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The Competition of Combination and All-cargo Airlines in a Deregulated General Air Cargo Market

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Abstract: Under deregulation, the competition for air general cargo business between all-cargo airlines and combination airlines is foreseeable. This paper proposes a model structure that analyzes the pricing and service strategies between two kinds of carriers within a competitive framework, and evaluates airline profits based on game theory and a microeconomic theory of airline behavior. The model is applied to a case study, with empirical airline operation cost data, and acquire some results. The results show that combination carriers mostly have significant dominance over the market and might expand their freight aircraft fleets for competition. All-cargo airlines could expand their operation via better service in the markets, especially where combination airlines provide insufficient shipping capability for air cargo service.

Keywords: *Airlines; Competition; Game theory; All-cargo*

1. INTRODUCTION

Air cargo transporting service has become a remarkable market. Besides the relationship between air cargo demand and global economics, the industry's sustained growth is the main cause to attract attention. Bowen (2004) argues that some factors, including the growth of world trade, the prevalence of e-commerce, the raising proportion in the global trade of the high-priced, low-weighted electric products, the long-term downgrading of air freight fare, business supply-chained operations, trigger the air cargo business expand continuously, of which the evidence is the increment of scheduled air freight service and dedicated freight airplanes. According to Boeing's projection, the demand of air cargo will increase up to three times in the next 20 years. It is more appreciable in some regions, especially Asia-pacific, northern America, mid-Eastern, European, which are the main air cargo markets in the future.

Some studies (Morrell and Pilon, 1999; A. Zhang and Y. Zhang, 2002a；Bowen, 2004; A. Zhang, Hui and Leung, 2004; Gardiner and Ison, 2008) have explored the development and issues about air cargo industry after international aviation liberalization. Besides the forementioned issues and the prospects of industry, the interaction with air passenger business is another significant topic. It doesn't only concern with airport resource disposition, such as the airport landside space and time slots arrangement, but also the overall development of the air cargo industry in the future and the aviation policies of some countries (Bowen, 2004).

Combination and all-cargo airlines are major general cargo operators and coexist in some markets. Traditionally, airfreights are viewed as the byproducts of passenger airlines, namely combination airlines, shipping by the aircrafts' belly-hold space. Those, such as Northwest

Airlines, Lufthansa Airlines and China Airlines etc, take advantage of the networks and lower cost to operate. The shortage of the capability of shipping and handling used to be a problem, but some improvements have been taken in practice. In contrast with the formers, all-cargo airlines, including all-cargo carrier and integrated express carrier, ship general cargo and express/time-definite cargo by dedicated freight aircrafts. Accompanying the growth of air cargo market, the latter expands their worldwide service network and scale and aggressively develop hub-and-spoke network for efficient delivery. Besides promoting original items of services, they have tried to enter general cargo market (A. Zhang and Y. Zhang, 2002b).

Although combination airlines are seemingly dominant in general air cargo markets, there are some changes emerging from the air cargo industry. All-cargo airlines accounted for 49.3% of the revenue of international air freight of the United States in 1995 and 63.8% in 2005. According to FAA, it will be 68% until 2017. The Boeing predicts by 2019 integrator may occupy 40% of global air cargo carriage in Asia, which is the most important region of international air cargo. All-cargo airlines will play an important role in the future, and their competition in the general cargo market may be inevitable. Take Mainland China as an example, while integrated express carrier, such as UPS and FedEx Express, aggressively expand their service and some new local all-cargo carriers, such as Jade Cargo International and Great Wall Airlines, also set up increasingly. Those all-cargo ones all focus on the growing air cargo demand of Mainland China and compete with the passenger airlines.

How firms facing competitors choose strategies has been an important issue being studied, but most of past literature about the air industry were focused on the air passenger (Hansen and Kanafani, 1990; Brueckner and Spiller, 1991; Oum and Yu, 1998; Adler, 2001; Martín and Román, 2003; Alder and Smilowitz ,2007; Wei and Hansen, 2007). However, only A. Zhang and Y. Zhang (2002b) and A. Zhang et al. (2007) discussed the competition between combination and all-cargo airlines. Zhang and Zhang examined the effect of the separation of one country's passenger and cargo rights on competition between foreign all-cargo and home combination carriers, by developing a theoretical model to depict the competition in general cargo market. The result showed that passenger carriers with substantial cargo business in competitive condition will response to expand service by the increment of dedicated cargo aircrafts and use passenger and dedicated cargo aircrafts on passenger routes. A. Zhang et al. (2007) discussed another pattern of their competition in air cargo business. They examined the effect of multimodal integration on the rivalry between a forwarder– airline alliance and an integrator under the economies of traffic density. These previous studies put emphasis on the competition which exists or will exist between two kinds of airlines with respective air cargo market segments. It seems that there is a lack of discussing how the different operation features affect the competition of the general air cargo business.

To fill the gap, this study propose a non-cooperative, multi-player game theoretical model, incorporating the operative features of both combination airlines and all-cargo ones, and explore the competition between them in the deregulated aviation markets. The carriers will decide simultaneously their airplane sizes, frequencies and fares under the consideration of maximizing their respective profit. The model was applied to a case study, and undertook sensitivity analysis to examine how various market conditions affect the equilibrium of the market. It is expected that the results of this study would be helpful in making related decision s and policy analysis.

2. MODEL FORMULATION

Suppose the air cargo market being studied is oligopsonistic with airlines i, including combination ones A ($a_1, a_2, ..., a_n \in A$) based at airport h, and all-cargo ones B ($b_1, b_2, ..., b_m \in B$), which are not constrained to the base but operate air cargo business at airport h. Both provide general air cargo service to ship goods from airport h to airport k ($K = \bigcup_{\forall i \in A,B} D(i)$). $D(i)$ is termed as the given set of airports for airline i offering the scheduled route, of which the one end airport is airport h, and there may be some differences between those of any two airlines. Every airline in the market could operate on route hk without any regulation. The combination airlines usually ship to the end without transferring, just landing and taking off at certain of airports for fueling and maintenance. The all-cargo ones empirically use the hub-and-spoke (HS) network to deliver. Figure 1 presents an example of the HS network, in which the airports of the network include spokes and hubs. All hubs chosen by airline b_m are reasonably assumed to be directly interconnected, and all spoke airports only directly connect to the hub in its region. As a result, the number of legs to ship on a route depends on the location of the two end airports; e.g., to ship inter-regional goods from a hub to a hub or intra-regional goods from a hub to a spoke (or vice versa) involve one leg; to ship inter-regional goods from a hub to a spoke (or vice versa) or intra-regional goods from a spoke to a spoke involve two legs; to ship inter-regional goods from a spoke to a spoke involves three legs. Besides, the two-way demands of each route are assumed to be equal.

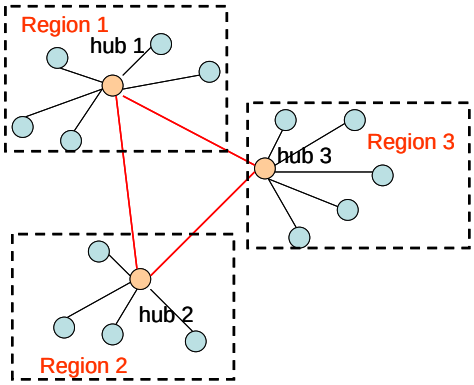

Figure 1 The hub-and-spoke network configuration

2.1 THE MODEL OF FLIGHT FREQUENCY ON A ROUTE

Before discussing, some denotations are shown as follows: Q_{if}^{cd} is airline i's shipments on leg cd, S_{if}^{cd} is the freight airplane size using by airline i on leg cd, U_{if}^{cd} and τ_{if}^{cd} is the payload and load factor of airplane S_{if}^{cd} on leg cd. Besides, F_{if}^{cd} denotes the flight frequency of airline i on leg cd. For simplification, it is assumed that an airline flies uniform dedicated freight airplanes on one route.

Because using the belly capacity of the passenger planes to ship freight is viewed as the virtually costless, they might ship by passenger planes prior to dedicated freight planes; i.e. the latter planes are flied if the capability of the former is not enough to ship all the demand. The freight frequencies of airline a_n on route hk must satisfy all the demand and can be shown as:

$$F_{a_n p}^{hk}(S_{a_n p}^{hk})\tau_{a_n p}^{hk}U_{a_n p}^{hk} + \Delta F_{a_n f}^{hk}(S_{a_n f}^{hk})\tau_{a_n f}^{hk}U_{a_n f}^{hk} \geq Q_{a_n f}^{hk} \quad , \forall k \in D(a_n) \tag{1}$$

where $F_{a_n p}^{hk}$ and $\Delta F_{a_n f}^{hk}$ denotes the passenger and dedicated freight plane frequencies on route *hk*. The former is given and the latter is affected by some factors, including fleet scale, mechanical operation constraints and maintenance. Letting $BT_{a_n f}^{S_{a_n f}^{hk}}$ denote the occupied time of airplane $S_{a_n f}^{hk}$ of airline a_n's fleet $W_{a_n f}^{S_{a_n f}^{hk}}$ on route *hk*, the maximum rate of utilization of airplane $S_{a_n f}^{hk}$, namely $\eta_{a_n f}^{S_{a_n f}^{hk}}$, can be written as $\Delta F_{a_n f}^{hk} * BT_{a_n f}^{S_{a_n f}^{hk}} \le \eta_{a_n f}^{S_{a_n f}^{hk}} * W_{a_n f}^{S_{a_n f}^{hk}}$.

As mentioned, the HS networks are adopted by all-cargo airlines and a flight route consists with one or more legs. The flight frequency of route *hk* is decided by the frequencies of the legs of route *hk*. Given that leg *cd* is on route *hk* for airline b_m, the flights on leg *cd* might include the originating (from airport *c*) flights $\Delta F_{b_m f}^{cd}$ and the transfer ones $\overline{F}_{b_m f}^{cd}$. For the transfer flights, in addition to the existent shipments, the cargos (termed as $Q_{b_m f}^{cd}$) from airport *c* to airport *d* and others to the different end airports (termed as $\overline{Q}_{b_m f}^{cd}$) carried on leg *cd* are shipped by airplanes. It is reasonably assumed that the originating flights are not needed if the capability of the transfer flights is enough to ship all the demand. Letting $F_{b_m f}^{cd}(S_{b_m f}^{cd})$ be airline b_m's frequency on leg *cd*, it must be subject to the restriction:

$$\overline{F}_{b_m f}^{cd}(\overline{S}_{b_m f}^{cd})\overline{\tau}_{b_m f}^{cd}\overline{U}_{b_m f}^{cd} + \Delta F_{b_m f}^{cd}(\overline{\overline{S}}_{b_m f}^{cd})\overline{\overline{\tau}}_{b_m f}^{cd}\overline{\overline{U}}_{b_m f}^{cd} \ge Q_{b_m f}^{cd} + \overline{Q}_{b_m f}^{cd} + \hat{Q}_{b_m f}^{cd}\overline{F}_{b_m f}^{cd} \tag{2}$$

where $\overline{S}_{if}^{cd}$ and $\overline{\overline{S}}_{if}^{cd}$ denote the aircraft sizes adopted for flights $\overline{F}_{b_m f}^{cd}$ and $\Delta F_{b_m f}^{cd}$ on leg *cd*; $\overline{\tau}_{b_m f}^{cd}$ and $\overline{U}_{b_m f}^{cd}$ denote the planning load factor and the study payload of aircraft $\overline{S}_{if}^{cd}$; $\overline{\overline{\tau}}_{b_m f}^{cd}$ and $\overline{\overline{U}}_{b_m f}^{cd}$ denotes the planning load factor and the study payload of aircraft $\overline{\overline{S}}_{if}^{cd}$; $\hat{Q}_{b_m f}^{cd}$ denotes the average existent shipments of the aircraft $\overline{S}_{if}^{cd}$ per flight on leg *cd*.

The all-cargo airlines usually take the operation in coordination to reduce the incremental time from the transshipment and complete the pickup and delivery work at the transshipment airport within quite limited hours. The frequency on a route could be viewed as the first leg's frequency on that route. Letting $F_{b_m f}^{hk}$ be airline b_m's flight frequency on route *hk*, it can be written as：

$$F_{b_m f}^{hk} = \begin{cases} F_{b_m f}^{hk} & ,h \in g(b_m) \text{ and } k \in sp_{b_m}^{h} \\ & \text{or } k \in g(b_m) \text{ and } h \in sp_{b_m}^{k} \\ & \text{or } h,k \in g(b_m) \\ F_{b_m f}^{hg_1} & ,h,g_1 \in g(b_m) \text{ and } k \in sp_{b_m}^{g_1} \\ & \text{or } k,g_1 \in g(b_m) \text{ and } h \in sp_{b_m}^{g_1} \\ & \text{or } h,k \in sp_{b_m}^{g_1} \text{ and } g_1 \in g(b_m) \\ & \text{or } h,k \notin g(b_m) \text{ and } h \in sp_{b_m}^{g_1} \end{cases}, \forall k \in D(b_m) \tag{3}$$

where $g(b_m)$ denotes the set or airline b_m's hubs and $sp_{b_m}^{g}$ denotes the set of the spoke airports connecting directly with hub *g* for airline b_m. The constraints of aircraft utilization are also applied to dedicated freight airlines.

The airport capability of aircraft movements and airport time slots arrangement also reflect on airlines' scheduling, including flight times and frequencies. The priority of the passenger

flights time slots is usually higher than that of the all-cargo flights in the most international airports. Dedicated freight aircrafts operate during the off-peak or nighttime period and shipments carried by the passenger aircrafts are shipped during normal hours. The difference of time slots might result in the delivering time gaps. So all-cargo flights must compete with the passenger for time slots at some congested airports (Bowen, 2004).

Assume airport *h*'s operation time can be divided into two periods: z_1 and z_2. z_1 is the peak load times in the daytime and z_2 is the off-peak times including the nighttime. It is simplified to assume that all flights of airline a_n are supplied during time period z_1 and those of airline b_m during time period z_2. The assumption is plausible because the passenger flights are prior to the freight ones and the passenger airlines are usually the home airlines with some dominance over the airport resource. Despite of the integration of the production and distribution systems, the additional time or resource for the nighttime work is inevitable. The consignments are not sensitive to the flight departing time; however, the inconvenience and extra cost stemming from the flights during the off-peak times is crucial for a firm or individual and might affect the consignors or forwarders to choose how to deliver, especially for urgent shipments.

2.2 THE COST FUNCTION

The airline operating costs are usually classified into two groups: direct operating cost (DOCs) and indirect operating cost (Holloway, 2003). DOCs are the costs and expenses arising from aircraft operating, including fuel expense, flight crew expense, airport & en route charges, maintenance expense, depreciation and amortization expense. Those largely depend on the types of aircraft fleets and the flight operation and might be classified into fixed and variable ones. The former is fixed with the flight distance and the latter, on the other hand, varies. Indirect operating costs are independent of aircraft fleets and utilizations, including sales expenses, station and ground expenses, general and administration expense. The discussion aims at how different compositions of aircrafts in the fleet and flight frequencies and the scale of operations affect the airlines' costs. Therefore this study will focus on the direct operating costs of airlines. The direct operating costs herein are classified into two categories: aircraft operating costs, comprising "fixed" and "variable" two components, and airport user charges.

Airport user charges (AUC) generally include landing charges, noise charges, parking charges, security charges, terminal navigation charges and so on. Those are mostly charged on flight basis, and the rates are classified by aircrafts or weight categories. Among the expenses occurred at the airport, freight handling charges are collected from and priced by the freight handling agents and not the expenses of airlines. Letting AUC_{if}^{cd} denote the charges for aircraft S_{if}^{cd} of airport *h* on leg *cd*, it can be expressed as flight times multiplied the airport charge rates ($\delta^{S^{cd}}$), that is $AUC_{if}^{cd} = AUC_{if}^{cd}(F_{if}^{cd}, S_{if}^{cd}) = F_{if}^{cd}\delta^{S_{if}^{cd}}$.

There are two main components of the aircraft operating costs (AOC): one is directly related to the flight distance (such as fuel and oil costs, the salary and expense of flight crew, and other expenses on the trip) and the other is indirectly related to the flight distance (such as flight equipment maintenance expense, depreciation and amortization expense).

The costs of the flight on a route consist of aircraft operating costs and airport user charges of the flight on all legs of the route. Note that the flights of airlines from airport *h* to next airport might be the passenger or transfer or originating ones. Nevertheless, except for the originating, the general cargos from airport *h* on a specific leg (or route) are not the only "shipments"

carried on the planes and the research calculates the costs based on the proportion of the shipping weights instead of item by item with difficulty.

For combination airlines, the costs include the extra costs which passenger aircrafts increase from carrying cargos on and the costs of the all-cargo aircrafts flied. As airport user charges are mostly calculated on the basis of the aircraft sizes per flight, the incremental costs of the passenger airplanes carrying cargos on are the increase of the aircraft operating costs (termed as ΔAOC). Letting C_{if}^{hk} denote the costs of shipping the general cargos of route *hk* for airline a_n, it can be shown as:

$$C_{a_n f}^{hk} = C_{a_n f}^{hk}(F_{a_n f}^{hk}, S_{a_n f}^{hk}, F_{a_n p}^{hk}, S_{a_n p}^{hk}) = \begin{cases} C_{a_n f}^{hk}(F_{a_n f}^{hk}, S_{a_n f}^{hk}, F_{a_n p}^{hk}, S_{a_n p}^{hk}) & , F_{a_n f}^{hk} > F_{a_n p}^{hk} \\ C_{a_n f}^{hk}(F_{a_n p}^{hk}, S_{a_n p}^{hk}) & , else \end{cases} \tag{4}$$

$$= \begin{cases} F_{a_n p}^{hk} \Delta AOC_{a_n p}^{hk} + \Delta F_{a_n f}^{hk}(\beta_1^{S_{a_n f}^{hk}} d^{hk} \tau_{a_n i}^{hk} U_{a_n f}^{hk} + \beta_{0\,a_n f}^{hk} + \delta^{S_{a_n f}^{hk}}) & F_{a_n f}^{hk} > F_{a_n p}^{hk} \\ F_{a_n p}^{hk} \Delta AOC_{a_n p}^{hk} & , else \end{cases}$$

The flights of the all-cargo airlines serving airport *h* consists of the transshipment and the originating, and the shipments on a freighter aircraft might be from different legs. The costs of additional payload on an aircraft are hard to estimate and the empirical data is unavailable. So the incremental costs are calculated in proportion to the incremental weights. Letting $C_{b_m f}^{cd}$ denote the costs of shipping the general cargos of leg *cd* for airline b_m, it can be shown as:

$$C_{b_m f}^{cd} = \frac{Q_{b_m f}^{cd}}{Q_{b_m f}^{cd} + \overline{Q}_{b_m f}^{cd}} \Delta F_{b_m}^{cd} [\beta_1^{\overline{\overline{S}}_{b_m f}^{cd}} d^{cd} \overline{\overline{\tau}}_{b_m f}^{cd} \overline{\overline{U}}_{b_m f}^{cd} + \beta_0^{\overline{\overline{S}}_{b_m}^{cd}} + \delta^{\overline{\overline{S}}_{b_m}^{cd}}] \tag{5}$$

$$+ \frac{Q_{b_m f}^{cd}}{Q_{b_m f}^{cd} + \overline{Q}_{b_m f}^{cd} + \hat{Q}_{b_m f}^{cd} \overline{F}_{b_m}^{cd}} \overline{F}_{b_m}^{cd} [\overline{\beta}_1^{\overline{S}_{b_m f}^{cd}} d^{cd} \overline{\tau}_{b_m f}^{cd} \overline{U}_{b_m f}^{cd} + \overline{\beta}_0^{\overline{S}_{b_m}^{cd}} + \overline{\delta}^{\overline{S}_{b_m}^{cd}}]$$

The costs of shipping the general cargos on route *hk* for airline b_m, termed as $C_{b_m f}^{hk}$, are the sum of the costs occurring on the legs through the route and can be shown as:

$$C_{b_m f}^{hk} = \sum_{\forall cd \in R(hk)} C_{b_m f}^{cd} \tag{6}$$

where $R(hk)$ denotes the legs of route *hk*.

2.3 THE AIRLINE MARKET SHARE MODEL

According to the discrete choice model, the probability of the airline chosen by shippers depends on the utility they perceive from the airline's service. The greater the utility, the higher the probability of the airline would be chosen. The choice model can be expressed by the multi-nominal logit model. Letting μ_{ifm}^{hk} denote consigner *m*s' utility to deliver general cargos from airport *h* to airport *k* through airline *i*, it can be written as:

$$\mu_{ifm}^{hk} = V_{iffm}^{hk} + \varepsilon_{ifm}^{hk} \qquad , \forall i \in A, B \tag{7}$$

where V_{ifm}^{hk} and ε_{ifm}^{hk} represents the deterministic and random portion of the μ_{ifm}^{hk} respectively. There is an assumption that ε_{ifm}^{hk} is independently and identically distribution with Gumbel type I distribution. Denote $prob_{if}^{hk}$ as the probability of airline *i* chosen by shippers to ship from airport *h* to airport *k*, it can be shown as:

$$prob_{if}^{hk} = \frac{e^{V_{if}^{hk}}}{\sum e^{V_{if}^{hk}}} \quad ,\forall i \in A,B \tag{8}$$

The variable $prob_{if}^{hk}$ also represents the market share of airline *i* on route *hk*, using the notation as MS_{if}^{hk}. The variable MS_{if}^{hk} is also subject to the following restrictions:

$$0 \le MS_{if}^{hk} \le 1 \quad ,\forall i \in A,B \tag{9}$$

$$\sum_{\forall i \in A,B} MS_{if}^{hk} \le 1 \tag{10}$$

If TQ_{f}^{hk} denotes the total amounts of the general cargo from airport *h* to airport *k*, the amounts carried by airline *i*, denoted Q_{if}^{hk}, can be written as:

$$Q_{if}^{hk} = TQ_{if}^{hk} * MS_{if}^{hk} \tag{11}$$

2.4 THE PROFIT MODEL

Letting π_i denotes the profits of airline *i* from the general cargo service at airport *h*, it can be written as:

$$\pi_i = \sum_{\forall k} [Q_{if}^{hk} p_{if}^{hk} - C_{if}^{hk}] = \sum_{\forall k} [TQ_{if}^{hk} MS_{if}^{hk} p_{if}^{hk} - C_{if}^{hk}(F_{if}^{hk}, S_{if}^{hk})] \tag{12}$$

where p_{if}^{hk} denotes airline *i*'s fare on route *hk*. It is assumed that each airline sets fare by a multiplier $(1+\phi_{if}^{hk})$ based on the fares $\overline{p}_{f}^{hk}$ in the route market, such as the gross rates of the TACT (The Air Cargo Tariff) rules published by the IATA. The variable ϕ_{if}^{hk} is the airline's pricing adjustment factor, which could be set as a positive number, negative number or zero.

According to the above equation, one airline's profits are decided by the sets of the frequencies, aircraft sizes, and fares of the airline's operating routes. Facing the rival airlines in the general cargo market at airport *h*, one airline decides those sets to maximize the profits. Letting χ_i denote the sets of the routes of airline *i*, it could be shown as the function of the set of the variables, that is F_{if}^{h}, S_{if}^{h} and p_{if}^{h}. The maximizing profit objective of airline *i* can be shown as:

$$Max\ \pi_i = \pi_i(\chi_i) = \pi_i(\chi_i(F_{if}^{h}, S_{if}^{h}, p_{if}^{h})) \tag{13}$$

2.5 THE COMPETITIVE MODEL

A non-cooperative theoretical-game is applied to present the competition of the airlines. One of the most important concepts in game theory is the "strategy" of each player, which is different from an "action" in depicting airlines' choices in the models. A player's strategy is a full set of choices of "actions" in every feasible situation in the game. In the study, an airline's strategy is the full set of the choices of each route's flight frequencies, aircraft sizes and airfares. Shipments are allocated among competitive airlines through a market share model, taking shippers into consideration indirectly. Airlines select their best strategies to optimize their own pay-off function, i.e. the profits.

The formulated model is a one-stage simultaneous game. Given strategies and pay-off functions of all airlines in the market are known, every airline decides its strategy at the same time and it is assumed that the others will make optimal choices for their own benefit; i.e. one airline's optimal choice depends on its rivals'. Given the explicit competition, Nash equilibria are sought by calculating the profit matrix of all airlines. The Nash equilibrium could be described as a set of strategies chosen by each player in the game, in which any player have no incentive to change their respective strategies when given the competitors' strategies.

Mathematically, there are multiple optimization goal functions in the game, where airlines' routes flight frequencies, aircraft sizes and airfares are decision variables. It can be written as:

$$\underset{\forall i \in A,B}{Max}\ \pi_i = \pi_i(\chi_i) \tag{14}$$

Subject to

$$\sum_{\forall i \in A,B} Q_{if}^{hk} \le TQ_f^{hk}, \forall k \in K \tag{15}$$

$$f_{if}^{hk}, f_{ip}^{hk} \ge 0 \quad and\ are \text{ integers} \tag{16}$$

$$\Delta F_{if}^{hk} * BT_{if}^{S_{if}^{hk}} \le \eta_{if}^{S_{if}^{hk}} * W_{if}^{S_{if}^{hk}}, \forall i \in A\ and\ k \in K \tag{17}$$

$$\sum_{\forall cd \in R(hk)} F_{if}^{cd} * BT_{if}^{S_{if}^{cd}} \le \eta_{if}^{S_{if}^{hk}} * W_{if}^{S_{if}^{hk}}, \forall i \in B\ and\ k \in K \tag{18}$$

$$0 \le \tau_{if}^{hk} \le 1, \forall i \in A, B\ and\ k \in K \tag{19}$$

$$\sum_{i \forall A} \sum_{k} (f_{if}^{hk} + f_{ip}^{hk}) \le \overline{F}(z_1) \tag{20}$$

$$\sum_{i \forall B} \sum_{k} f_{if}^{hk} \le \overline{F}(z_2) \tag{21}$$

The objective function (14) maximizes the respective profit of each airline, depending on the selected strategies. Constraint (15) restricts the aggregation of all airlines' shipments on specific route market can't exceed the demand on that market. Constraint (16) specifies the flight frequency variables are non-negative integers. Constraint (17) and (18) restricts the utilization of aircraft on any route for the combination and all-cargo airlines should not exceed the capability of the fleets. Constraint (19) specifies the load factors are between 1 and 0. Constraint (20) and (21) restricts total aircraft movements to the allowed maximums of airport *h*'s aircraft movement capacity for different time periods, where $\overline{F}(z)$ denotes the allowed maximums of aircraft movements during the specific time *z*.

The solution of the above is non-linear mathematical programming model might be sought through some well-known methods such as the conjugate-gradient projection algorithm, the ε-constraint method, the global criterion method, the minimum deviation method and the multi-objective Simplex method, etc. However, the optimization might be not available. Sufficient conditions for the existence of a Nash equilibrium is that strategies set of each player should be bounded, convex and close, each payer's own pay-off functions be concave in its own strategy sets and continuous. Nevertheless, each player's payoff function is not continuous and concave in its own strategy sets. So the existence of Nash equilibrium in the game might be not necessary.

3. MODEL APPLICATION

3.1 CASE DESCRIPTION

In airlines' business, every market has some specific features and it is hard to fully capture the reality of any one especially with the constraints of lacking of airlines' commercial data, such as real aircraft fleets operation and maintenance plans. A hypothetical and simplified, yet typically, duopoly market is used as an example. Even so, empirical aircraft operating cost data and the airline market share model from the literature is used and stated later. The following is the case description:

(1) There are two route markets at airport *h*: a short-haul one hk_1 and a long-haul one hk_2. Two routes' distance and cargo demands are showed as Table 1. In two markets, there are two airlines: the combination airline *a* basing at airport *h* and the all-cargo one *b* selecting airport *h* as its regional hub.

(2) Airline *a*'s passenger flight frequency is 20 times weekly. After carrying baggage and other prior goods, aircraft available space to cargo empirically varies with the flight distance and the aircraft type. According to the airlines' empirical estimation, the average maximal available load factor of an aircraft for short-distance flight is 40%, and that for long-distance flight is 30%. Given the optimal utilization, assume the operator will take it as his average load factor for each aircraft type.

(3) The transfer flights of airline *b* on two routes are both 5 times per week by MD-11F, virtually adopted by airlines such as FedEx Express and Lufthansa Cargo. For the volumes of legs or routes for airlines are confidential and unobtainable with efforts, it is assumed that the general cargos are the only shipments at airport *h* and the average aircraft load factors on both routes increase from 50% to 60% after airport *h*.

(4) The airlines' available aircraft types are shown as Table 2. There are two airport *h*'s operation time periods: z_1 and z_2. Both passenger and dedicated freight flights of airline *a* land and take-off during time z_1, which is the interval 06:00 a.m. ~09:00 p.m., while airline *b*'s flights flied during time z_2. The allowed hourly aircraft movements for all-cargo flights are 3 per hour during time z_1 and 5 per hour during time z_2.

(5) Based on the empirical data provided by the Airfreight Forwarder's Association of the Taipei City of the ROC, the average air fare for route hk_1 and hk_2 are estimated as 1.23 and 4.02 US dollars per kilogram.

Table 1 Two markets' flight distance, cargo demand and passenger flights

Route	Flight distance(kilometer)		General cargo demand (ton/week)
	Airline *a*	Airline *b*	
Route hk_1	2,000	2,000	800
Route hk_2	6,000	6,000	800

Notes: Assume two airlines flights on route hk_1 and hk_2 are both non-stop flights.

Table 2 Airlines' available aircraft type and operating features

Aircraft type	Airline	Study payload (ton)	Fleet size (aircraft)		Scheduled block time (hr)		Maximum aircraft utilization (hr/week)	
			hk_1	hk_2	hk_1	hk_2	hk_1	hk_2
B747-400	A	14	-	-	-	-		
B747-400F	A	112.68	1	1	3	9:50	70	70
MD-11F	B	91.56	1	1	3	9:50	70	70

B767-300ERF	B	54.89	1	1	3:10	10	70	70
B757-200F	B	39.65	1	1	3:10	10	70	70

Notes: Each aircrafts maximum payload is assumed to each aircrafts maximum structural payload. The fleet size and maximum aircraft utilization is set according to the airline empirical operation. Flying times per flight of each aircraft are estimated from the relative airlines' time tables.

3.2 ESTIMATION OF COST PARAMETER

As discussed above, airline operating costs include aircraft operating costs and airport user charges. Airport user charges of Taoyuan-Hong Kong flight was taken to estimate two routes' parameters as shown in Table 3.

Table 3 Airport user charges for each aircraft type

Aircraft type	B747-400	B747-400F	MD-11F	B767-300ERF	B757-200F
Charges ($)	7,068.00	7,068.00	5,063.96	3,394.27	2,172.02

Regarded as confidential data by all airlines, the freighter aircraft operating cost data directly from the carriers is few in the literature. Even so, data on the aircraft operating costs is partly unveiled to analyze from two useful sources. First, in the SIKA's *The identification of air freight operating cost parameters for use in the SIKA SAMGODS freight model by Swedish Institute for Transport and Communication Analysis* (2002), some information about 2002's freighter aircrafts operating costs are used. Second, in the NASA Ames Research Center's *An economic model of U.S. airline operating expenses* (2005), aircraft operating costs based on 1999's American air industry business accounting data were calculated. SIKA's report is adopted as the primary source because it provides common freighter aircrafts' operating cost data and is convenient to adjust, but supplemented by the NASA's data when appropriate and necessary. According to the SIKA, the percentage distribution of costs on route of nominal length 2000 km and 6000 km are shown as Table 4.

Table 4 Percentage distribution of costs on route of nominal length 2000 km and 6000 km

	Airline operating cost items	B747-400F		MD-11F		B767-300 ERF		B757-200F	
		2000	6000	2000	6000	2000	6000	2000	6000
Variable DOCs	Flight crew, fuel, and other flight operation	15.40 %	18.90 %	15.20 %	18.30 %	15.60 %	18.40 %	16.40 %	18.70 %
Fixed DOCs	Airport & en route, maintenance overhaul, depreciation and amortization	37.60 %	36.40 %	38.20 %	37.20 %	43.80 %	43.50 %	50.00 %	49.90 %
IOCs	Station and ground, payload	47.00 %	44.70 %	46.60 %	44.50 %	40.60 %	38.10 %	33.60 %	31.40 %

	service, ticketing, general and administratio n, and other operating costs								
Total annual operating costs		100%	100%	100%	100%	100%	100%	100%	100%

Notes: The classification of operating cost item is based on section 2.2.

The percentages of airline operating costs, which fuel cost accounts for before and after adjustment of fuel and oil base price, are shown as Table 5. After calculations, aircrafts operating cost parameters β_0 and β_1 for each aircraft type are showed in Table 6.

Table 5 Percentage of fuel cost accounts for airline operating costs

	Before adjustment (2002)		After adjustment	
	2000 km	6000 km	2000 km	6000 km
B747-400F	11.7%	15.1%	32.3%	39.03%
MD-11F	11.1%	14.2%	31.01%	37.34%
B767-300 ERF	11.2%	13.2%	29.47%	37.34%
B757-200F	10.6%	12.5%	29.02%	33.06%

Notes: According to the IATA (2008), the percentage of operating expenses which fuel costs account for global commercial aviation industry in 2003 is 14% and 30% in 2008.

Table 6 Estimated aircrafts operating cost parameters β_0 and β_1 for each aircraft type

	β_0 ($ per unit tonne per flight)		β_1 ($ per unit tonne-km per flight)	
	Route hk_1	Route hk_2	Route hk_1	Route hk_2
B747-400F	15,640	34,737	0.1516	0.0458
MD-11F	12,256	27,449	0.1491	0.0455
B767-300 ERF	10,537	24,032	0.1669	0.0565
B757-200F	9711	22,648	0.2143	0.0715

As the passenger aircraft carries passengers and cargos concurrently, the incremental aircraft operating costs are hard to separate accurately by accounting methods. In practice, the extra shipments directly bring in the increase of fuel usage, not flight crew and maintenance. For the fuel expense is a large proportion of the aircraft operating costs, the extra expense of fuel consumption is regarded as the incremental aircraft operating costs in the study. According to NASA, the estimated incremental aircraft operating costs for B747-400 on two routes are 0.052 and 0.048 US dollars per unit weight-distance per flight.

3.3 THE CHOICE MODEL OF GENERAL CARGO SHIPPERS

The choice model for air cargo service companies developed by Hsu et al. (2005) was directly applied here. They investigated the firms' shipping demand in Hsinchu Science Park in Taiwan for air cargo service and conducted a well-designed questionnaire survey to identify the important factors for selecting the shipper. Based on the returned questionnaires, a logit model is calibrated to describe the firms' choice behavior of the air cargo shippers. The specification of the utility function calibrated in that study is as following:

$$V = \alpha_0 + \alpha_1 C + \alpha_2 T + \alpha_3 N + \alpha_4 X \tag{22}$$

Where C denotes shipping charge, T denotes shipping time, N denotes the flight frequency, X denotes the door to door service, and α_0 is the alternative specific constant for delivering by the foreign air cargo service company. The estimated parameters were listed in Table 7. In this case study, the door-to-door services for two types of airlines are assumed to be indifferent for the shipments considered here are airport-to-airport. The alternative specific constant was not used in this case study.

Table 7 Estimated parameters of utility function

Parameter	Estimated value	Standard Error
α_1	-0.1759	0.1615
α_2	-0.0403	0.0179
α_3	0.001	0.2913
α_4	1.2355	0.3429

3.4 EQUILIBRIUM ANALYSIS

The game consists of two airlines' choices of two routes' frequency, aircraft type and air fare. The available choices of two airlines' aircrafts are countable and limited. It is assumed that each airline could provide the maximum flight frequency on a route is the capability to individually ship all demand of the route market alone, and the adjustment unit of the variable ϕ_{if}^{hk} was set as 1% to raise or lower the fare.

Table 8 Airlines' strategies from the Nash Equilibrium in the case study

	Route hk_1		Route hk_2	
	Airline *a*	Airline *b*	Airline *a*	Airline *b*
Selected all-cargo aircraft type	B747-400F	MD-11F	B747-400F	MD-11F
Air freight frequency (weekly)	24	8	25	8
Base price adjustment factor (%)	0	0	0	0
Market share	68.60%	31.40%	68.75%	31.25%
Profit ($, week)	468,450	186,369	1,915,597	1,140,992

The conditions of the existence of a unique Nash equilibrium have been proved by Gabay and Moulin (1980), but the procedure of the proof is complicated and lengthy. The optimization result of the model is found by using the Mathematica V5.2 for Windows (2005) package and there is a unique Nash equilibrium solution. The outcomes for all strategies sets are too huge to display here. Under the Nash equilibrium condition, airline *a* ships by passenger and freight aircrafts with 24 flights on route hk_1 and adopt the base air fare rate; airline *b* flies 8 flights by MD-11F, including transit and extra flights on route hk_1 and adopt the base air fare rate. Except for airline *a*'s 25 flight times, the actions of both airlines on the long-distance route hk_2 are the same as those on the route hk_1. Results of airlines operation from the Nash Equilibrium are listed in Table 8.

According to the results, airline *a* has dominance in the two markets to increase aircraft capability and frequencies for more shipments. Airline *b* seems to be in an inferior position. The fare rates set by both airlines are equal because of the high parameter value of shipping

charges. In fact, the combination carriers might set lower fare rate because they have advantage on operating costs. It will be downside to all-cargo carriers when competitors set lower charges.

3.5 SENSITIVITY ANALYSIS

After the equilibrium solutions was found in the case study, a sensitivity analysis was conducted to explore how results might change with some change of the given or assumed conditions. Listed in Table 9 are the results for scenarios of different demand levels on route hk_1: the first scenario is low demand level and the last is high demand. Table 9 indicates that at all demand level, the combination carrier *a* owns higher market share and keeps increasing its freight frequency and shipping capability. However, the carrier *b* can't offer more besides transit flights to avoid a deficit when the demand level is low. As the demand level is high, carrier *b* increases freight frequency to get more profits and higher market share.

Table 9 Sensitivity of route hk_1 freight demand to airlines' operations

Air freight demand (ton weekly)	Increased flight frequency (weekly)		Market share		Profit ($, week)	
	Airline *a*	Airline *b*	Airline *a*	Airline *b*	Airline *a*	Airline *b*
50	0	0	73.23%	26.77%	58,134	-116,738
200	1	1	71.13%	28.87%	138,783	30,805
350	2	1	71.30%	28.70%	221,044	72,806
500	3	2	69.76%	30.24%	295,458	105,375
650	4	2	69.91%	30.09%	376,087	149,017
800	4	3	68.60%	31.40%	468,450	186,369
950	5	3	68.75%	31.25%	547,752	231,344
1,100	6	4	67.84%	32.16%	616,194	269,916

Graph in figure 2, 3, 4 and 5 respectively depict the ratio of two airlines' market share and both airlines' profit for route hk_1 when airline *a*'s passenger frequency or airline *b*'s transit frequency varies assuming all other conditions remain unchanged. It is shown that the increase of airline *a*'s passenger frequency or airline *b*'s transit frequency results in the increase of the carrier himself own market share and profit. Therefore the larger the operation scale, the greater the advantage for the airline itself in the general cargo service market.

It is worth to observe that how the equilibrium result would be, under the condition that airline *a* operates no passenger flight. The result is airline *a* possesses a little higher market share. The availability of flight time slots plays a critical role in the competition. Although the nighttime flight is convenient for the delivery of export products, the distribution of the combination carriers' flight times are various and helpful to save shipping time and expense. All-cargo carriers could expand their operation via better service in the markets, especially where combination airlines provide insufficient shipping capability for air cargo service.

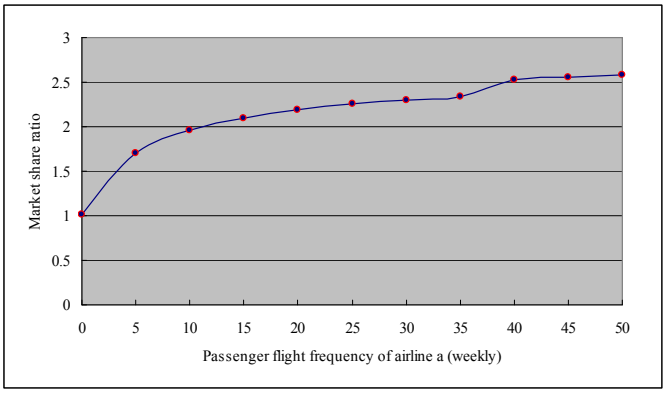

Figure 2 Effects of flight frequency of airline *a* on market share ratio

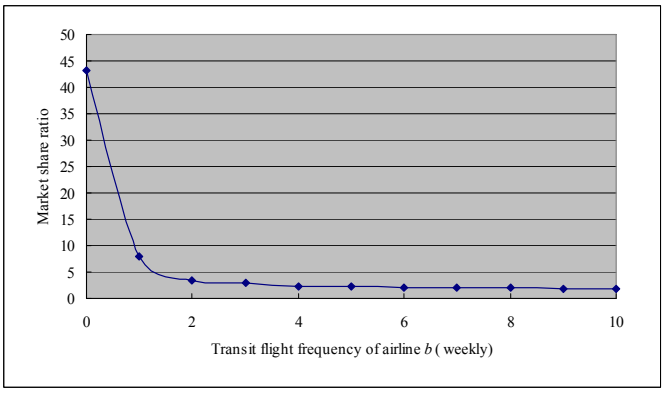

Figure 3 Effects of flight frequency of airline *b* on market share ratio

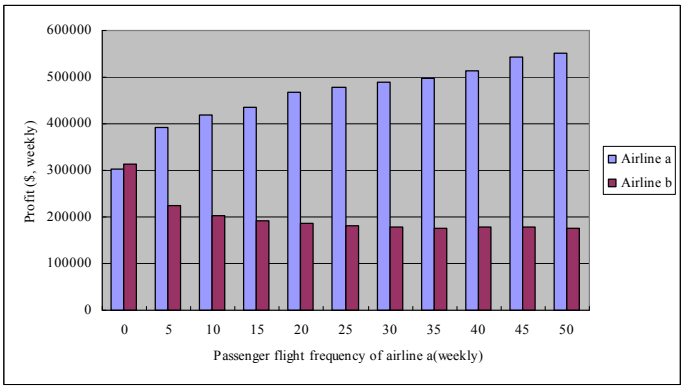

Figure 4 Effects of flight frequency of airline *a* on profit for route hk_1

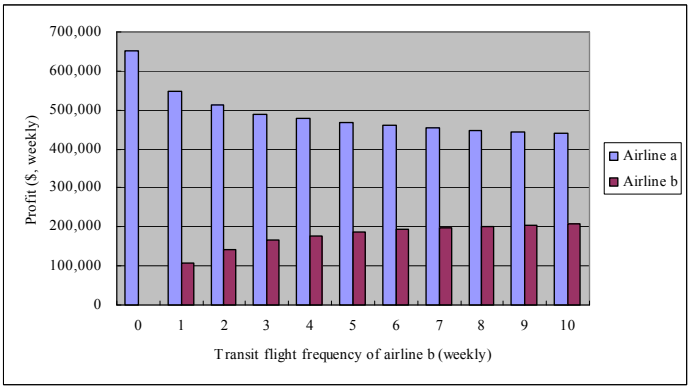

Figure 5 Effects of flight frequency of airline *b* on profit for route hk_1

Listed in Table 10 are the results with the existence of two similar combination airlines, both possessing the same operation condition as those of airline *a*, and an all-cargo airline on route hk_1. It is shown that the profit and market share of each airline in the market becomes lower than only one combination airline in the market. However, the aggregate performance of combination airlines is greater and the all-cargo becomes worse. It happens in many international air cargo markets with several passenger airlines. For example, there are China airline and Eva airline in Taiwan's international general cargo market, which have significant dominance over the general cargo service, and the other all-cargo carriers have few market shares.

Table 10 Airlines operation strategies on route hk_1 from the Nash Equilibrium in the case study with two homogeneous combination airlines and one all-cargo airline

	Airline a_1	Airline a_2	Airline *b*
Selected all-cargo aircraft type	B747-400F	B747-400F	MD-11F
Air freight frequency (weekly)	22	22	6
Base price adjustment factor (%)	0	0	0
Market share	41.62%	41.62%	16.76%
Profit ($, week)	302,675	302,675	105,834

4. CONCLUSIONS

This study explores the competition between the combination and all-cargo airlines in the deregulated aviation markets, and analyzes how the difference of operation features for two kinds of carriers affects competition in general cargo service. Each airline in the airport-pair markets can decide their best strategy, including aircraft patterns, freight frequencies and airfare, by the non-cooperative, multi-player game theory model as formulated in this study.

The result of the case study reveals that the competition of airlines for general air cargo service are affected by the demand level of the market, the scale of joint production and the amount of combination airlines in the market. The demand level of the market has obvious impact on the operation of the all-cargo airline; high demand level contributes that the carriers provide more frequencies and shipping capability and, otherwise, they sustain the service by their transit freight flights as the demand level is low. The combination airlines mostly have significant dominance over the market and expand their freight aircraft fleets for competition to operate more flights. It will be downside to all-cargo carriers' market share when competitors lower their charges. It was found that all-cargo airlines become harder to compete in the market with more combination carriers. This study suggests that all-cargo carriers could expand their operation via better service in the markets, especially where combination airlines provide insufficient shipping capability for air cargo service.

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