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MODELING AIRLINE COMPETITION WITH TWO FARE CLASSES UNDER STATIC AND DYNAMIC GAMES

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Abstract

Due to the deregulation of airline's entry and airfares in the last decade, Taiwan's domestic air travel market becomes very competitive. In order to explore the competition behavior among airlines, this paper analyzes airline's strategies on airfares and frequency by applying static and dynamic game theory. The airline's payoff function consists of an O-D travel demand model, an airline market share model, and a cost function. Four solution approaches are proposed and presented in the case study based on data collected from the Taipei-Kaohsiung air travel market.

INTRODUCTION

Taiwan's airline business has come to a turning point due to the deregulation in the late 1980s. The restrictions on airline's entry, airfares, and flight frequency were removed in the last decade. In addition, the ever-deteriorating traffic condition on major freeway systems has diverting more and more people from driving to flying. Currently there are 9 airlines competing on 37 flight segments with annual traffic over 18 millions passengers. Taiwan's domestic air travel market has now become one of the most competitive markets in Southeast Asia.

To assess the impact of deregulation, this paper applies game theory to seek for the strategic interaction among airlines in the oligopolistic competition environment. The strategies related to pricing include discount prices, service upgrade, and frequent flyer programs; the quality of service may include the quality and quantity of foods, comfort of seating, entertaining programs, reliability of schedule, baggage handling, and the frequency of direct and transfer flights. This paper focuses on the price and frequency competition of domestic airlines. Meanwhile, since the flight distances of all Taiwan's domestic routes are less than 500 miles, therefore, this paper would only focus on direct flights.

The objectives of this paper are as follow:

- Develop a mathematical model that interpret and predict the interaction among airlines in the competition market.
- Provide a guideline for airlines in the decision of prices and frequency of flights.
- Present an analytical tool for policy makers in the impact assessment of deregulation.

This paper is organized as follows:

- Reviews of literature on game theory and related papers;
- Formulation of the airline's payoff functions;
- Proposed solution approaches to the static and dynamic games;
- A case study based on data collected from the Taipei-Kaohsiung air travel market is presented;
- Conclusion of the paper.

LITERATURE REVIEW

In the studies of oligopolistic market behavior, the most often referred models are the Cournot model, the Bertrand model, and the Stackelberg model. (Gibbons, 1992)

The Cournot model is also called the quantity competition model. This model assumes that two companies seek to maximize their own profit by choosing the optimal production quantities given that the quantities produced by their opponents remain constant. In other words, if the quantities produced by company A is denoted as q_a, then, the optimal quantities produced by company B denoted as q_b^* should be a function of q_a. Similarly, the optimal quantities produced by company A denoted as q_a^* should be a function of q_b. The market equilibrium can be reached if $q_a^* = q_b^*$.

On the other hand, the Bertrand model, which is called the price competition model, assumes that two companies seek to maximize their own profit by choosing the optimal prices given that the prices set by their opponents remain constant. It should be noted that both models assumes linear relationship between prices and quantities in the production and consumer demand functions. Meanwhile, both Cournot and Bertrand models are referred as the static game models.

As for the dynamic game model, the most commonly used is the Stackelberg model. This model often assumes that one firm is the leader and the other firm is the follower. Therefore, the leader set the price or quantity of its own, then the follower chooses its optimal price and quantity according to the price and quantity set by the leader. In other words, the quantity produced by the follower, denoted as q_f, is a function of the quantity produced by the leader, denoted as q_l. Since q_f equals $f(q_l)$, the leader can then chooses the optimal quantity q_l^* with the predicted quantity q_f^* ($=f(q_l^*)$) that yields the maximum profit for the leader.

Meanwhile, the game theory can be viewed as an extension of the above models. First, the number of players, i.e., the competitors, is unlimited; second, the rules of the games are more flexible. For instance, if each airline knows the payoff functions of the other opponents and is capable of predicting the actions taken by his opponents, then it is called a game with complete information. On the contrary, if the information regarding to opponent's payoff function is uncertain, then it is called a game with incomplete information (Gibbon, 1992).

The game theory seeks to reveal the behavior of all players under market equilibrium, if equilibrium does exist. The market equilibrium in the game theory, often referred as Nash equilibrium, is defined as the best response for each airline given the predicted actions of the other airlines. A static game, such as Cournot and Bertrand models, means that all airline choose their strategies simultaneously, in other words, they compete on the same basis. On the other hand, a dynamic game assumes that one airline may choose its best strategy when its opponent's reactions are known. For example, Stackelberg model of duopoly assumes that the market followers would response to the actions taken by the market leader.

Although the game theory and other oligopolistic models were widely applied in the fields of economics and marketing researches, only a few applications had been done in transportation studies. On of them is the study of airline competition in a hub-and-spoke environment by Hansen (1990).

The major assumptions of his study are as follows:

- Each airline seeks to maximize its own profit given that the responses of all other opponents are known;
- Airfares and frequency are treated as separate decision variables;
- Business and leisure travelers have the same elasticity related to price and frequency;
- The opportunity costs of airplane routing is not included in the cost function;
- The capacity of airport is unbounded.

The first assumption is the basic idea of static games, the second one is a contrast to the traditional oligopolistic models which assumes that prices and quantities are mutually affected in the market equilibrium. The second assumption, however, can be easily released in the future study if a heuristic is developed to solve the competition problems sequentially. The third assumption is driven by the fact that Hansen applied only one airfare, i.e., the average airfare, in the formulation of the payoff function. The fourth and the last assumptions are the common restrictions to this approach since the problem is rather demand oriented than supply oriented. The fourth assumption is often replaced by setting constraints on airlines' frequencies. The fifth assumption can be released if a heuristic is developed to incorporate airline routing problem in future research. His study, however, provided an analytical tool for studying the interaction among airline under hub-and-spoke environment.

MODEL DEVELOPMENT

The model developed in this paper is described in two parts: 1) basic model assumptions; and 2) formulation of the payoff function.

Basic model assumptions

In addition to the assumptions made in Hansen's paper, this paper adds one more assumption, and relaxes the first and the third assumptions as follows:

- The payoff functions of all airlines are known, but the games could be static or dynamic;
- All flights are direct, the demand of an O-D market is independent of the other O-D pairs;
- Business and leisure travelers may have different tastes regarding to airfare and frequency.

The first assumption states the rules to be static or dynamic games with complete information. The second assumption addresses the fact that the method developed in this paper will be limited to the applications of direct flight market. The last assumption implies that leisure and business trips would be treated as separate markets in this paper.

Formulation of the payoff functions

The payoff function for an airline consists of three parts: 1) the air travel demand model of an O-D market; 2) the market share function of an airline; and 3) the cost function of an airline. These functions are stated below:

The air travel demand model of an O-D market

The demand models are formulated as two separate functions to incorporate the variation of tastes for the leisure and business travelers. The leisure travelers are often assumed to be more sensitive to changes of airfares and incomes since most of their trips are planed in advance. For instance, if the airfares increased or the depreciation of local currency caused the shrinkage of incomes, these travelers might cancel their trips. The business travelers, on the other hand, are assumed to be more sensitive to frequency rather than airfares and personal incomes since the expenses are often paid by their company and usually these trips cannot be canceled.

In addition, the travel time and fares of the other competing modes of travel should be included in the model. Based on Wu (1990), the formulation of the air travel demand models for two separate markets are presented as follow:

$$\ln Q_{ij}^1 = \ln \alpha_0^1 + \alpha_1^1 \ln POP + \alpha_2^1 \ln INC + \alpha_3^1 \ln AF + \alpha_4^1 \ln HF + \alpha_5^1 \ln RF \quad (1)$$

$$\ln Q_{ij}^2 = \ln \alpha_0^2 + \alpha_1^2 \ln POP + \alpha_2^2 \ln Af + \alpha_3^2 \ln AT + \alpha_4^2 \ln HT + \alpha_5^2 \ln RT \quad (2)$$

Where,

Q_{ij}^1 : the volume of leisure trips by air between cities i and j;

Q_{ij}^2 : the volume of business trips by air between cities i and j;

POP: the total population of cities i and j;
INC: the average incomes of cities i and j;
AF: the average airfare between cities i and j, often weighted by market shares;
HF: the bus fare between cities i and j;
RF: the train fare between cities i and j;
AT: the travel time by air between cities i and j;
HT: the travel time by bus between cities i and j;
RT: the travel time by train between cities i and j;
Af: the frequency of flights between cities i and j.

It should be noted that the functional forms of the air demand models are log-linear, which implies that the models could be calibrated by using the time series data provided by Taiwan's Bureau of Civil Aviation (1996). If the survey data of individual behavior is available, the demand model can be formulated as a modal choice model using techniques derived from discrete choice analysis (Ben-Akiva, 1985).

The market share models

This model describes how travelers choose the airlines to fly. Therefore, it should include all the attributes related to the quality of service and airfares. The formulation of the model is shown below:

$$S_{ij}^{m1} = \frac{e^{V_{ij}^{m1}}}{\sum_{n=1}^{N} e^{V_{ij}^{n1}}} \tag{3}$$

$$S_{ij}^{m2} = \frac{e^{V_{ij}^{m2}}}{\sum_{n=1}^{N} e^{V_{ij}^{n2}}} \tag{4}$$

Where,

S_{ij}^{m1} : The market share in the leisure travels for airline m between cities i and j;

S_{ij}^{m2} : The market share in the business travels for airline m between cities i and j;

N: The number of airlines served between cities i and j;

V_{ij}^{m1} : The utility function of the leisure travel for airline m between cities i and j;

V_{ij}^{m2} : The utility function of the business travels for airline m between cities i and j;

Equations (3) and (4) show that the market share model are formulated as multinomial logit model (Ben-Akiva, 1985). The variables of the utility functions often consist of the airfares and frequency of all competing airlines, and the airline-specific constant, which represent the quality measures of these airlines. The functional forms of these utility functions are as follow:

$$V_{ij}^{m1} = \beta_{11} F_{ij}^{m1} + \beta_{21} \ln v_{ij}^{m} + c_{m1} \tag{5}$$

$$V_{ij}^{m2} = \beta_{12} F_{ij}^{m2} + \beta_{22} \ln v_{ij}^{m} + c_{m2} \tag{6}$$

Where,

F_{ij}^{m1} : The average air fare of airline m for leisure travelers between cities i and j;

F_{ij}^{m2} : The average air fare of airline m for business travelers between cities i and j;

v_{ij}^{m} : The frequency of flights of airline m between cities i and j;

β_{11}, β_{21} : The model parameters in the utility function of the leisure travelers;

β_{12}, β_{22} : The model parameters in the utility function of the business travelers;

c_{m1} : The specific constant for airline m in the utility function of the leisure travelers;

c_{m2} : The specific constant for airline m in the utility function of the business travelers.

It should be noted that only (N-1) airline-specific constants could be calibrated in the model. Meanwhile, the marginal utility of flight frequency should decrease as frequency increases, therefore, the variable of frequency has the logarithm form in the utility function.

The cost functions

The costs of a one-way flight are often addressed in two parts, the fixed costs and the variable costs. The fixed costs include the fees of airports and other administration costs. The variable costs include the costs of fuel and labor, which should vary with flight distance and aircraft types. Although the cost data are often confidential, there are some good estimates of these costs, which can be found in official reports. By using the rule of thumb, the cost function is assumed to be a linear function as follows:

$$C(v_{ij}^{m}) = C_{ij}^{m} \times v_{ij}^{m} \tag{7}$$

Where,

C_{ij}^{m} : The estimated costs of a one-way flight for airline m between cities i and j.

Combining equation (1) and equation (7) produces:

$$\pi_{ij}^{m} = \sum_{k=1}^{2} Q_{ij}^{k} \times S_{ij}^{mk} \times F_{ij}^{mk} - C_{ij}^{m} \times v_{ij}^{m} \tag{8}$$

Where,

π_{ij}^{m} : The payoff function of airline m for the air travel market between cities i and j.

SOLUTION APPROACH

With the payoff function formulated in the previous section, this section presents the solution approaches for airfare and frequency competition under static and dynamic games.

Airfare competition in the static game

Because airfare is a real variable, the price competition in static games can be written as follows:

$$\max_{F_{mk}} \pi^m (F_{mk}, \mathbf{F}_{m'k}) \qquad \forall m' \neq m, \quad \forall m,k \tag{9}$$

Where,
$\mathbf{F}_{m'k}$: The vector of air fares for the other competitors.

With the concavity of the payoff function, the following system of equations can solve equation (9):

$$\frac{\partial \pi^m (F_{mk}, \mathbf{F}_{m'k})}{\partial F_{mk}} = 0 \qquad \forall m,k \tag{10}$$

In other words, the Nash equilibrium is achieved by solving the system of first order conditions in equation (10).

Frequency competition in the static game

Because frequency is an integral variable, the price competition in static games can be written as follow:

$$\max_{v_m} \pi^m (v_m, \mathbf{v}_{m'}) \qquad \forall m \tag{11}$$

Where,
$\mathbf{v}_{m'}$: The vector of frequencies for the other competitors.

With the concavity of the payoff function, equation (11) can be solved by the following approach:

Step 1: Initial Real Values

Solve the following system of equations shown below and obtain the initial real values of $\widetilde{v}_1$, $\widetilde{v}_2$, ⋯, and $\widetilde{v}_N$.

$$\frac{\partial \pi^m (v_m, \mathbf{v}_{m'})}{\partial v_m} = 0 \qquad \forall m \tag{12}$$

Step 2: Compute these Frequencies by the Branch-and-Bound

Compute the values of v_1^* , v_2^* , ⋯, and v_N^* by solving the system of equations shown below in ascending order.

$$v_1^* = \arg\max_{v_1} \pi^1(v_1, \widetilde{v}_2, \ldots, \widetilde{v}_N)$$

$$v_2^* = \arg\max_{v_2} \pi^2(v_1^*, v_2, \widetilde{v}_3, \ldots, \widetilde{v}_N)$$

$$\vdots$$

$$v_N^* = \arg\max_{v_N} \pi^N(v_1^*, v_2^*, \ldots, v_{N-1}^*, v_N) \tag{13}$$

It should be noted that these values are integers. The solution obtained in step 2 can be viewed as a heuristic to the problem.

Airfare competition in the dynamic game

Assuming that the airline with the lowest marginal cost is the market leader, and the one with the second lowest marginal cost is the first follower, the one with the third lowest marginal cost is the second follower, and so on. Let the airlines from the leaders to the followers be labeled in ascending order, i.e., airline 1 is the market leader of all airlines, airline 2 follows the action of airline 1 and is followed by the other airlines, etc. Then, the simulation of the dynamic process can solve the problem for the airfare competition in dynamic games. In addition, given that the demands of the leisure trips and the business trips are separable, the airfare competition problems for these two fare classes can be separately solved.

Step 1: Initialization

Set the initial values of the airfares for the last (N-1) airlines to be a large number. Label these values as $F_{2k}^{(0)}$, $\cdots$, $F_{N-1,k}^{(0)}$, and $F_{Nk}^{(0)}$. The reason for setting large initial values for the followers is that the leader may appear to be monopolistic in the beginning of the competition.

Step 2: Update of Airfares

Compute the values of $F_{1k}^{(i)}$, $F_{2k}^{(i)}$, $\cdots$, and $F_{Nk}^{(i)}$ for the ith iteration by solving the system of equations shown below in ascending order. This step is the simulation of reactions occurred in the dynamic process.

$$F_{1k}^{(i)} = \arg\max_{F_{1k}} \pi^1(F_{1k}, F_{2k}^{(i-1)}, F_{3k}^{(i-1)}, \ldots, F_{Nk}^{(i-1)})$$

$$F_{2k}^{(i)} = \arg\max_{F_{2k}} \pi^2(F_{1k}^{(i)}, F_{2k}, F_{3k}^{(i-1)}, \ldots, F_{Nk}^{(i-1)})$$

$$F_{Nk}^{(i)} = \underset{F_{Nk}}{\arg\max}\, \pi^N (F_{1k}^{(i)}, F_{2k}^{(i)}, \ldots, F_{N-1,k}^{(i)}, F_{Nk}) \tag{14}$$

Step 3: Convergence Test

If the difference of airfares in two consecutive iterations is less than a very small value, then stop; otherwise, return to Step 2. The criteria for convergence could be set as follows:

$$\Delta F = \frac{\left|F_{mk}^{(i)} - F_{mk}^{(i-1)}\right|}{\left|F_{mk}^{(i)} + F_{mk}^{(i-1)}\right|} \le \varepsilon \quad \forall m, k \tag{15}$$

Where ε is the tolerance level.

Frequency competition in the dynamic game

Assuming that the airline with the largest market share is the market leader, the one with the second largest market share is the first follower, the one with the third largest market share is the second follower, and so on. Let the airlines from the leaders to the followers be labeled in ascending order, i.e., airline 1 is the market leader of all airlines, airline 2 follows the action of airline 1 and is followed by the other airlines, etc. Then, the simulation of the dynamic process can solve the problem for the frequency competition in dynamic games.

Step 1: Initialization

Set the initial values of the frequencies for the last (N-1) airlines to be zeros. Label these values as $v_2^{(0)}$, $\cdots$, $v_{N-1}^{(0)}$, and $v_N^{(0)}$. The reason for setting zero initial values for the followers is that, when the leader first enter the market, it should enjoy the benefit of monopoly.

Step 2: Update of Frequencies

Compute the values of $v_1^{(i)}$, $v_2^{(i)}$, $\cdots$, and $v_N^{(i)}$ for the ith iteration by solving the system of equations shown below in ascending order. This step is the simulation of reactions occurred in the dynamic process.

$$\begin{aligned}
v_1^{(i)} &= \underset{v_1}{\arg\max}\, \pi^1 (v_1, v_2^{(i-1)}, v_3^{(i-1)}, \ldots, v_N^{(i-1)}) \\
v_2^{(i)} &= \underset{v_2}{\arg\max}\, \pi^2 (v_1^{(i)}, v_2, v_3^{(i-1)}, \ldots, v_N^{(i-1)}) \\
&\vdots \\
v_N^{(i)} &= \underset{v_N}{\arg\max}\, \pi^N (v_1^{(i)}, v_2^{(i)}, \ldots, v_{N-1}^{(i)}, v_N)
\end{aligned} \tag{16}$$

Step 3: Convergence Test

If the frequencies in two consecutive iterations are the same, i.e., $v_m^{(i)} = v_m^{(i-1)}, \quad \forall m$, then stop; otherwise, return to Step 2. In case that the equilibrium may not be found, or there are multiple equilibria in the process, the criteria for convergence should be modified as follows (Hansen, 1990):

$$\Delta v = 2\frac{\left|v_m^{(i)} - v_m^{(i-1)}\right|}{\left|v_m^{(i)} + v_m^{(i-1)}\right|} \leq \varepsilon \quad \forall m \tag{17}$$

Where ε is the tolerance level.

CASE STUDY

The analysis is based on the data acquired in the Taipei-Kaohsiung market for 5 airlines (Shyr, 1998). Table 1 lists the calibrated costs of these airlines based on Hansen's cost functions (1990). It should be noted that the average costs per seat among these airlines appear to be very similar. As a result, there could be no apparent market leader in the dynamic airfare competition game.

Because of the lack of sufficient data, the O-D air travel demand model was not calibrated, instead, the following equation based on previous study of the elasticity of airfare with respect to O-D demand was applied:

$$Q_{ij} = 94451183 \cdot AF^{-1.28} \tag{18}$$

The average airfare, *AF*, is calculated by the weights of current market shares. Table 2 shows the calibration results of the market share model. The survey data was based on travelers' stated preferences (SP). The likelihood ratio test for the null hypothesis that the market share models in leisure and in business purposes are the same is as follows:

$$-2[\text{Ln}\, L_l(\beta) + \text{Ln}\, L_b(\beta) - \text{Ln}\, L_c(\beta)] = 6.4 \tag{19}$$

Where $L_l(\beta)$, $L_b(\beta)$, and $L_c(\beta)$ are the likelihood values for the leisure trip model, the business trip model, and the combined model, respectively.

The critical χ square value with 4 degree of freedom and 95% confidence level is 9.49. The test statistics suggests that the differences between these two calibrated models are not significant, therefore, the combined market share model is used for further application.

Table 1 - The cost data of Taipei-Kaohsiung airlines

Airlines	A	B	C	D	E
Cost per flight (NTD[1])	130382	164855	159110	190136	170601
No. of seats per flight	130	160	155	182	165

[1] New Taiwan Dollar, 1USD = 34 NTD.

Cost per seat (NTD)	1003	1030	1027	1045	1034

Table 2 - The estimated parameters of the market share model (t values in the parentheses)

Variables	Leisure	Business	Combined
Airline-specific constant C	1.037(4.946)	1.060(6.981)	0.994(8.741)
Airline-specific constant D	0.880(3.739)	0.906(5.452)	0.826(6.612)
Airfare (NTD)	-0.00405(-7.143)	-0.00255(-5.204)	-0.00317(-8.698)
Daily frequency (in natural log)	0.0404(4.551)	0.0371(4.786)	0.0397(6.969)
LN(β)	-334.45	-409.55	-747.2
LN(0)	-400.75	-478	-878.75
ρ^2	0.16	0.14	0.15
No. of sample	249	297	546

Table 3 shows the airfare ranges of which the payoff functions are concave. In other words, these ranges are the feasible values used in the case study. Table 4 shows the solutions obtained by the application of the methods developed for static and dynamic games. It should be noted that currently most airlines are not profitable due to the fact of low ridership and high supply of airline tickets. The result of the static game with respect to frequency suggests that, with the reduction of frequency and the increase of ridership, most airlines will become profitable under current airfares.

Table 3 - The airfare ranges in the case study

Airlines	A	B	C	D	E
Ranges (in NTD)	0~1154	0~1160	0~1315	0~1412	0~1225

Table 4: The payoffs in static and dynamic games

Airlines	A	B	C	D	E
Current daily flights	20	18	20	24	8
Current airfares (NTD)	1284	1298	1233	1220	932
Current profits (NTD/day)	-1333793	-1740695	1277588	-1176779	-1457286
Frequencies in static game	10	7	26	19	8
Resulted profits (NTD/day)	211698	290042	660902	520830	-134568
Airfares in static game (NTD)	950	900	1250	1050	1250
Resulted profits (NTD/day)	-272347	-943089	638601	-282405	250778
Frequencies in dynamic game	6	5	30[2]	13	8
Resulted profits (NTD/day)	113456	234589	865432	401324	-134568

On the other hand, the result of the static game with respect to airfares shows that most airlines will enjoy larger profits if the current airfares could be even lower under current timetable. Finally, given that airline C has the largest share in the market, it has the potential to become the market leader. Suppose that airline C is indeed the leader, as a result, it will earn even more profit under the rules of the dynamic game. This result is consistent with the Stackelberg model.

CONCLUSIONS

This paper develops a model to interpret domestic air travel market behavior. The model consists of two parts: the formulation of payoff functions, and five solution approaches to the corresponding

[2] The market leader

games. The payoff functions contain the cost function, the O-D air travel demand models and the market share models for leisure and business trips. The solution approaches are derived based on solving the first order conditions of the payoff function with respect to airfares and simulation with respect to service frequencies.

Finally, a case study based on Taipei-Kaohsiung air travel data is presented as model application. With the airline costs estimated by Hansen's cost functions and the market share models calibrated by travelers' SP survey data, the solutions of the static games show that current operations effectiveness may be improved if the frequency or airfares can be reduced. The result of the dynamic game also suggests that airline C, which currently has the largest market share, may earn more profit than that of the static game if airline C truly becomes a market leader.

The model developed in the paper can be extended to incorporate the hub-and-spoke operations in the future study. In addition, the assessment of market impact under various strategies, such as airline alliance, may also be analyzed by the inclusion of cooperative game theory for further researches.

REFERENCES

Ben-Akiva, M. and Lerman, S. (1985) **Discrete Choice Analysis.** Cambridge, MA, MIT Press.

Gibbons, R. (1992) **A Primer in Game Theory.** Harvester Wheatsheaf, Hemel Hempstead, Hertfordshire, Great Britain.

Hansen, M. (1990) Airline competition in a hub-dominated environment: an application of non-cooperative game theory. **Transportation Research -B, Vol. 24B,** No.1, pp. 27-43.

Li, C. (1997) **A Study of the Airline Oligopolistic Competition Behavior in the Domestic Market.** Master thesis, Tamkang University, Taipei, Taiwan.

Shyr, F. (1998) **A Study of the Airline Competition Behavior in the International and Domestic Market.** Research Report for the National Science Committee, No. NSC 87-2415-H-032-008, Taipei Taiwan.

Taiwan's Ministry of Transportation, Bureau of Civil Aviation (1996) **The Statistics of Civil Aviation.**

Wu, C. H. (1990) **An Analysis of Domestic Airline Passenger Demand in Taiwan.** Master thesis, National Taiwan University, Taipei, Taiwan.