



Analyzing competition of international air cargo carriers in the Asian general air cargo markets

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ABSTRACT

This paper presents a model structure to analyze the competitive strategies available to air cargo carriers in the Asian markets, in which all-cargo airlines and combination airlines offer service. Through a two-stage, Nash best-response game, equilibria in the air transportation industry are searched to evaluate individual airline's profit. First, airlines choose whether or not to enter a market and second, they attempt to optimize profits through choice of service frequencies, aircraft sizes and airfreight rate, given the decisions of others. Taipei-Hong Kong and Taipei-Los Angeles route markets are selected as the empirical cases of model application. The examples indicate that combination airlines have competitive advantages in the markets and the equilibria in the markets may change due to the changes of air cargo demand in the market, air passenger travel demand, the operation scale of all-cargo carriers and the availability of time slots at the airports for all-cargo operators.

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1. Introduction

With increasing globalization, the transport of cargo by air has become increasingly important. Asian market in particular is driving air cargo demand more than any other, especially China. Some researchers (Zhang and Zhang, 2002; Bowen, 2004; Senguttuvan, 2006) studied the growth of the Asian air cargo industry and compared the different patterns of air cargo development between Asia and the US. They pointed out that a large number of air cargo carriers from the US and other nations are competing fiercely in the Asian air cargo market, where profitability is assured for only the strongest carriers.

Combination and all-cargo airlines are the two main types of international general air cargo service providers. In Asia, air cargo has been for the most part carried in the belly compartments of passenger aircraft, which are typically wide-bodied, and passenger airlines compete keenly for general air cargo business. As such, the development of passenger route networks is closely linked with that of cargo business. The flag or domestic airlines may have more and better slots, but it is most likely that they have had these slots for years, and have continued to utilize these slots. In addition to the establishment of partnerships with the airport authorities/companies, these flag or domestic airlines have priorities over the utilization of the airport's infrastructure facilities (Albers et al., 2005). All-cargo airlines, such as all-freight

carriers and integrated carriers, ship general cargo and express/time-definite cargo by freighter aircraft, expanding their networks in Asia during the 1990s, serving principally the major hubs in the region. However, while shortages of available slots at international airports in Asia force integrated carriers to use adjacent secondary airports as their hubs or principal base airports, airport curfews further restrict carriers to operating during off-peak hours at some airports. To continue to earn substantial share of revenue from shipping general air cargo, combination airlines would have a keen, competitive interest in competing head-on with all cargo carriers. It should be interesting to investigate the potential equilibria in the Asian air cargo industry and how airlines develop their strategies.

Numerous studies have attempted to address airline competition and airline strategies in an air transportation market, but most of these papers focused on the air passenger market. See, for example, Hansen (1990), Alder (2001), Martín and Román (2003), and Wei and Hansen (2007). In few published papers about air cargo market (Zhang and Zhang, 2002; Zhang et al., 2007; Hsu et al., 2009; Hwang and Shiao, 2010), they mostly assume that all air cargo carriers are homogeneous with similar operation characteristics. They lack discussion of how different operational features of carriers affect their competitive position in the Asian air cargo industry.

To fill the gap, this study proposes a mathematical programming model within a game theoretical framework to evaluate the optimal strategies for an airline in the Asian air cargo market in which both combination and all-cargo airlines exist. A two-stage, Nash best-response game proposed here consists of a set of

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airlines whose strategy sets include the decision of entering an air cargo market, frequency of service, aircraft size, and airfreight rates. Through this game model, equilibria in an international air cargo transportation market and the most profitable strategies for all airlines in the market can be searched. The developed model is then applied to two important route markets: one intra-regional route, TPE-HKG, and one inter-regional route, TPE-LAX. Sensitivity analyses are also conducted to examine how various market conditions affect the equilibrium of the market.

2. Model formulation

2.1. Glossary

I	set of potential carrier i offering international air cargo service between airport-pair $hk(I \subset A \cup B)$
A	set of potential combination carrier offering international air cargo service between airport-pair $hk(a_1, a_2, \dots, a_n \subset A)$
B	set of potential all-cargo carrier offering international air cargo service between airport-pair $hk(b_1, b_2, \dots, b_m \subset B)$
cd	a leg on route hk for airline b_m
R_{b_m}	legs on route hk for airline b_m
F_i	total cargo flight frequencies offered by airline i on route hk
Q_i	airline i 's shipments on route hk
S_i	freight aircraft size using by airline i on route hk
SF_i	freight aircraft sizes in the fleet sizes of airline i
$\tau(S_i)$	planning load factor of aircraft S_i on route hk
$U(S_i)$	study payload of aircraft S_i on route hk
$F_{a_n p}$	passenger flight frequency offered by airline a_n on route hk
ΔF_{a_n}	dedicated freight flight frequency offered by airline a_n on route hk
TQ	total general cargo demand from airport h to airport k
$\Delta F_{b_m}^{cd}$	originating flight frequency from airport c of airline b_m on leg cd
$\bar{F}_{b_m}^{cd}$	transshipment flight frequency of airline b_m on leg cd
$\bar{F}_i(z_i)$	the allowed maximums of aircraft movements during the specific time z_i for airline i
z_i	allowed time periods for airline i 's departure and arrival at airport h
$\bar{S}_{b_m}^{cd}$	dedicated aircraft size adopted by airline b_m for flights $\bar{F}_{b_m}^{cd}$ on leg cd
$\bar{S}_{b_m}^{cd}$	aircraft size adopted by airline b_m for flights $\Delta F_{b_m}^{cd}$ on leg cd
$Q_{b_m}^{cd}$	amounts of general cargos from airport c to airport d shipped by airline b_m on leg cd
$\bar{Q}_{b_m}^{cd}$	amounts of other cargos shipped by airline b_m on leg cd
$\hat{Q}_{b_m}^{cd}$	average shipment volume of transshipment flights for airline b_m on leg cd before carrying $Q_{b_m}^{cd}$
AOC_i^{dcd}	variable elements of direct aircraft operating costs of airline i on leg cd
$AOC_i^{id,cd}$	fixed elements of direct aircraft operating costs of airline i on leg cd
β_1^S	average distance-dependent direct operating costs of aircraft S on leg cd (cost per ton per unit of distance per flight)
β_0^S	average distance-independent direct operating costs of aircraft S on leg cd (cost per ton per flight)
d^{cd}	flight distance of leg cd
p_i	freight rate of airline i on route hk
\bar{p}	upper bound of freight rates on route hk
π_i	profit of shipping the general cargos of route hk for airline i
TC_i	cost of shipping the general cargos of route hk for airline i
$C_{b_m}^{cd}$	total operating costs (excluding indirect operating costs) of carrying general cargo from airport c to airport d for airline b_m

δ^{shk}	landing related charge per aircraft S on route hk
α_i	ratio of the indirect operating costs to the direct operating costs for airline i on route hk
$\Delta AOC_{a_n p}$	extra aircraft operating costs of carrying cargos on passenger aircraft on route hk per flight for airline a_n
MS_i	market share of airline i over O-D shipment (h, k) for air cargo shipments

The analysis is based on the following assumptions:

- (i) There are airlines I in the market offering scheduled cargo flights between airport h and airport k , including combination carriers A and all-cargo carriers B . Assume the daily operation time of airport h can be explicitly 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.
- (ii) Airport h or k is the hub or principal base airport of the combination airlines A , offering air cargo services on route hk .
- (iii) All-cargo airlines operate on a hub-and-spoke (HS) network. All hubs chosen by an airline are reasonably assumed to be directly interconnected, and all spoke airports only directly connect to a regional hub. Therefore, the number of legs on a route depends on the location of the two end airports.
- (iv) The balanced flights in two directions of a scheduled route are assumed to be offered based on the projections for route shipping demand. Since the payload is concerned with air cargo revenue and costs, for carrier i , it applies an average load factors to the maximum payload that could be achieved by an aircraft. The application of these assumptions allows a 'study payload' for each aircraft to be calculated.

2.2. The function of flight frequency

Because the use of belly space in passenger aircraft is regarded as virtually costless, combination carriers would first consider ship cargo by passenger planes and then dedicated freighters if the demand of shipment exceeds the capability of passenger aircraft. The frequency of freight flights of airline a_n on route hk can be shown as:

$$F_{a_n p} \tau(S_{a_n p}) U(S_{a_n p}) + \Delta F_{a_n} \tau(S_{a_n}) U(S_{a_n}) \geq Q_{a_n} \quad (1a)$$

Given leg cd on path hk for airline b_m , flights on leg cd might include originating flights from airport c and transshipment flights with shipments of transshipped cargo, O-D cargo from airport c to airport d , and others (such as cargo from airport c to other destination airports). It is assumed that the airline flies originating flights when the shipping demand exceeds the capability of transfer flights. The frequency of flights offered by airline b_m on leg cd can be shown as:

$$\bar{F}_{b_m f}^{cd} \tau(\bar{S}_{b_m f}^{cd}) U(\bar{S}_{b_m f}^{cd}) + \Delta F_{b_m f}^{cd} \tau(\bar{S}_{b_m f}^{cd}) U(\bar{S}_{b_m f}^{cd}) \geq Q_{b_m f}^{cd} + \bar{Q}_{b_m f}^{cd} + Q_{b_m f}^{cd} \bar{F}_{b_m f}^{cd} \quad (1b)$$

All-cargo airlines usually operate at a transshipment airport with concentration of arriving and departing flights and finish the pickup and delivery work synchronically at the transshipment airport within quite limited hours (Rodrique, 1998). The flight frequency offering by carrier b_m on route hk is reasonably assumed as the minimal frequency of the legs on this path, and it can be written as:

$$F_{b_m} = \min_{vcd \in R_{b_m}} F_{b_m}^{cd} \quad (1c)$$

In practice, movements of passenger flight mostly locate at the peak load hours due to passenger preference and all-cargo flights in off-peak times at many international airports. Moreover, this is typical of congested airports where airlines have chosen their flight times first on account of grandfathering rights and newcomers, such as all-cargo carriers, are restricted to operate in the remaining

slots. Some studies (Salvanes et al., 2005; Barbot, 2005) explored the effects of departure-time differentiation on the competition in the airline industry. Although cargo might be less sensitive to flight departure time than passengers, inconvenience and longer waiting time due to flights at the off-peak time is crucial for a firm or individual to affect consignors or forwarders to choose carriers (Hsu et al., 2005). Given that operation times of airport h is simply divided into two periods, we assume that the peak time period (z_A) is allocated to the flights of combination airlines and the flights of all-cargo operators supply in the off-peak time period (z_B). Different departure time of flights means different waiting time for the shipments to get on a flight to the destination airport.

2.3. The cost function

An airline's operating costs (AOC) are usually classified into two groups: direct operating costs (DOCs) and indirect operating costs (Holloway, 2003). DOCs are costs and expenses arising from aircraft operating, including fuel expense, flight crew expense, airport user charges, maintenance expense, depreciation and amortization expense. Those largely depend on the types of aircraft and aircraft operation and might be classified into fixed and variable ones. The former is independent of flight distance and the latter varies with distance. Distance-dependent direct operating costs of an aircraft comprise fuel, en-route user charges and hourly maintenance. The fixed aircraft operating costs in this study are all the remainder of the DOCs. 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. Airport user charges are dependent on the frequencies of flight departures and the types of aircraft and could be estimated independently.

Indirect operating costs (IOC) are independent of aircraft fleets and utilizations including sales expenses, station and ground expenses and general and administrative overhead. Restricted by the data availability, the IOCs are estimated through a ratio of the IOCs to the DOCs in this study.

To analyze the profitability, this study focuses on cost items, including aircraft operating costs (comprising fixed and variable components), airport user charges and indirect operating costs. The aircraft operating costs Both kinds of airlines ship cargos between airport h and k jointly with passengers and/or transshipment goods. The costs will be calculated based on the proportion of the weights of shipments.

For combination airlines, the aircraft operating costs of carrying cargo include the extra costs of carrying cargos on passenger aircraft and the operating costs of all-cargo aircraft. The costs of shipping the general cargos of route hk for airline a_n can be formulated as

$$TC_{a_n} = \begin{cases} (1 + \alpha_{a_n})[F_{a_n p} \Delta AOC_{a_n p} + \Delta F_{a_n} (\beta_1^{S_{a_n}} d^{hk} \tau(S_{a_n}) U(S_{a_n}) + \beta_0^{S_{a_n}} + \delta^{S_{a_n}})] & F_{a_n} > F_{a_n p} \\ (1 + \alpha_{a_n}) F_{a_n p} \Delta AOC_{a_n p}, & \text{else} \end{cases} \quad (2a)$$

Total direct operating costs of carrying general cargo from between airport-pair cd for an all-cargo airline include the costs of carrying those cargo on the aircraft of the transshipment and originating flights (if required) on the basis of proportion of cargo weights. That can be formulated as

$$C_{b_m}^{cd} = \frac{Q_{b_m}^{cd}}{Q_{b_m}^{cd} + \bar{Q}_{b_m}^{cd}} \Delta F_{b_m}^{cd} \left[\beta_1^{\bar{S}_{b_m}^{cd}} d^{cd} \tau(\bar{S}_{b_m}^{cd}) U(\bar{S}_{b_m}^{cd}) + \beta_0^{\bar{S}_{b_m}^{cd}} + \delta^{\bar{S}_{b_m}^{cd}} \right] + \frac{Q_{b_m}^{cd}}{Q_{b_m}^{cd} + \bar{Q}_{b_m}^{cd} + \hat{Q}_{b_m}^{cd} F_{b_m}^{cd}} \bar{F}_{b_m}^{cd} \left[\beta_1^{S_{b_m}^{cd}} d^{cd} \tau(S_{b_m}^{cd}) U(S_{b_m}^{cd}) + \beta_0^{S_{b_m}^{cd}} + \delta^{S_{b_m}^{cd}} \right] \quad (2b)$$

The costs of shipping general cargos on route hk for airline b_m can be formulated as:

$$TC_{b_m} = (1 + \alpha_{b_m}) \sum_{\forall cd \in R_{b_m}} C_{b_m}^{cd} \quad (2c)$$

2.4. Airline market share model

According to the discrete choice model, the probability of an airline chosen by freight forwarders, consolidators, and 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 probability of an airline chosen represents the market share of that airline in the route market. The amount shipped by airline i on route hk as shown in Eqs. (3a) and (3b), was formulated based on a Multi-nominal logit choice model derived by Ben-Akiva and Lerman (1985).

$$Q_i = TQ \times MS_i \quad (3a)$$

$$MS_i = prob_i = \frac{e^{V_i}}{\sum e^{V_i}}, \quad \forall i \in I \quad (3b)$$

The utility V_i was plausibly formulated as function of total time for cargo delivery service, flight frequency and airfreight cost.

2.5. The game-theoretic model of airline competition

The competitive model can now be defined as a multi-airline, non-cooperative, two-stage game. A game consists of a set of players, a set of strategies available to those players, and a specified payoff for each combination of strategies. Each player uses a set of alternative actions or strategies to maximize his payoff function, whose value relies on simultaneous actions of all players. The game in this paper consists of a set I of airlines whose strategy sets include the frequency of service, aircraft size, and freight rates. In the first stage, airlines simultaneously decide whether or not to enter the market. In the second stage, each airline attempts to optimize their own pay-off function, i.e. the profits, through its choice of service frequency, aircraft sizes, and freight rates, given the decisions of all other airlines.

A mathematical programming model is developed herein. The decision variables of the model include freight rate per airline, aircraft size per airline, and service frequency per airline. The profit function is based on an airline's revenue and cost functions. The revenue function computes earnings based on freight rates, maximal demand, and the airline's market share, which is based on the consignor's utility function. The cost function takes account of the airline operating costs occurring from shipments and calculates on the basis of the characteristics of airline operation and the airline's market share. Empirically airlines set their fare based on the freight rate in the route market, such as the route specific line-haul rates published by the IATA, within a feasible range. It is assumed that each airline sets its freight rate between an upper bound of the freight rate, which might be under price regulation or a given natural cap, and 0.

The following model computes airlines' payoffs in the second stage

$$\text{Max}_{\forall i \in I} \pi_i = TQ \times MS_i \times p_i - TC_i \quad (4a)$$

Subject to

$$\sum_{\forall i \in I} Q_i \leq TQ \quad (4b)$$

$$0 \leq f_i \leq F_i(z_i), \text{ and are integers, } \forall i \in I \quad (4c)$$

$$0 \leq p_i \leq \bar{p}, \quad \forall i \in I \quad (4d)$$

$$S_i \in SF_i, \quad \forall i \in I \quad (4e)$$

The objective is to maximize the respective profit of each airline, depending on the selected strategies. Eq. (4b) states the aggregation of all airlines' shipments on a specific route market cannot exceed the demand on that market. Eq. (4c) ensures that frequencies are integers, which are between 0 and an upper bound of allowed maximal aircraft movements for different time periods available for airline i . Eq. (4d) states that freight rates are set between 0 and an upper bound of freight rates on the market. Eq. (4e) specifies that each airline chooses its aircraft size from his fleet types.

The non-linear payoff function (4a) can be solved easily using standardized conjugate gradient methods. The model solves the objective function per airline, given all other airlines' initially hypothesized strategies, using a relevant method for nonlinear objective functions and linear constraints. While the strategy set of each player is bounded, convex, and closed, the uniqueness or existence of the equilibrium of the entire game is not guaranteed because the profit function is not concave with respect to the strategy variables (aircraft size). Once the equilibria of all the subgames have been evaluated, the existence of a subgame perfect equilibrium of the overall game can be analyzed.

3. Model application

3.1. The empirical data of cases

Two independent air route markets are selected as cases of model application in this study: a short haul market (Taipei-Hong Kong, TPE-HKG) and a long haul market (Taipei-Los Angeles, TPE-LAX). The carriers on TPE-HKG are China Airline (CI), Eva Airways (BR), Cathay Pacific Airways (CX), Dragon Air (KA) and FedEx (FX), in which FX is an all-cargo carrier and others are all combination carriers. CI, BR and FX are also the carriers on route TPE-LAX. For FX, Taiwan Taoyuan International Airport is one of the regional hubs in its global hub and spoke network. The adopted demands

on the two airport pairs are based on the numerical values published by the Taiwan Civil Aeronautics Administration, which were the aggregate of the overall shipments, including any shipments that go through an intermediate point on route, by all air cargo carriers in the markets of TPE-HKG and TPE-LAX. And in terms of weekly demands, the corresponding values in year 2004 were 1,296,346 kg and 397,309 kg. However, some carriers shipping insignificant amounts of cargo in the markets, such as the US passenger carriers in the TPE-LAX market, are excluded in the model application. Table 1 lists the base service parameters of these carriers. The daily time interval allowed for the aircraft arrival and departure of FX is from 09:00 p.m. to 06:00 a.m. of next day. The allowed hourly aircraft movements for CI, BR, CX and KA are assumed to be respectively 50 flights during time z_A and 20 flights for FX during time z_B .

The input data of parameters of cost items are derived from three published sources. Airport user charges are taken from International Air Transport Association's Airport and Air Navigation Charges Manual (IATA, 2008). Aircraft operating costs are derived from the Swedish Institute for Transport and Communication Analysis (2002) and Harris (2005). The details can be found in Hwang and Shiao (2010). The ratio of the IOCs to the DOCs is assumed to be 1, which empirically ranges from 0.667 to 1.22 (Holloway, 2003). Estimated aircraft operating cost parameters for each aircraft type are shown in Table 2.

Based on the data published by the Taiwan Civil Aeronautics Administration, the average weight load factors of dedicated freighters and wide-body aircraft of Taiwan's two main carriers (CI and BR) is about 71.4% in the year 2007. It is therefore assumed an average load factor of 70% by weight. Similarly, the average space on a passenger aircraft available for general cargo in a short-distance flight is set as 30% to the maximum payload and that in a long-distance flight is 20% based on passenger operators' estimation. Besides, the average spaces on FX's freighter for transshipment flight on both routes are set as 20% to the maximum payload. In other words, 20% of the capacity for transfer flights on a hub-and-spoke

Table 1

The base service parameters of carriers.

Source: The websites of Taiwan Taoyuan International Airport and airlines.

Carrier	Route distance	Passenger flight frequency (flight/week)	Passenger aircraft type	Transshipment flight frequency (flight/week)	Available freighters
TPE-HKG					
CI	932	224	B747-400	–	–
BR	932	98	B747-400 Combi	–	B747-400 F, MD11 F
CX	932	216	B747-400	–	B747-400F
KA	932	110	A330-300	–	B747-400F
FX	932	–	–	11	MD11F
TPE-LAX					
CI	10,942	28	B747-400	–	B747-400 F
BR	10,942	28	B747-400	–	B747-400F, MD11 F
FX	11,308	–	–	33	MD11F

Table 2

Estimated aircrafts operating cost parameters for each aircraft type.

	δ (\$ per flight)		β_0 (\$ per unit tonne per flight)		β_1 (\$ per unit tonne-km per flight)	
	TPE-HKG	TPE-LAX	TPE-HKG	TPE-LAX	TPE-HKG	TPE-LAX
B747-400 F	7,068.00	5,512.45	10,899	49,011	0.1970	0.1375
MD-11F	5,063.96	3,900.82	8,505	38,628	0.1926	0.1349
B747-400	–	–	–	–	0.0598	0.0470
B747-400 Combi	–	–	–	–	0.0594	0.0469
A330-300	–	–	–	–	0.0613	–

Note: Airport user charges for MD-11F at Anchorage airport is \$1,839.28 per flight.

network is available for the TPE-LAX traffic. Based on the empirical data provided by the Airfreight Forwarder's Association of the Taipei City, the upper bound of freight rates for TPE-HKG and TPE-LAX are set as 1 and 5 US dollars per kg.

The choice model for air cargo service companies developed by Hsu et al. (2005) was directly applied here. They investigated many 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

$$V = \alpha_0 + \alpha_1 P + \alpha_2 T + \alpha_3 F + \alpha_4 X \quad (5)$$

where P denotes shipping charge, T denotes total shipping time for cargo service, F 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 are listed in Table 3. In this study, the door-to-door services for two types of airlines are assumed to be indifferent for

Table 3
Parameters estimated in the choice model.

Parameter	Estimated value	Standard error
α_0	-0.1759	0.1615
α_1	-0.0403	0.0179
α_2	0.001	0.2913
α_3	1.2355	0.3429

Table 4
Equilibrium outcomes of the two markets.

TPE-HKG					
	CI	BR	CX	KA	FX
Selected freighter aircraft type	-	-	-	-	MD-11F
Frequency (weekly)	224	98	216	110	12
Freight rate	1.0	1.0	1.0	1.0	1.0
Estimated market share	24.42%	21.05%	24.21%	21.40%	8.92%
Profit (\$, week)	211,729	227,288	212,746	220,811	49,040
TPE-LAX					
	CI	BR	FX		
Selected freighter aircraft type	B747-400F	MD-11F	MD-11F		
Frequency (weekly)	29	29	33		
Freight rate	5.0	5.0	5.0		
Estimated market share	38.03%	38.03%	23.94%		
Profit (\$, week)	226,788	298,770	202,185		

Table 5
Equilibrium outcomes in the two cargo demand scenarios.

Route	Item	High demand scenario	Low demand scenario
TPE-HKG	Profit	(526272, 345285, 524580, 419805, 110078)	(0, 63128, 23914, 53937, 38067)
	Market share	(24.34%, 21.04%, 24.13%, 21.35%, 9.13%)	(0, 27.95%, 32.15%, 28.41%, 11.49%)
	Frequency	(224, 100, 216, 111, 13)	(0, 98, 216, 110, 11)
TPE-LAX	Profit	(536214, 536214, 673666)	(217343, 217343, 0)
	Market share	(38.08%, 38.08%, 23.84%)	(50%, 50%, 0)
	Frequency	(30, 30, 33)	(28, 28, 0)

the shipments considered here are airport-to-airport. The alternative specific constant was not used in this study.

3.2. Analysis of results

Applying the proposed models to the example markets described above, the results are summarized in Table 4. There is a single subgame perfect equilibrium in both games. On the TPE-HKG route, where there is a competitive subgame equilibrium outcome, all carriers choose to enter. Combination carriers, generally providing higher flight frequencies in the short haul route, obtain more than 90% of air cargo shipments. CI gains the largest market share (24.42%) but not the highest profit among them. While combination carriers provide high-frequency service, they may suffer loss due to corresponding low freight load factor. That is why BR has a higher profit than CI. Despite of relative lower frequencies than rivals, it is worthwhile for FX to join the game and increase flight frequency on route TPE-HKG.

The equilibrium of the three-airline subgame is sustainable because each airline gains profit on the TPE-LAX route. In the oligopolistic equilibrium, both two combination carriers increase flight frequencies gaining higher market shares. The difference in their profits is due to different choices of dedicated freighters. In this case, TPE-LAX is one intercontinental, hub-to-hub path for FX with higher flight frequencies. With this advantage, FX earns a market share of 23.94% without adding more flight frequency, due to lower operating costs. The freight rates set by airlines in the equilibria of two games are equal.

3.3. Sensitivity analyses

3.3.1. Effect of cargo demand

To explore how the demand disparity might affect airline competition, two scenarios for cargo demand are set: low demand (as 30% of initial input demand) and high demand (as doubled initial input demand). The equilibrium outcomes are shown in Table 5. The results in Table 6 show that the two markets' equilibrium conditions are sustainable when demands become doubled. It directly results in the increase of the dedicated freighter aircraft services and slight changes in airline's market shares. Given knowledge that competitors would add flight frequency, some airlines choose to increase flight frequency as their best-response strategies and others do not.

There are some variations in the two markets' equilibrium conditions under the low demand scenario. When three airlines

Table 6
Forecasted yearly volumes carried by CI and FX from year 2010 to 2012 (tons).

Route	Airline	Year 2010	Year 2011	Year 2012
TPE-HKG	CI	32,303	32,389	32,476
	FX	11,800	11,831	11,863
TPE-LAX	CI	19,974	20,002	20,056
	FX	12,570	12,588	12,622

operated in the TPE-LAX market, the potential profits of airlines, CI, BR and FX, are (14,5702, 14,5702, -13,0015). When one chooses not to enter, there are three subgame equilibrium outcomes, with which airlines' profit sets are (0, 28,4304, -42,275), (28,4304, 0, -42,275) and (21,7343, 21,7343, 0). The unique subgame perfect equilibrium is (217343, 217343, 0). In this duopolistic equilibrium, the best response strategy of FX is not to play. In the TPE-HKG market, if all airlines choose to enter the market, the potential profits are (-9541, 36,584, -6617, 26,955, and 27,160), since demand would not be sufficient to sustain five airlines. When one chooses not to enter, there are five subgame equilibrium outcomes, with which airlines' profit sets are (0, 63,128, 23,914, 53,937, and 38,067), (15,959, 0, 18,663, 49,297, and 36,191), (20,904, 62,824, 0, 53,629, and 37,943), (16,496, 59,025, 19,196, 0, and 36,381) and (-489, 44,386, 2356, 34,886, and 0). The oligopolistic solutions show only four airlines attain profits. The single subgame perfect equilibrium is that CI chooses not to play with the profits set as (0, 63,128, 23,914, 53,937, and 38,067).

To analyze the stability of two markets' equilibria with cargo demand in the short run, a cargo demand model developed for international scheduled routes at the Taiwan Taoyuan International Airport developed by Hwang and Shiao (2011) was directly applied here, which was calibrated by the Fixed Effects Model estimation with route effects only and the statistics of adjusted R-squared is 0.993. The calibrated model is specified as:

$$\ln T_{hkt} = 8.245 + \lambda_{hk} + .142 \ln N_{ht} N_{kt} - .261 \ln R_{hkt} \quad (6)$$

where T_{hkt} is the total amounts of international cargo shipped between airport h and airport k in year t ; λ_{hk} is route-specific effects; N_{ht} and N_{kt} are the population (in thousands) of two urban agglomerations at both airport h and airport k in year t ; R_{hkt} corresponds to the average freight cost of goods on the route hk in year t .

According to the population projections of the Urban Agglomerations of United Nations Population Division Department of Economic and Social Affairs (2007), two case route cargo shipping demands from 2010 to 2012 were forecasted by this model and the subgame equilibria were attained. The results demonstrate that cargo demands appear to be strong enough, at least in the short term, to sustain the five major airlines on TPE-HKG and three major airlines on TPE-LAX, and therefore, keeping the air cargo service running seems to be their best-response strategies for those players in the markets. The predicted yearly shipments of CI and FX are shown in Table 6.

Table 7
Equilibrium outcomes in the two passenger demand scenarios.

Route	Item	High demand scenario	Low demand scenario
TPE-HKG	Profit	(129463, 169524, 131461, 54469, 88579)	(254538, 176077, 254757, 174607, 61044)
	Market share	(26.16%, 20.11%, 25.74%, 20.64%, 7.34%)	(23.68%, 21.30%, 23.55%, 21.61%, 9.85%)
	Frequency	(448, 196, 432, 220, 11)	(112, 50, 108, 56, 12)
TPE-LAX	Profit	(610605, 610605, 169485)	(240660, 240660, 255077)
	Market share	(38.86%, 38.86%, 22.28%)	(36.70%, 36.70%, 26.60%)
	Frequency	(56, 56, 33)	(15, 15, 33)

Table 8
Equilibrium outcomes in the two scenarios of all-cargo carrier's operation scale.

Route	Item	High operation scale scenario	Low operation scale scenario
TPE-HKG	Profit	(209020, 224955, 210063, 18440, 116744)	(218174, 232842, 219136, 226457, 29209)
	Market share	(24.19%, 20.85%, 23.98%, 21.19%, 9.78%)	(24.89%, 21.46%, 24.68%, 21.81%, 7.15%)
	Frequency	(224, 98, 216, 110, 17)	(224, 98, 216, 110, 7)
TPE-LAX	Profit	(216199, 288181, 82574)	(249266, 321248, 289737)
	Market share	(37.50%, 37.50%, 25.00%)	(39.16%, 39.16%, 21.68%)
	Frequency	(29, 29, 50)	(29, 29, 17)

3.3.2. Effect of passenger demand

Two scenarios for air passenger demand are set herein: low demand scenario (passenger flight frequency is half of the initial input) and high demand scenario (passenger flight frequency is double of the initial input), and the two market equilibrium outcomes under different scenarios are shown in Table 7. In the low air passenger demand scenario, the market equilibrium outcomes are a competitive equilibrium on TPE-HKG route and oligopolistic equilibrium on TPE-LAX route. Some combination carriers with low passenger flight frequencies choose to add the dedicated freighter aircraft service due to sufficient cargo demand as their best-response strategies; BR and KA respectively increase one flight on TPE-HKG route; CI and BR choose the same type of dedicated freighter aircraft to provide one flight on TPE-LAX route. Given that combination carriers have dedicated freighter fleet, all-cargo carriers gain minimal shift of market share from passenger carriers. The market equilibria in the two markets in high air passenger demand scenario remain the same as those in the base case, but airlines' best-response strategies tend to alter. It is worthwhile for airlines to not increase frequency due to abundant cargo space of passenger aircraft in this scenario. All-cargo carriers lose a small portion of their market share as expected.

3.3.3. Effect of all-cargo carrier's transshipment frequency

Table 8 lists the two market equilibrium outcomes under two scenarios of the all-cargo carrier's operation scale: high operation scale scenario (transshipment flight frequency is 1.5 times of the initial input) and low operation scale scenario (transshipment flight frequency is half of the initial input). Under both scenarios, the five airlines in the TPE-HKG market and the three airlines in TPE-LAX market all gain profits, suggesting that a five-airline competitive market and a three-airline oligopolistic market could exist in both TPE-HKG and TPE-LAX market. The results show that the higher its operation scale, the more market share and profit the all-cargo carrier gets.

3.3.4. Effect of time slots for all-cargo carrier

Given available landing and takeoff slots for all-cargo carriers at peak hours, the equilibrium outcomes are reevaluated and shown in Table 9. The results indicate that five-airline competitive subgame equilibrium in TPE-HKG route could exist because of the profitability of all airlines. FX gains more profits and market share

Table 9
Equilibrium outcome in airline competition game with available landing and takeoff slots for all-cargo carriers at peak hours.

TPE-HKG					
	CI	BR	CX	KA	FX
Frequency	224	98	216	110	12
Estimated market share	23.14%	19.94%	22.93%	20.27%	13.71%
Profit (\$, week)	195,087	212,945	195,248	206,231	111,102
TPE-LAX					
	CI	BR	FX		
Frequency	29	29	33		
Estimated market share	33.10%	33.10%	33.80%		
Profit (\$, week)	128,896	200,879	397,969		

than the base case as expected. Furthermore, in the three-airline market of the TPE-LAX route, FX becomes the carrier with the largest market share. It indicates that the availability of time slots affects all-cargo carriers' profitability in the competitive market, especially on routes with demand of high flight frequencies.

4. Summary and conclusions

All-cargo airlines enter the Asian general air cargo markets one after another in the past 30 years, where combination carriers play a significant role. Most sources in the literature emphasize their fleets and networks but few focuses on their different operational characteristics and limitations to analyze empirically the lasting, competitive game in Asia. In the model framework proposed, an airline profit-maximizing objective function contains a discrete choice model, in which each airline's market share is computed based on a function of frequency, freight rate, total shipping time, and the decision variables of the other airlines. A two-stage, non-cooperative game has been developed to incorporate the airlines' decisions in a competitive context. In the first stage, the airlines simultaneously choose whether or not to participate. In the second stage, each airline competes for market share, given the other airlines' decisions. The iterative process of backward induction evaluates each airline's best-response strategy. The uniqueness or existence of the equilibrium of the entire game is not guaranteed because the profit function is not concave.

To illustrate the capability, the proposed model was then empirically applied to two selected route markets: short haul of TPE-HKG and long haul of TPE-LAX. In the base case of the two route markets, it is found that a single competitive five-airline subgame equilibrium exists in the TPE-HKG market and an oligopolistic three-airline subgame equilibrium exists in the TPE-LAX market. In both cases, combination carriers appear to be the dominators in the markets, especially on short-haul passenger routes in which there are highly-concentrated passenger flights with large quantum of belly space available. Profitable all-cargo carriers choose to enter two markets as their best-response strategies and tend to focus their attention on those routes with heavy demand for cargo space.

The results of the case study also reveal that the competition of airlines for general air cargo service are affected by cargo demand and passenger demand in the market, air travel demand on passenger routes, the operation scale of all-cargo carriers and the availability of time slots at the airports for all-cargo operators. First, cargo demand plays an important role in market equilibrium and the rapid growth of intra-Asia and out-of-Asia cargo

demand contributes all-cargo carriers to participate in Asian general cargo services. Next, when combination airlines face large demand variation on passenger or cargo sectors, their trade-off is to increase passenger or dedicated freighter aircraft in their fleets. In fact, for many passenger airlines in Asia, it appears that they look forward to increasing cargo demand and tend to acquire dedicated freighter aircraft as their strategic actions. Third, it is worthwhile for all-cargo carriers to enter the market by growing their scale of operation through expanding their HS networks. In addition, for all-cargo operators, it would be helpful to cooperate with the airport authorities in Asia to establish hubs and obtain scarce landing and takeoff slots to increase their competitiveness.

Strategic airline alliances for passenger business have worked well for air passenger markets and bring out the global networks. With deregulations of air transportation markets in many parts of the world, it may be interesting to analyze the effect of air cargo alliances on competition and identify the suitable condition of air cargo alliances, such as market scales.

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