased substantially. To meet the strong flight demands, several low cost carriers have begun to offer flight services. In addition, full service carriers have been motivated to establish their own subsidiary low cost carriers to maintain their market share against rival low cost carriers. This paper studies the management strategies of three kinds of airlines - full service carrier, its subsidiary low cost carrier and rival low cost carrier - based on game theory in the competitive air transport market. Each airline is assumed to act as a player and chooses strategies regarding airfare, flight frequency, and the number of operating aircrafts for specific routes while maximizing its own profits. Demand leakages between the airlines are considered in the flight demand function according to the selected strategies of all airlines. Through various game situations reflecting realistic features, this study provides managerial insights that can be applied in the competitive air transport market.

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1. Introduction

1.1. The emergence of LCCs

After the declaration of the 1978 Airline Deregulation Act in the United States, the market situation of the air transport industry changed significantly. With the adoption of free competition, airlines tried to improve their customer services. They began flight services in new routes and developed various airfare policies to ensure their survival. Various new airlines, including low cost carriers (LCCs), entered the air transport market to satisfy diverse air transport demands. The concept of LCCs is to offer the flight services with the attractive prices that are much lower than the conventional full service carriers' (FSCs) and even comparable to those of a car or train. By increasing the number of passengers, LCCs can get sufficient profits even though the unit profit per passenger tends to be less than that of FSCs. In addition, LCCs have tried to reduce all kinds of cost-related elements to secure their operating profits. Therefore, even though they cannot provide sophisticated services as compared with FSCs, the demand for LCCs has increased steadily by passengers who want only a basic transportation function.

1.2. The characteristics of LCCs

The fare class structure of LCCs is relatively simple because they only operate one class: Economy and LCCs generally offer two kinds of airfares: Discount fare and regular fare. In addition, they usually provide flight services in point-to-point routes for simple and easy management. LCCs tend to choose lower-tariff airports (Marcus and Anderson, 2008). To get rid of commission payments, LCCs do not use travel agents and adopt the electronic ticketless systems or e-ticket utilizing websites. In addition, they keep a high flight frequency to maximize their utilization and adopt team competitive wages and profit sharing to maintain high productivity and efficiency (Evangelho et al., 2005). Generally, LCCs' airfares are 30–40% lower than FSCs', and LCCs' operating costs are 40–50% compared to FSCs' (Doganis, 2001). Through the emergence of LCCs, various alternatives are given to customers when they are choosing their airline, in terms of preference, airfare, flight frequency, etc. Thus, with the remarkable growth of the customer demand for LCCs, it is difficult for FSCs to ignore the LCC market and focus on the premium market.

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1.3. FSCs' response strategies

In response to the steady growth of LCCs and to keep the market share at certain air transport market, some FSCs have developed certain tactics. Some have: (1) Established their own LCC as an internal unit or subsidiary against rival LCCs. (2) Tried to optimize their present operations by cutting off wasteful expenses while maintaining their current business model. (3) Transformed their business model to similar one of LCCs by reducing their current service levels (Morrell, 2005). Among the alternatives described above, this study has examined the first one, i.e., the FSC strategy of opening a subsidiary LCC against the rival LCC through a three player game situation.

1.4. The current situation of the Korean air transport market

Nowadays, there are five successfully operating LCCs in the Korean air transport market. Among them, Eastar Jet, T'way airline, and Jeju Air were established as pure LCCs, whereas Jin Air and Air Busan were launched as subsidiary LCCs of Korean Air and Asiana Airline, respectively. Both Korean Air and Asiana Airline are regarded as FSCs in the Korean air transport market. At first, LCCs only operated within the domestic air transport market, because several domestic routes such as Gimpo-Jeju and Gimhae-Jeju are highly profitable, regardless of season or day. After they secured the sufficient air transport demands of these domestic routes, they tried to advance the international air transport market by introducing large-size aircrafts such as the Airbus 330 and Boeing 777.

Fig. 1 depicts the LCC market share between 2010 and 2014, while the values of the 2014 year are forecasted. At present, the market share of LCCs is expected to be more than half of the entire domestic air transport market. In addition, the market share of LCCs in the international air transport market tends to increase continuously. Thus, the FSCs choose response strategies to deal with the increasing market share of rival LCCs, such as competing directly by launching subsidiary LCCs.

1.5. The aim of this study

This study dealt with the airline's optimal response strategies in the competitive air transport market by assuming operation situations both under a single route and multiple routes. According to the business purpose and the competing environment, four kinds of game theoretic situations are defined. For each, this study tries to find optimal values for the airfares, the operating flight frequencies and the number of operating aircrafts of all airlines to maximize their profits. In addition, the demands of all airlines are regarded as a function of both the airfares and their operating flight frequencies.

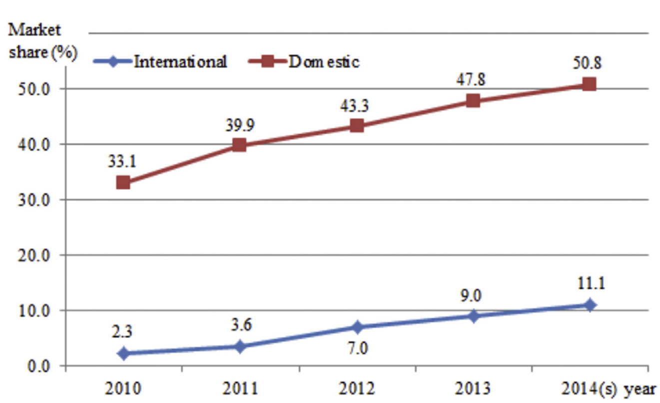

Fig. 1. The market share of LCCs at Korea air transport market between 2010 and 2014.

2. Previous study

After the US Airline Deregulation Act in 1978, many low cost airlines emerged, expanded, and disappeared over 35 years in the US, Europe, and Asia. Market competition in the air transport industry has increased due to the establishment of LCCs, and many researchers have investigated the characteristics of LCCs. Button and Ison (2008) mentioned the general characteristics of LCCs in terms of economics. Mason (2000) performed a preference (SP) survey against European business travelers to evaluate the propensity of business travelers who use the short haul services of low cost carriers. They used evaluation elements such as price, airline reward schemes, flight frequency, and in-flight comfort service attributes in their determination. Reynolds-Feighan (2001) examined the traffic distribution patterns of both FSCs and LCCs. He insisted that LCCs tend to concentrate their traffic flows around a limited number of key nodes. Further, many researchers focused on specific factors of LCCs such as their service quality, airport, network construction, etc. (Jiang, 2013; Graham, 2013; Müller et al., 2012).

Several research studies investigated the airfare pricing, scheduling and the features of airlines in the competitive air transport market. Strassmann (1990) described all airfares tended to decrease when new airlines emerged in the US domestic market. Meanwhile, when a LCC stops operating in a certain route, the airfare of that route has tended to increase (Morrison and Winston, 1995). Whinston and Collins (1992) presented that the average airfare of 15 routes were reduced by 34% due to the operation of a new LCC, People Express, based on data from 1980 to 1984. Brueckner and Zhang (2001) presented a comprehensive economic analysis of scheduling decisions in airline networks. They mentioned that flight frequency increased in a hub-and-spoke network than in a fully-connected network while charging a higher fare to local passengers. In addition, Brueckner and Flores-Fillol (2007) provided a simple model of airline schedule competition between two duopoly carriers considering the combinations of fare and expected schedule delay. Givoni and Rietveld (2009) investigated the phenomenon that airlines increase their flight frequencies rather than aircraft size to cope with customer demand at the competitive environment. Brueckner (2010) proposed a simple model of schedule competition where transport providers choose service frequency and fares while passengers were influenced by average schedule delay and brand loyalty to particular carriers.

Recently, Brueckner et al. (2013) introduced the fare impacts of LCCs in competitive situations with FSCs. They addressed that the average fares of FSCs have weak effects, while the average fares of LCCs have dramatic impacts, whether occurring on an airport-pair, at adjacent airports, or as a potential competitor. Hernandez and Wiggins (2014) evaluated the effects of competitive conditions on nonlinear pricing strategies in the airline industry. In addition, Obermeyer et al. (2013) tested the effects of competition on price dispersion in European airline markets. They proved that efficient airlines have a more dominant position, which allows them to differentiate their fares more than their less efficient counterparts. Kawamori and Lin (2013) presented airline mergers as the response strategy of FSCs against rival LCCs. They calculated merged airlines' profits from both hub carrier's operating costs and connecting passengers' hub-through additional time costs.

There are some studies in the literature that deal with FSC's response to the emergence of rival LCCs of establishing a subsidiary LCC. Graf (2005) introduced the chances and risks of the "airline within airline" business model, which is launching a subsidiary LCC within the same group as a FSC through the analysis of five case studies. In addition, Morrell (2005) presented the difference of operation strategies between full service carriers and low cost carriers in the US air transport market to demonstrate the reasons behind the failure of the "airline within airline" model. Graham and Vowles (2006) explained the segmentation of brands and how the mainline airlines reposition themselves within the market to cope with the challenges of low cost competitors by establishing subsidiary "carriers-within-carriers" (CWCs) as lower unit costs. Both detailed analysis and discussion of the evolution of CWC strategies were provided across space and through time, up to March 2005. Ko and Hwang (2011) dealt with the management strategies of both FSCs and their subsidiary LCCs against rival LCCs. However, they only presented about a single route and simple repeated game model.

In this study, it is treated the airline's management strategies under the competitive air transport market for both single and multiple flight routes, assuming various game theoretical situations.

3. Model development

3.1. Problem description

There are hypothetical air transport markets that consider both a single flight route and multiple flight routes operated by three airlines: a FSC, its subsidiary LCC, and a rival LCC. In this study, mathematical models are developed for problems that can be described with the following three stages: At the initial stage, a FSC is assumed the only airline operating in a particular air transport market. At the second stage, for responding to government deregulation and the increase in air transport demand, a rival LCC has emerged in air transport market against the existing FSC. A rival LCC decides its management strategy on the airfare and flight frequency with the objective of maximizing its own profits considering the policies of a FSC. At the final stage, it is assumed that a FSC establishes a subsidiary LCC to defend its market share. A subsidiary LCC also makes managerial decisions by considering the other airlines' strategies.

Thus in proposed game model, three airlines are participating as players competing in certain air transport markets that have either single or multiple flight routes, and each airline chooses its own strategy regarding airfares, flight frequencies and the number of operating aircrafts in order to achieve its business goals, while taking the strategies of the other airlines into account. That is, it is assumed that each airline's profits are dependent on both its strategies and those of its competitors. This study will examine four cases of the game situations, in which a FSC and its subsidiary LCC make their decisions either separately or together when they play the game as a group, and whether a FSC has a dominant position or not at this air transport market due to its high market share or business relationships. It has an advantage of taking on decisions as a Stackelberg game leader.

Fig. 2 shows the demand structure of a LCC from the European Low Fairs Airline Association (LFA). The emergence of a LCC on an existing route can lead to new demand from other transportation modes or new customers attracted by the low airfare. To be more specific, the demand of LCCs consists of newly generated demand (59%) and shifted demand (37%) from FSCs and other LCCs in the airline market. Thus, the demand leakages among airlines require consideration in the formulation of flight demand functions.

3.2. Notations

For the development of the mathematical model, the following notation is adopted.

Subscripts: *F* implies FSC, *SL* subsidiary LCC, and *L* rival LCC.
Superscripts: 1, 2, … *R* implies *r*th flight route (use in multiple flight routes case).

3.2.1. Known parameters

cvc_i	Unit variable cost of a passenger for an airline *i* [$/unit passenger]
ovc_i	Unit variable cost of a flight operation of an airline *i* [$/unit flight]
fc_i	Unit fixed cost of an aircraft of an airline *i* [$/unit aircraft]
s_i	Seat capacity of an aircraft of an airline *i* [total passenger seat/unit flight]
k_i	Maximum flight frequency of an aircraft of airline *i* per unit time [flight frequency of unit aircraft/unit time]
d_i	Demand of airline *i* [passenger/unit time]
α_i	Initial demand of airline *i* [passenger/unit time]
β_i	Demand decrement when airline *i* increases its airfare by one unit [passenger/$/unit time]
$\gamma_{i,j}$	Demand leakage between airline *i* and airline *j* resulting from one unit difference in airfare [passenger/$/unit time]
δ_i	Demand increment when airline *i* increases its flight frequency by one unit [passenger/flight frequency/unit time]
$\varepsilon_{i,j}$	Demand leakage between airline *i* and airline *j* with one unit difference in flight frequency [passenger/flight frequency/unit time]
p_I	Standard airfare set by IATA [$/unit passenger]
R	Number of flight routes

3.2.2. Decision variables

p_i	Unit airfare of airline *i* [$/unit passenger]
f_i	Flight frequency of airline *i* [frequency/unit time]
n_i	Number of aircrafts operated by airline *i* [number of aircrafts]

3.3. Assumptions

1. Three players, a FSC, a subsidiary LCC, and a rival LCC, compete in a certain air transport market with single/multiple flight routes.
2. It is assumed the point to point operation situation at multiple flights routes to compare the behaviors both FSC and LCCs.
3. It is regarded that each flight route is dealt as independently. That is, there are no demand complementarities at multiple flight routes.
4. Demand of each airline (at each route *r*) is a function of airfare, flight frequency and the differences among those of other airlines (at each route *r*).
5. Fixed cost is dependent on the number of aircrafts in operation while variable cost is dependent on the number of customers and flight frequencies (at each route *r*).
6. No airline's airfare (at each route *r*) can exceed the standard airfare set by the IATA.
7. The airfare of a LCC (at each route *r*) is at most equal to those of a FSC.
8. Each aircraft can be operated at most k_i times per unit time (at each route *r*) and has limited passenger capacity.
9. Each airline may lose unsatisfied demand without penalty.
10. Each airline operates a single type of aircraft.

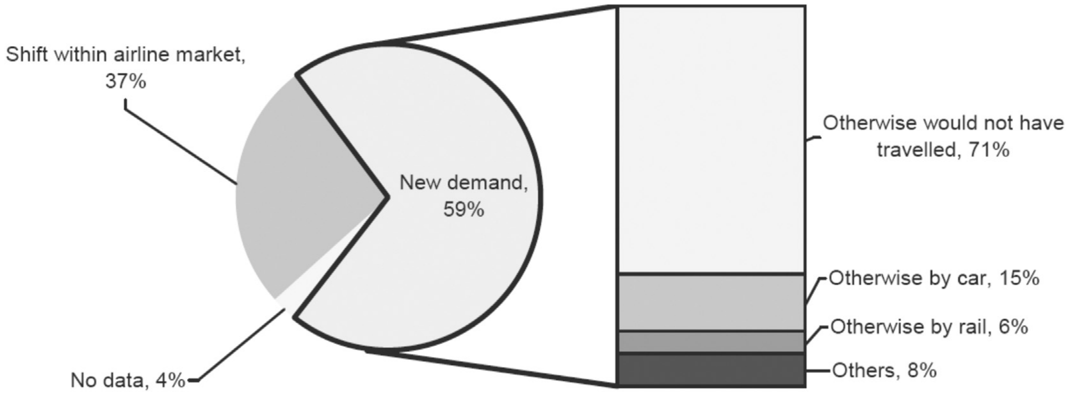

Fig. 2. Demand structure of LCC.

11. The customer always takes a round trip by direct non-stop flights.
12. A non-zero sum game-theoretic model is adopted.
13. This study concentrates on airlines' long-term behavior on the level of single/multiple flight routes.

3.4. Demand functions

When there exist differences in airfares and flight frequencies among three airlines, a customer may migrate from a high airfare segment to a low airfare segment and from a low flight frequency segment to a high flight frequency segment. To capture more customers, each airline may try to adjust their airfare and flight frequency, while considering other airlines' decisions. When certain airline provides more frequent flights, customer preference about that airline can increase because of reduction of schedule delay due to airport standby. In the literature, Zhang and Bell (2007) proposed that demand leakage is a linear function of the differences between airfares and flight frequencies. Based on the above, the demand functions, d_F for a FSC, d_{SL} for a subsidiary LCC and d_L for a rival LCC are formulated as Equations (1)–(3), respectively.

$$d_F = \alpha_F - \beta_F p_F - \gamma_{F,L}(p_F - p_L) - \gamma_{F,SL}(p_F - p_{SL}) + \delta_F f_F + \varepsilon_{F,L}(f_F - f_L) + \varepsilon_{F,SL}(f_F - f_{SL}) \quad (1)$$

$$d_{SL} = \alpha_{SL} - \beta_{SL} p_{SL} - \gamma_{F,SL}(p_{SL} - p_F) - \gamma_{L,SL}(p_{SL} - p_L) + \delta_{SL} f_{SL} + \varepsilon_{F,SL}(f_{SL} - f_F) + \varepsilon_{L,SL}(f_{SL} - f_L) \quad (2)$$

$$d_L = \alpha_L - \beta_L p_L - \gamma_{F,L}(p_L - p_F) - \gamma_{L,SL}(p_L - p_{SL}) + \delta_L f_L + \varepsilon_{F,L}(f_L - f_F) + \varepsilon_{L,SL}(f_L - f_{SL}) \quad (3)$$

In the case of multiple flight routes, it can extend equations (1)–(3) to equations (4)–(6), respectively, by using a superscript r, which represents a flight route r.

$$d_F^r = \alpha_F^r - \beta_F^r p_F^r - \gamma_{F,L}^r(p_F^r - p_L^r) - \gamma_{F,SL}^r(p_F^r - p_{SL}^r) + \delta_F^r f_F^r + \varepsilon_{F,L}^r(f_F^r - f_L^r) + \varepsilon_{F,SL}^r(f_F^r - f_{SL}^r) \quad (4)$$

$$d_{SL}^r = \alpha_{SL}^r - \beta_{SL}^r p_{SL}^r - \gamma_{F,SL}^r(p_{SL}^r - p_F^r) - \gamma_{L,SL}^r(p_{SL}^r - p_L^r) + \delta_{SL}^r f_{SL}^r + \varepsilon_{F,SL}^r(f_{SL}^r - f_F^r) + \varepsilon_{L,SL}^r(f_{SL}^r - f_L^r) \quad (5)$$

$$d_L^r = \alpha_L^r - \beta_L^r p_L^r - \gamma_{F,L}^r(p_L^r - p_F^r) - \gamma_{L,SL}^r(p_L^r - p_{SL}^r) + \delta_L^r f_L^r + \varepsilon_{F,L}^r(f_L^r - f_F^r) + \varepsilon_{L,SL}^r(f_L^r - f_{SL}^r) \quad (6)$$

Note that the demand of each airline at flight route r is regarded that it is independent on the demand of the other flight routes.

3.5. Mathematical models

Since the objective is to maximize profits, it consists of four terms: Sales revenue, customer variable cost, operation variable cost, and fixed cost of aircraft.

3.5.1. Single flight route case

The mathematical model for maximizing profit of a FSC ($i = F$), a subsidiary LCC ($i = SL$), and a rival LCC ($i = L$) can be expressed as:

$$\begin{aligned} \text{Max } & \pi_i = (p_i - cvc_i)\cdot \text{Min}\{d_i, s_i\cdot f_i\} - ovc_i\cdot f_i - fc_i\cdot n_i \\ \text{s.t. } & f_i \le k_i\cdot n_i \\ & 0 < p_L,\ p_{SL} \le p_F \le p_I \\ & f_i \text{ and } n_i \text{ are positive integers} \end{aligned} \quad (7)$$

d_i is the total demand of airline i during a day, and $s_i f_i$ represents the sum of the capacity offered by airline i during a day. Therefore, Min{d_i, $s_i f_i$} means the actual number of passengers taking a trip with airline i. The first constraint defines that the flight frequency is limited according to the number of aircrafts while each aircraft can operate at most k_i times in a day. The second constraint ensures that the airfare of a FSC is below the standard airfare of the IATA, and the airfare of a LCC is always cheaper than that of a FSC. The final constraint requires that the flight frequency and the number of owned aircrafts are positive integers.

3.5.2. Multiple flight route case

The mathematical model for maximizing profit of a FSC ($i = F$), a subsidiary LCC ($i = SL$), and a rival LCC ($i = L$) can be expressed as:

$$\begin{aligned} \text{Max } & \pi_i = \sum_{r=1}^{R}\left[(p_i^r - cvc_i^r)\cdot \text{Min}\{d_i^r, s_i\cdot f_i^r\} - ovc_i^r\cdot f_i^r\right] - fc_i\cdot n_i \\ \text{s.t. } & \sum_{r=1}^{R}\lceil f_i^r / k_i^r \rceil \le n_i \\ & 0 < p_L^r,\ p_{SL}^r \le p_F^r \le p_I^r, \quad \forall r \\ & f_i^r \text{ and } n_i \text{ are positive integers} \end{aligned} \quad (8)$$

d_i^r is the total flight demand of airline i on route r over one day and $s_i f_i^r$ represents the sum of capacity offered by airline i on route r

during a day. Therefore, Min{d_i^r, $s_i f_i^r$} represents the actual number of passengers taking a trip with airline i on route r. The objective function represents the profit of each airline for multiple flight routes. In the first constraint, $\lceil f_i^r / k_i^r \rceil$ means the number of aircrafts operated by airline i on route r. Then, the first constraint defines the total number of aircrafts operated by airline i on multiple flight routes as smaller than the number of aircrafts they own, while each aircraft can operate at most k_i^r times in a day on route r. The second constraint ensures the maximum flight frequency on route r, and the third constraint represents the airfare of a LCC is always cheaper than that of a FSC. The final constraint ensures that the flight frequency and number of aircrafts are positive integers.

3.6. Model application

Based on equations (7) and (8), this study will apply three-player games to understand and predict an airline's strategic decisions. Since it is concerned with the long-term strategies of each airline that result from the interactive behavior, there are two fundamental questions when analyzing an airlines' decisions under single/multiple flight routes: (1) Do the FSC and its subsidiary LCC collude or compete when they are making decisions on the choice of airfare, frequency and number of aircrafts? (2) Do the three airlines in the market make decisions at the same position, or does one airline have an advantage over the others and so make decisions first?

This study deals with four different game theoretic models with three airlines according to the answers to those two questions. These four games are: (Game 1) A repeated game under competition, (Game 2) a repeated game in which the FSC and its subsidiary LCC collude, (Game 3) a leader-and-follower Stackelberg game with competition between the LCCs, and (Game 4) a leader-and-follower Stackelberg game in which the FSC and its subsidiary LCC collude. Equilibrium solutions will be found through Nash equilibrium point for the game models.

4. Game establishment

In this study, the profit function of each airline is a mixed-integer programming problem. Therefore, it is adopted finite solution sets to find a Nash equilibrium solution. Nash (1951), one of the pioneers in the field of game theory, proved that every finite game has an equilibrium point. The finite solution sets used in this study are as follows.

Game description for single flight route case.

1. There is a hypothetical single flight route in the game.
2. There exist three players, a FSC, its subsidiary LCC, and a rival LCC, in the market.
3. For a discount airfare, a FSC can choose from 0%, 5%, 10%, 15%, and 20%, and for the flight frequency per unit time it can select from 1, 2, 3, 4, 5, 6, 7, 8, and 9.
4. LCCs can choose their airfare discount rates among five different values, i.e., 30%, 35%, 40%, 45%, and 50%, and select flight frequencies per unit time from eight different numbers, 1–8.
5. For each aircraft, a FSC can operate at most three times per unit time, while LCCs can operate four times per unit time.
6. The system parameter values of each airline are given.

Game description for multiple flight routes case.

1. There are multiple hypothetical flight routes in the game. For the ease of analysis for the proposed system, it is assume that each airline operates two flight routes: One medium haul route and one short haul route.
2. There are three players, a FSC, its subsidiary LCC, and a rival LCC, in the market.
3. A FSC operates three aircrafts, while each LCC operates two aircrafts. Each airline has to decide how many aircrafts will be assigned between the two flight routes.
4. In the medium haul, the maximum number of possible operations for a FSC's aircraft and LCCs' aircraft are two and three, respectively. In addition, in the short haul, the maximum number of possible operations for a FSC's aircraft and LCCs' aircraft are three and four, respectively.
5. A FSC will choose one of five airfare discount rates: 0%, 5%, 10%, 15%, or 20% on each route, while each LCC will choose one of five airfare discount rates: 30%, 35%, 40%, 45%, and 50% on each route.
6. The system parameter values of each airline are given.

4.1. Game 1: a repeated game under competition

The first game is a repeated game under competition. In this type of game, a FSC, its subsidiary LCC, and a rival LCC perform the game as players at the same position level. The black line between the airlines in Fig. 3 means that they perform a repeated game. According to the previous mentioned market assumption in problem statements, a FSC finds its initial optimal strategy independently. Then, a rival LCC finds its optimal strategy by considering the FSC's decision. Finally, a subsidiary LCC finds its optimal strategy by considering decisions of both a FSC and a LCC. Now, all players participate in the game, and this is the end of the first stage. In the second stage, each airline chooses an optimal strategy by referring to the other airlines' previous strategies. This game continues until no airline changes its strategy at a certain stage compared to the previous stage. Mathematically, there are three optimization problems facing the airlines while the decision variable of each airline is airfare ($= p_i$), flight frequency ($= f_i$), and the number of aircrafts ($= n_i$). π_i denotes each airline's profit function. Then, the three airlines' problems, under the repeated game competition, can be formulated as follows:

$$\begin{aligned} &\underset{p_F, f_F, n_F}{Maximize} && \pi_F(p_F, f_F, n_F | p_{SL}, f_{SL}, n_{SL}, p_L, f_L, n_L) \\ &\underset{p_{SL}, f_{SL}, n_{SL}}{Maximize} && \pi_{SL}(p_{SL}, f_{SL}, n_{SL} | p_F, f_F, n_F, p_L, f_L, n_L) \\ &\underset{p_L, f_L, n_L}{Maximize} && \pi_L(p_L, f_L, n_L | p_F, f_F, n_F, p_{SL}, f_{SL}, n_{SL}) \end{aligned} \tag{9}$$

Nash equilibrium is a solution concept of a game involving two or more players. In here, each player is assumed to know the payoffs or strategies of the other players and no player can benefit by only changing his or her own strategy unilaterally. If each player has chosen a strategy and no player can benefit by changing his or her strategy while the other players keep theirs unchanged, then the current set of strategy choices and the corresponding payoffs constitute Nash equilibrium. A pure strategy provides a complete definition for how a player will play the game. A mixed strategy is an assignment of a probability to each pure strategy. This allows a player to select a pure strategy randomly. Therefore, if there is no pure-strategy Nash equilibrium, this study uses a mixed-strategy to find Nash equilibrium for the solutions of this game.

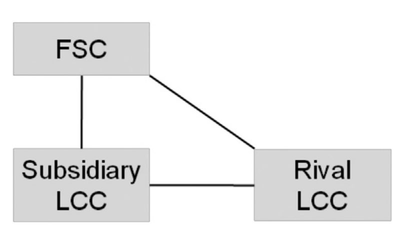

Fig. 3. A repeated game under competition.

4.2. Game 2: a repeated game in which a FSC and its subsidiary LCC collude

The second game is a repeated game in which a FSC and its subsidiary LCC collude. In this type of game, a FSC and its subsidiary LCC are regarded as one group, and a rival LCC is another group. As shown in Fig. 4, two groups perform a game at the same position level. The start of this game is similar to the first stage of Game 1. A FSC finds its optimal strategy independently, and then a rival LCC finds its optimal strategy by considering FSC's decision. When a subsidiary LCC emerges in the game, a FSC and its subsidiary LCC find their optimal strategies by considering the decisions of a rival LCC. In addition, a rival LCC decides its strategy with respect to the strategies of both a FSC and its subsidiary LCC. It is repeated until no player is inclined to change his or her strategy. Mathematically, a FSC and its subsidiary LCC are regarded as one group, and the total profit function of this group is the sum of both airlines' primary profit functions. Each choice has six types of decision variable, because it is needed airfare, frequency, and the number of aircrafts belonging to each airline. Then, the three airlines' problems in which a FSC and its subsidiary LCC collude can be formulated as follows:

$$\begin{aligned} &\underset{p_F,f_F,n_F,p_{SL},f_{SL},n_{SL}}{\text{Maximize}} \quad [\pi_F+\pi_{SL}](p_F,f_F,n_F,p_{SL},f_{SL},n_{SL}|p_L,f_L,n_L) \\ &\underset{p_L,f_L,n_L}{\text{Maximize}} \quad \pi_L(p_L,f_L,n_L|p_F,f_F,n_F,p_{SL},f_{SL},n_{SL}) \end{aligned} \tag{10}$$

4.3. Game 3: a leader-and-follower Stackelberg game with competition between LCCs

The third game is a leader-and-follower Stackelberg game with competition between LCCs. In this type of game, a leader player dominates the market due to a contraction or its high market share. Therefore, it is regarded that it has the advantage of always taking decisions first. Then the following players can choose an optimal strategy by observing the leader's strategy. This is called a Stackelberg game in game theory. An arrow denotes the Stackelberg relationship in Fig. 5. In here, a FSC takes a role of leader while two LCCs, as followers, play a repeated game at the same position level. A FSC makes the best strategy on the possible decision list by considering the reaction of two LCCs for each of FSC's strategies.

$$\underset{p_F,f_F,n_F,}{\text{Maximize}} \quad [\pi_F+\pi_{SL}]\left(p_F,f_F,n_F|p^*_{SL},f^*_{SL},n^*_{SL},p^*_L,f^*_L,n^*_L\right) \tag{11}$$

$$\begin{aligned} &\text{subject to} \\ &(p^*_{SL},f^*_{SL},n^*_{SL}) = \underset{p_{SL},f_{SL},n_{SL}}{\arg\max} \ \pi_{SL}(p_{SL},f_{SL},n_{SL}|p_F,f_F,n_F,p_L,f_L,n_L) \\ &(p^*_L,f^*_L,n^*_L) = \underset{p_L,f_L,n_L}{\arg\max} \ \pi_L(p_L,f_L,n_L|p_F,f_F,n_F,p_{SL},f_{SL},n_{SL}) \end{aligned} \tag{12}$$

The solution process occurs in the opposite way to the airlines' decision process. First, two LCCs play a repeated game and find equilibrium solutions by conditioning on any possible decision made by a FSC using equation (12). Then, the FSC finds its optimal strategy by pursuing the maximization of profits for both a FSC and its subsidiary LCC by referring to the reaction sets of the two LCCs.

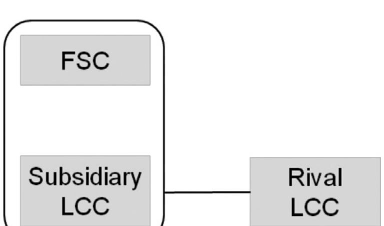

Fig. 4. A repeated game in which a FSC and its subsidiary LCC collude.

4.4. Game 4: a leader-and-follower Stackelberg game in which a FSC and its subsidiary LCC collude

The fourth game is a leader-and-follower Stackelberg game in which a FSC and its subsidiary LCC collude. In this type of game, a FSC and its subsidiary LCC are regarded as one group, and a rival LCC is another group, as shown in Fig. 6. For the Stackelberg game, the FSC and its subsidiary LCC are act as the leader.

$$\underset{p_F,f_F,n_F,p_{SL},f_{SL},n_{SL}}{\text{Maximize}} \quad [\pi_F+\pi_{SL}]\left(p_F,f_F,n_F,p_{SL},f_{SL},n_{SL}|p^*_L,f^*_L,n^*_L\right) \tag{13}$$

$$\begin{aligned} &\text{subject to} \\ &(p^*_L,f^*_L,n^*_L) = \underset{p_L,f_L,n_L}{\arg\max} \ \pi_L(p_L,f_L,n_L|p_F,f_F,n_F,p_{SL},f_{SL},n_{SL}) \end{aligned} \tag{14}$$

The solution process is similar to the third game. First, a rival LCC decides its strategy on condition of any possible decision made by a FSC and its subsidiary LCC using equation (14). Then, a FSC and its subsidiary LCC find their optimal strategy by pursuing the maximization of their summed profits by reacting to the actions of a rival LCC.

5. Numerical example

The proposed four types of games are illustrated with example problems. Each airline can choose one strategy among the possible decision list mentioned in the game description, and then the potential demand of each airline can be generated from equations (1)–(6). Based on this demand, it can be calculated the profit of each airline through equations (7) and (8) with hypothetical system parameters. Because the demand and profits of each airline depend on the airfares and flight frequencies of three airlines, if the strategy of particular airline changes during the game, then the demands and profits of three airlines should be recalculated. The hypothetical system parameters of the four kinds of games are presented at Tables 1 and 2. Both cost and other relative parameters for FSC and LCCs are generated based on real data with scaled number while demand relative parameters are assumed considering features of customer behaviors about flight frequency and airfare of each airline.

Superscript 1 and 2 represent the short haul route and the medium haul route, respectively. R represents the number of the routes on multiple flight routes, and in this example problem, the value of R is set as two. It is because there are two routes, one short- and one medium-haul route, operated by three airlines.

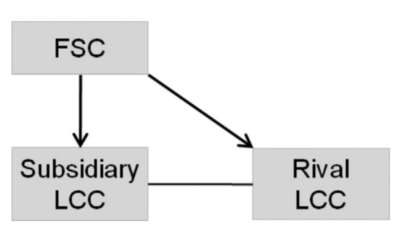

Fig. 5. A leader-and-follower Stackelberg game with competition between LCCs.

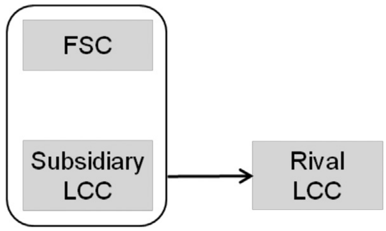

Fig. 6. A leader-and-follower Stackelberg game in which a FSC and its subsidiary LCC collude.

5.1. Computational results for single flight route case

The four types of games that are proposed at the Game Establishment section are executed with the above hypothetical system parameters. Table 3 lists the strategy, potential demand, and profits of each airline under the four kinds of game theoretic situations. Table 4 represents changes in the profits, the gap, for a FSC and its subsidiary LCC under the four types of games, based on the results of Table 3, where

$$gap = \frac{\text{profit under Game } i - \text{profit under Game 1}}{\text{profit under Game 1}} \times 100 \qquad (15)$$

The following observations can be made from Tables 3 and 4

- (Game 1 vs. Game 2) To compare the case of a FSC and its subsidiary LCC under competition, their profits sum increases approximately 3.23% under collusion. It is because they do not focus on maximizing their own profits but the sum of their combined profits. A subsidiary LCC increases its airfares to reduce demand leakage from a FSC in spite of the profit losses of a subsidiary LCC itself. As a result, a FSC can operate this route with fully booked aircraft while a subsidiary LCC does not take the sufficient passengers.
- (Game 1 vs. Game 3) In here, a FSC and its subsidiary LCC do compete, but a FSC does a Stackelberg game as a leader by considering the profit sum of a FSC and its subsidiary LCC, while two LCCs act as followers. In this case, a FSC increases its airfare and reduces its flight frequency and the number of operational aircrafts. Then, two LCCs can afford to impose higher airfares, because they can expect sufficient passengers from the demand leakage of a FSC due to the FSC's high airfare policy. In spite of the FSC's profit reduction, the profit sum of a FSC and its subsidiary LCC increase by approximately 6.22%, coming from a subsidiary LCC's remarkable profit increment.
- (Game 1 vs. Game 4) In this kind of game, a FSC and its subsidiary LCC collude, and they play a Stackelberg game as a leader. Therefore, similar to as mentioned previously, their profits sum is improved by about 14.36%. In here, a FSC directly competes with a rival LCC to get more profits from this route. However, a subsidiary LCC increases its airfares, and decreases both its flight frequency and the number of operational aircrafts. In this case, if a subsidiary LCC pursues the passengers who want a more careful service but do not want to pay the amount of the FSC's airfare level, the subsidiary LCC can positioning itself in the market as a medium-cost airline.

5.2. Computational results for a multiple flight routes case

The decision variables of this game theoretic model are airfare and flight frequency for each route of each airline. Though the number of operating aircrafts at each route for each airline is also regarded as a decision variable, they are decided automatically by each airline's flight schedule through the first constraints of equation (8). The solutions of the example problem for four kinds of games are organized as in Table 5. Note that it is assumed the medium haul route is more profitable than short haul route for airlines.

Table 5 illustrates airfares, flight frequencies, and the number of operating aircrafts for both the short- and medium-haul routes of each airline. With the strategy of each airline shown in Table 5, the demands and profits of each airline can be calculated. In addition, the changes in the profits, the gap, for a FSC and its subsidiary LCC under the four kinds of games are represented in Table 5.

The following observations can be made from Table 5.

- When three airlines do game under competition (Game 1), they provide flight services that are focused on profitable medium haul routes, and two LCCs do not even operate the short haul route. However, when a FSC and its subsidiary LCC collude (Game 2), a subsidiary LCC also operates the short haul route. Then, a FSC can secure more customers at the medium haul route because of the demand leakage reduction based on the lower competitive rate at the medium haul route. Their profits sum is improved approximately 8.90% by the collusion.
- If a FSC has the role of a leader in the Stackelberg game and two LCCs are regarded as followers (Game 3), a FSC tempts two LCCs to serve a short-haul route by increasing its airfare for the short haul route. Then, two LCCs can make relatively reasonable profits from the short haul route, based on the FSC's high airfare policy. Then, a FSC can increase its airfare for the medium haul route without considering two LCCs, based on the lower competitive rate. Upon comparison with Game 1, this game is unfavorable for customers, because all airlines increase their airfares for both the short and medium haul routes. As a result, a FSC and its subsidiary LCC can get approximately 9.72% more profits from their higher airfares.

Table 1
The hypothetical system parameters in case of single flight route.

Demand relative parameters														
α_F	α_{SL}	α_L	β_F	β_{SL}	β_L	δ_F	δ_{SL}	δ_L	$\gamma_{F,L}$	$\gamma_{F,SL}$	$\gamma_{L,SL}$	$\varepsilon_{F,L}$	$\varepsilon_{F,SL}$	$\varepsilon_{L,SL}$
2500	1400	1370	6	10	12	70	30	25	5	6	5	10	15	5

Cost relative parameters								
fc_F	fc_{SL}	fc_L	ovc_F	ovc_{SL}	ovc_L	cvc_F	cvc_{SL}	cvc_L
10,000	5000	5000	20,000	5500	5500	10	3	2

Other parameters						
s_F	s_{SL}	s_L	k_F	k_{SL}	k_L	p_I
200	100	100	3	4	4	200

Table 2
The hypothetical system parameters in case of multiple flight routes.

Demand relative parameters														
α_F^1	α_{SL}^1	α_L^1	β_F^1	β_{SL}^1	β_L^1	δ_F^1	δ_{SL}^1	δ_L^1	$\gamma_{F,L}^1$	$\gamma_{F,SL}^1$	$\gamma_{L,SL}^1$	$\varepsilon_{F,L}^1$	$\varepsilon_{F,SL}^1$	$\varepsilon_{L,SL}^1$
2400	1400	1370	6	10	12	70	30	25	5	6	5	10	15	5
α_F^2	α_{SL}^2	α_L^2	β_F^2	β_{SL}^2	β_L^2	δ_F^2	δ_{SL}^2	δ_L^2	$\gamma_{F,L}^2$	$\gamma_{F,SL}^2$	$\gamma_{L,SL}^2$	$\varepsilon_{F,L}^2$	$\varepsilon_{F,SL}^2$	$\varepsilon_{L,SL}^2$
2450	1150	1180	3	5	6	70	30	20	3	4	5	10	15	5

Cost relative parameters								
fc_F^1	fc_{SL}^1	fc_L^1	ovc_F^1	ovc_{SL}^1	ovc_L^1	cvc_F^1	cvc_{SL}^1	cvc_L^1
10,000	5000	5000	20,000	5000	5500	10	3	2
fc_F^2	fc_{SL}^2	fc_L^2	ovc_F^2	ovc_{SL}^2	ovc_L^2	cvc_F^2	cvc_{SL}^2	cvc_L^2
10,000	5000	5000	36,000	9000	10,000	30	10	8

Other parameters						
s_F^1	s_{SL}^1	s_L^1	k_F^1	k_{SL}^1	k_L^1	p_l
200	100	100	3	4	4	200
s_F^2	s_{SL}^2	s_L^2	k_F^2	k_{SL}^2	k_L^2	R
200	100	100	2	3	3	2

Table 3
The results of four kinds of games on single flight route.

	Airline	Airfare	Frequency	No. of aircraft	Demand	Profit	
Game 1	FSC	$170	6	2	1140	$42,400	$74,000
	Subsidiary LCC	$110	8	2	880	$31,600	
	Rival LCC	$100	8	2	790	$27,420	
Game 2	FSC	$170	6	2	1200	$52,000	$76,390
	Subsidiary LCC	$120	8	2	670	$24,390	
	Rival LCC	$100	8	2	840	$28,400	
Game 3	FSC	$190	3	1	625	$38,000	$78,600
	Subsidiary LCC	$120	8	2	885	$39,600	
	Rival LCC	$110	8	2	750	$31,000	
Game 4	FSC	$180	6	2	1210	$64,000	$84,625
	Subsidiary LCC	$130	4	1	375	$20,625	
	Rival LCC	$110	7	2	700	$30,600	

- When a FSC and its subsidiary LCC collude and have the role of leader in the air transport market (Game 4), a subsidiary LCC takes charge of operating the short haul route against a rival LCC, and a FSC competes directly with a rival LCC at the profitable medium haul route to get more profits. Therefore, a FSC and its subsidiary LCC can improve their profits sum by approximately 11.91% compared to the Game 1 situation. To compare the solutions of single route case, it can confirm that a rival LCC is less influenced by the strategy of a FSC and its subsidiary LCC, because a rival LCC can choose its operating route by considering which one is the best to maximize its profits.

6. Conclusion

In this study, it is dealt with the competitive market situation of the air transport industry with a FSC, a subsidiary LCC and a rival LCC, all of whom serve both single and multiple flight routes. It is examined four kinds of game theoretic situations with the case of collusion/competition and the case of a Stackelberg game. The demand of each airline is assumed a function of its airfare and flight frequency. The concept of demand leakage is also integrated into the demand function coming from the differences of airfares and flight frequencies among the three airlines. The mathematical model is developed with the objective of maximizing profits, while the decision variables are airfare, flight frequency, and the number of aircrafts in the fleet. To examine each airline's behaviors under the four game theoretic situations, example problems are solved with the hypothetical system parameter values under a finite solution domain. In the single flight route case, a FSC can make more profits when a FSC is colluding with its subsidiary LCC and positioned as the Stackelberg leader. This comes from the flexibility of strategic decisions. In addition, in Game 4, it can be checked the possibility that if a subsidiary LCC pursues to catch passengers who want to get more careful service but do not wish to pay the amount of a FSC's airfare level, a subsidiary LCC can be positioned in the market as a medium-cost airline. In the multiple flight route case, a FSC can make more profits when colluding with a subsidiary LCC and being positioned as the Stackelberg leader. When a FSC is

Table 4
Difference of profits sum between four kinds of games on single flight route.

	Gap under Game 1	Gap under Game 2	Gap under Game 3	Gap under Game 4
FSC and subsidiary LCC	0%	3.23%	6.22%	14.36%

$gap = \frac{\text{profit under Game } i - \text{profit under Game 1}}{\text{profit under Game 1}} \times 100.$

Table 5
The results of four kinds of games on multiple flight routes.

	Airline	Haul	Airfare	Flight frequency	No. of aircraft	Demand	Profit		
Game 1 Gap: 0%	FSC	Short	$180	3	1	725	$32,000	$103,600	$159,600
		Medium	$340	4	2	760	$71,600		
	Subsidiary LCC	Short	–	–	–	–	–	$56,000	
		Medium	$220	6	2	640	$56,000		
	Rival LCC	Short	–	–	–	–	–	$51,200	–
		Medium	$200	6	2	640	$51,200		
Game 2 Gap: 8.90%	FSC	Short	$190	3	1	675	$38,000	$122,000	$173,800
		Medium	$340	4	2	805	$84,000		
	Subsidiary LCC	Short	$130	4	1	465	$23,800	$51,800	
		Medium	$220	3	1	490	$28,000		
	Rival LCC	Short	–	–	–	–	–	$51,200	–
		Medium	$200	6	2	655	$51,200		
Game 3 Gap: 9.72%	FSC	Short	$200	3	1	625	$44,000	$114,000	$175,115
		Medium	$360	3	2	680	$70,000		
	Subsidiary LCC	Short	$140	4	1	395	$27,115	$61,115	
		Medium	$240	3	1	420	$34,000		
	Rival LCC	Short	$120	4	1	540	$22,000	$53,800	–
		Medium	$220	3	1	440	$31,600		
Game 4 Gap: 11.91%	FSC	Short	$190	3	1	675	$38,000	$138,000	$178,615
		Medium	$360	4	2	820	$100,000		
	Subsidiary LCC	Short	$130	8	2	745	$40,615	$40,615	
		Medium	–	–	–	–	–		
	Rival LCC	Short	$120	4	1	420	$22,200	$53,800	–
		Medium	$220	3	1	445	$31,600		

competing with its subsidiary LCC, two LCCs concentrate on the medium haul because of its higher marginal profits. However, when a subsidiary LCC is colluding with a FSC, a subsidiary LCC takes the short haul demand to maximize the profits of both a FSC and a subsidiary LCC. As a result, a subsidiary LCC can concentrate on the short haul journeys and a FSC will serve the more profitable medium haul when both colluding and playing a Stackelberg game.

For future studies, it is desirable to refine the objective function of the model to not only maximize profits, but also maximize market share or eliminate competing airlines. A multi-objective function could be implemented. In addition, if I can get real data from airlines or airports, it is needed to validate proposed game theoretic model with real data to derive more useful insights for practitioners.

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