学　位　申　請　論　文

Economic Analysis of Policies on Air-transportation Market
（航空輸送市場政策に関する経済分析）

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論文要旨

Economic Analysis of Policies on Air-transportation Market

航空市場に対する政策に関する研究

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本論文の目的は、航空市場における各意思決定主体の行動を分析し、航空産業における効率性を改善する政策的含意を提示することである。航空産業においては、空港と航空会社が主要なプレーヤーである。空港が提供する滑走路や搭乗橋、燃料補給といったサービスを利用し、航空会社がフライトサービスを消費者に提供するという垂直的構造が見られる。近年、航空会社の経営に対する規制緩和も推進されており、これに伴って、航空ネットワークもポイント・トゥ・ポイント型からハブ・スポーク型に変化した。また、空港の民営化が進められており、空港が市場支配力を背景に高額な利用料を徴収することが懸念されている。さらに、ハブ空港の地位をめぐる空港間の競争も激化している。このような状況から、航空市場を分析するためには、①航空会社のネットワーク選択問題を内生的に取り扱うとともに、②空港間の戦略的相互作用を考慮したモデルを開発することが必要である。

本論文では、まず、第２章で航空ネットワークの形状を固定したままで空港間の戦略的相互作用を分析する。続いて、第３章でネットワークの内生化を試み、大小２つの空港によるハブ空港の地位をめぐる競争を取り扱う。主要な結論として、第２章では、ネットワーク規模の大きなハブ空港ほど、乗継客向けの料金を低く設定することを明らかにした。また、ハブ空港から遠く離れた地方空港ほど、利用料を安く設定することを示した。さらに、より高い社会厚生を実現するために、ハブ空港が路線ごとに価格差別を行うことを政府は認めるべきであることを提案した。第３章では、航空会社が比較的小さな都市の空港をハブ空港に選ぶ場合があることを明らかにした。これは、小都市の空港は大都市からの需要を取り込むことで利用者数を大幅に増加させることができるので、利用料を積極的に引き下げるからである。

最後に第４章では、航空会社間の競争が社会厚生に与える影響を分析した。競争は価格を引き下げるという効果がある一方で、スケジュールを不均一にするという副作用を生じさせるため、競争が望ましい場合と、独占が望ましい場合の両方が存在する。結果は以下のとおりである。まず、スケジュールの不均一性が競争によって増加することを実証的に示した。次に、理論モデルを使って、運航便数が多い路線では競争によって厚生が改善する一方で、便数が少ない路線では独占状態の方が競争よりも厚生が高くなることを明らかにした。したがって、幹線においては競争を導入するべきであることを提示した。

Contents

Chapter 1

Introduction

1.1. Development of Air-Transport Market in the Past and the Future

The first commercial flight in history occurred in Florida, the United States in 1914. 100 years have passed and air-transportation market has developed greatly. 3.1 billion Passengers and 49.8 million tones freight were carried by air in 2013 [IATA: International Air Transport Association, 2014]. Nowadays, flight services are essential for our life and global economy. The purposes of air travel are various such as leisure, business and visiting friends and relatives. Air freight also supports global industries by connecting world-wide supply chains. Especially, high-value and time-sensitive goods, like precision instruments, are carried by air[1].

1,397 airlines and 3,864 airports contribute to both passenger and freight transportation as mentioned above. 58.1 million people work for aviation industry directly as airline staffs (flight and cabin crews, ground services and maintenance staffs), airport operators, civil aerospace staffs (engineers and designers of aircraft,

[1] Air freight consist 35% of world trade by value while it consists 0.5% by volume [ATAG 2014].

engine and components) and air navigation service providers (air traffic controllers). Moreover, the industry generates $2.4 trillion of economic impacts (including direct, indirect and induced) and consists 3.4% of global GDP [ATAG: Air Transport Action Group, 2014].

The industry is expected to grow rapidly in next several decades because of the growth in the middle-class in the emerging economies. The increase in middle-class people generates tourism demands and the progress of economic integrations, EU, ASEAN as well as other agreements, makes international business travel and cargo demands. According to the recent estimates by ATAG, demand for air transport will increase by 4.7% per year on average over the next 20 years and 6.63 billion passengers will travel by air in 2032, which is 2.6 times as large as in 2012. Moreover, aviation industry will have $5.8 trillion of economic impacts and generates 103.1 million jobs including indirect and induced effects in 2032 [ATAG, 2014].

1.2. Deregulation and Privatization in Air-Transport Market

International agreements and coordination are required to operate international flights and the huge amount of investment is needed for airport infrastructure development.

Therefore, the public sector operated airports and posed severe restrictions on airlines. The aviation regime in post-World War II period was formed by the Chicago Convention, which established International Civil Aviation Organization (ICAO). Under the Chicago regime, the first two freedoms of the air[2] are open to all signatories. Other rights and regulations on routes, capacities, frequencies and airfares are to be negotiated by bilateral agreements.

The turnaround of the regime is the Domestic Airline Deregulation Act in the US in 1978. The law removed the entrance barrier and allowed airlines to decide freely on routes and airfares for the domestic market. The US policy change aimed at deregulation leaded to liberalization of the international aviation market. In 1990s the US established "Open Sky" policy under which the third through seventh freedoms are accepted and airlines set their airfares freely. Japan has also promoted open skies policy since the treaty between the US and Japan in 2010. Japan signs open skies treaty with 27 countries as of 2014. In these treaty, the fifth freedom, "beyond right", is accepted.

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[2] ICAO [http://www.icao.int/Pages/freedomsAir.aspx] defines following nine freedoms of the air.
1st: the right of innocent passage
2nd: the right of technical landing
3rd: the right to fly from the home country to another
4th: the right to fly from another country to the home country
5th: the right to fly beyond the destination into third countries
6th: the right to fly, via the home country, between two other countries
7th: the right to fly between two foreign countries
8th: consecutive cabotage
9th: stand-alone cabotage
The first two rights are called "transit rights" and the others are "traffic rights".

Consequently, foreign airlines start various flight services in international flight market in Japan, e.g., Kansai-Guam route by Korean Air and Kansai-Saipan route by Asisana Airlines.

As part of Margaret Thatcher's economic reforms, British government started to privatize airports. British Airport Authority, which operated seven airports in London and Scotland, was privatized under the Airport Act in 1986 and was listed in London Stock Exchange in 1987. The movement of airport privatization has spread all over the world. Aéroports de Paris, which operates 14 airports including Charles de Gaulle International Airport, and Fraport AG, which manage Frankfurt Airport and holds stocks of several airports around the world, are listed in securities exchanges. Some of Japanese airports are also under privatization. Japanese government adopted concession style as the privatization method. Kansai airport and Itami airport were integrated into one company and the operation right will be sold in 2016. The main purpose of airport privatization is improving operation efficiency. Oum, Adler and Yu [2006] and Müller, Ülkü and Živanović [2009] showed evidences empirically that airports with government majority ownership are significantly less efficient than airports with a private majority. Therefore, it can be said that the main purpose of airport privatization can be achieved.

1.3. Key Issues on Air-Transportation Market

The characteristic of air-transportation market is the vertical relationship between airports, airlines and passengers. Airports provide their services both airlines (runways, cargo terminals, and so on) and passengers (passenger terminals). Airlines perform as downstream firms, that is, they utilize airport facilities as inputs and offer flight services to passengers. In the industry, both airports and airlines have market power.

1.3.1. Airports

The largest issue related to airports is runway congestion and flight delays. After the deregulation, airlines choose Hub-Spoke network structure in which all regional routes are concentrated at a hub airport. Therefore, major hub airports suffer from heavy traffic problem. For example, twenty percent of airline flights in the United States were delayed between 2000 and 2007 [Zhang and Czerny, 2012]. Ball et al. [2010] estimated that the total cost of transport delays in 2007 was $31.2 Billion. Many researchers have tried to solve this problem. In early period, Levine [1969] and Carlin and Park [1970] advocated the use of price mechanism, i.e., congestion tolls. Their models based on road congestion model and treated flights as "atomistic". However, the atomistic assumption doesn't capture correctly the usage of runways because a congested airport is usually dominated by only a few airlines. Daniel [1995] and Brueckner [2002] developed models which explicitly consider the airlines' market power. They raised the possibility of "self-internalization", that is, a large airline take into account the fact that its additional flight generates extra congestion costs for its own flights and passengers. The Brueckner [2002]'s model predicted the "market power" effect. An increase in the market share increases the degree of self-internalization, and therefore reduces airport congestion. Pels and Verhoef [2004], Zhang and Zhang [2006] and Basso [2008] investigated this "market power" effect and showed that the optimal airport charge for large airline should be lower than one for small airlines.

Airport privatization and regulation are also big issue. As mentioned in Section 1.2., many airports were privatized around the world. However, airport privatization has a serious side-effect. Privatized airports might utilize their market power owing to local monopoly position. In fact, Bel and Fageda [2010] found that private unregulated airports set their charges higher than public ones in their cross-sectional study. Zhang and Zhang [2003], Basso [2008] and Czerny [2012] supported the result theoretically.

Therefore, many types of price regulation regimes have been studied. Two price regulations, "Price-cap" and "Cost-based", are widely adopted. Yang and Zhang [2012] investigated the impact of economic regulations on investment and operation efficiency in transportation industry. Their result is that the level of capacity investment is higher under cost-based regulation than price-cap regulation. This result coincides with "Averch–Johnson effect" [Averch and Johnson, 1962]. In addition, they showed that welfare under price-cap regulation is higher than cost-based regulation. Oum et al [2003], Perelman and Serebrisky [2010] and Liebert and Niemeier [2010] compared the efficiencies under both regulation systems.

The above studies, however, focus on only a single airport and ignore airline networks. In order to completely capture the effects of congestion and market power of airports on social welfare, it is needed to consider the whole network. This is because airlines construct networks all over the world, and then strategic behavior of airports affects each other. The second problem is that most of researches on congestion conducted only normative analyses. They investigated optimal airport charges and investment, but haven't cleared what kind of "market failure" exists and what kind of markets suffers from serious welfare loss yet.

1.3.2. Airlines

After the deregulation and "open sky" agreements, airline alliances were established. Three global alliances (Star Alliance, One World, Sky Tram) made up 73.6% of the world international market in 2008 [Zhang and Czerny, 2012]. The alliance system enables airlines to access to markets all over the world by code-sharing, cooperative marketing, the joint frequent flyer program, etc. This new operation system made it convenient for passengers to transfer within an alliance, which promoted the development of hub-spoke networks.

Bruckner and Spiller [1994] started to analyze the effects of hub-spoke networks on user benefit. They pointed out that hub-spoke networks generate "economics of density" because the network structure leads to the use of larger and more efficient aircrafts and the convenience of higher flight frequency. Pels et al [2000] investigated the optimal network and showed that hub-spoke networks are better than point-to-point when the market size is large. Brueckner [2005], Alderighi et al. [2005], Flores-Fillol [2009] and Silva et al [2014] studied the topic from various viewpoints, such as airport congestion, competition between airlines and so on.

These researches have two problems. First, locations of hub airports are given exogenously. Most researches assume that the airport in the largest city or located at the geographical central can be the hub airport. Owing to this assumption, it is impossible to analyze the hub airport choice problem of airlines. Second, flight schedules have been ignored, that is, previous papers assumed that all flights are at the regular interval. However, departing time of flights affects passengers' scheduling delay cost which is one of components of "full price".

1.3.3. Innovative contribution of my thesis

The main purpose of my thesis is to explain what kind of distortion exists in the pricing strategy of airports and the network choice of airlines, and provide prescriptions by which policy makers make air-transportation market more efficient. In order to achieve the purpose, I relax some of assumptions which are set in previous papers. In chapter 2, I establish the model where locations of airports and populations of cities are arbitrary, which enable me to analyze the welfare loss for each origin-destination market. In chapter 3, the location of hub airport is determined endogenously, which allow me to investigate competition between airports for the hub position. In chapter 4, I focus on flight schedules to study the condition where airline competition should be introduced in terms of social welfare.

1.4. Plan of the Thesis and Preview of Results

This thesis proposes different models to answer various research questions and provide policy implications. Chapter 2 and 3 investigate pricing strategies of private airports. Chapter 2 studies airports in a hub-spoke network. The network is given exogenously while locations of local airports and population of local cities are arbitrary. Chapter 3 deals with airport competition for hub position. The model treats network endogenously by considering airline's decision on its route, and captures the strategy of each airport to be hub.

Chapter 4, which consists of both empirical and theoretical parts, analyses the effects of airline competition on flight schedules and social welfare. The empirical part checks the relationship between the competition and un-evenness of flight schedules. Then, the theoretical part clarifies the condition in which monopoly is better than competition for the social welfare. The basic setting and main results of each chapter are followings.

1.4.1. Airport Pricing of Private Airports in an Asymmetric Hub-Spoke Network

The purpose of Chapter 2 is to investigate pricing strategies of private airports in the asymmetric hub-spoke network. In the model, the hub-spoke network consists of one hub airport and the arbitrary number of local airports. The hub airport charges the different amount of airport fees on its departing passengers and transit passengers. The airline provides flight services and consumers decide their demand for air-travel according to the generalized cost.

The summary of results is following. First, local airports which are far from the hub set their airport fees low. This is because the demand from a spoke airport gets smaller as the distance between the spoke and the hub increases, due to the airline's high operating cost and high airfare. Second, the hub airport lowers its transit fee when the hub airport gathers transit passengers from local airports which are far from the hub. Transit passengers from distant local airports pay high airfare. Therefore, the hub needs to offer the discount of transit fee to increase transit demand.

Finally, we propose the policy implication from the viewpoint of price discrimination. In real, the hub airport applies the single transit fee to all transit passengers. However, the social welfare can be improved by allowing the hub airport to charge different transit fees according to the original local airports of transit passengers.

1.4.2. Price Competition of Airports and its Effect on the Airline Network

The purpose of Chapter 3 is to investigate price competition between two airports for the hub position. Especially, we clarify the mechanism; why relatively small airport (e.g., Singapore Changi airport in ASEAN region or Frankfurt airport in Germany) can be the hub of a network. We construct the model that includes the following two features: i) the airline can choose its network configuration (point-to-point or hub-spoke) and ii) two airports compete for airport charges by considering the airline's choice.

The summary of results is following. First, the relatively small airport is aggressive to discount its airport fee to be hub since small airport can increase its demand greatly by acquiring transit passengers. This is the reason relatively small airport is chosen as the hub airport. Second, a hub-spoke-network (point-to-point network) is realized if the fixed cost of an international flight is small (large) and the distance between two airports is short (long).

Finally, we compare the equilibrium network and optimal network to capture the network distortion by the airport competition. We find that a point-to-point network is more likely to be realized in equilibrium than in optimal, and that the relatively small airport shouldn't be the hub in optimal. To solve these distortions, we propose political implication that both the under and upper limit regulations on airport fees are needed.

1.4.3. The Effects of Airline Competition on Flight Schedules and the Social Welfare

The purpose of Chapter 4 is to investigate whether the new entrance and airline competition improve the social welfare or not. In general, it is thought that competition leads to lower price, and government should introduce and promote competition. However, by taking into account flight schedules, we may find the case in which competition harms the social welfare.

At first, we construct the empirical model to study the relationship between airline competition and un-evenness of flight schedules. Next, we develop theoretical model to clarify the condition in which monopoly is better than competition for the social welfare. The summary of results is following. First, airline competition leads to un-even flight schedules. This un-even schedule raises schedule delay cost (the valuation of the time difference between the desired departing time and the actual departing time). Second, the increment of schedule delay cost is large for routes with low frequency. This means that the negative effect of competition is large for such routes. Third, monopoly is better than competition for routes with low flight frequency and vice versa. This is because the negative effect (increasing schedule delay cost) dominates the positive effect (lowering airfares) in low frequency routes. Therefore, government should keep monopoly for low-demand local routes.

Chapter 2

Airport pricing of private airports in a Asymmetric Hub-Spoke Network

2.1. Introduction

After the liberalization in the aviation industry, the networks of airlines changed from the point-to-point to the hub-spoke design. As a result, passengers departing from airports at a spoke node (local airport) now have to transit at a hub when they travel. This transit at the hub imposes some additional costs on passengers from local airports. Therefore, transit passengers incur larger trip cost than those departing from hub airports. The cost related to the transit may include the airport fee payment; that is, transit passengers have to pay the airport fees at the departing local and hub airports. However, hub airport operators offer a discounted fee for transit passengers. Figure 2-1 summarizes the ratio of the discounted transit airport fee against the departing airport fee for the five largest airports in Europe in 2011: London Heathrow (LHR), Charles de Gaulle (CDG), Frankfurt (FRA), Amsterdam (AMS) and Madrid (MAD). In Figure 1, the degree of the discount differs among these five airports: LHR offers the highest transit fee, 82% of the departing fee, while MAD offers the lowest, 53% of the departing fee. Here, the fees include both airline fees (landing fees, noise charges and parking charges) and passenger fees (the Passenger Service Facility Charge (PSFC) and Passenger Security Service Charge (PSSC)). The object of discount is the latter.

The formation of the hub-spoke network may also affect the local airport fee. Figure 2-2 shows the relationship between the fee of European airports and the minimal distance to the five largest airports in Europe: LHR, CDG, FRA, AMS, and MAD. Each dot represents an European airport with more than one million passengers in 2011, while the bold line in Figure 2-2 represents the fitted line. The fitted line may suggest that the airport fee decreases as the minimal distance to the major hubs increases. This chapter aims to clarify the mechanisms of the data presented in Figures 2-1 and 2-2; that is, (i) why do local airports, which are farther from the hubs, set their airport fees lower and (ii) what is the determinant of the discount rate for the transit passengers offered by hub airports?

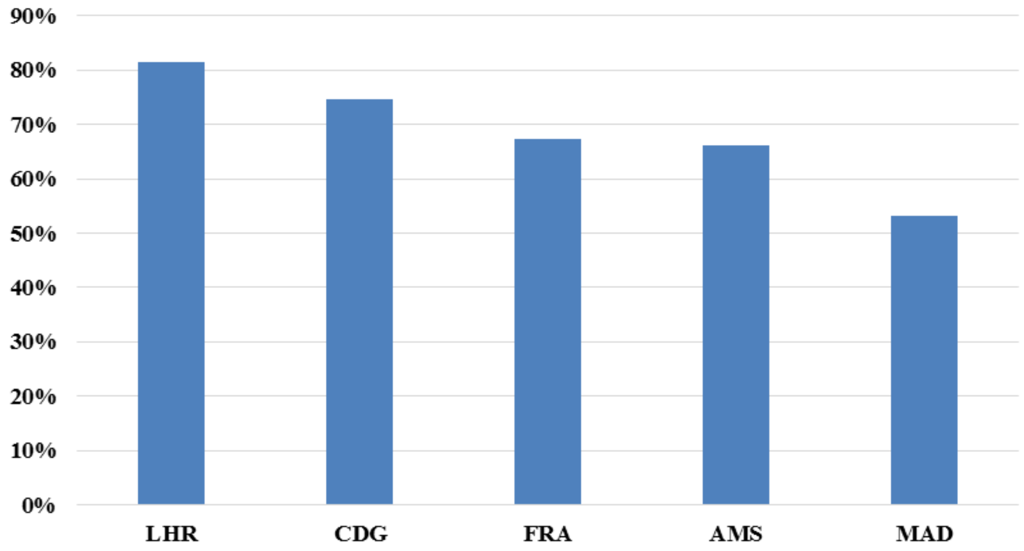

Figure 2-1: The ratio of the transit fee against the departing fee*

*This figure compares the fees of departing and transit passengers from a B787 passenger jet (280 seats). To compute the fees, we use the IATA Airport, ATC and Fuel Charges Monitor (IATA, 2013) and set several assumptions: the aircraft utilises the parking for three hours during the daytime; the loading factor is 71%; and the MTOW (Maximum Takeoff Weight) is 301 t.

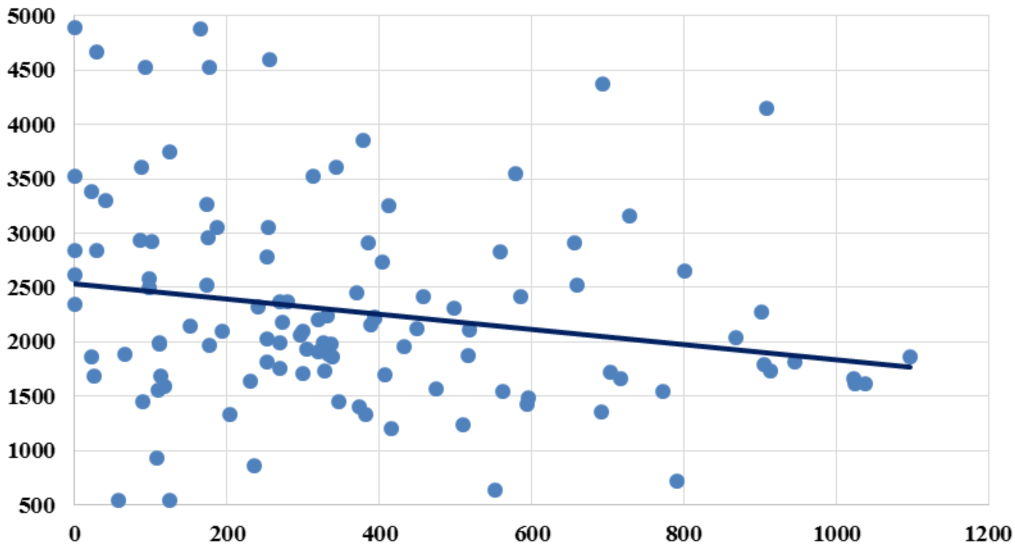

Figure 2-2: The relationship between the airport fee and the distance to the hub*

*: This figure demonstrates the departing fees for passengers boarding a B787 passenger jet (280 seats) for European international airports, which are appeared in the IATA Airport, ATC and Fuel Charges Monitor (IATA, 2013). In computing the airport charges, we set the same assumptions as in Figure 1.

Silva and Verhoef (2013), Silva et al. (2014), Pels and Verhoef (2004) and Czerny and Zhang (2015) examined welfare-maximizing public airports. These studies showed that optimised airport charges internalize congestion externalities and correct the inefficiency caused by airlines' market power exertion. However, research focused on private airports is needed because many airports all over the world, especially in the United Kingdom, have been privatized, or undergoing the process of privatization.

Focusing on the private airport setting, airport competition is the largest concern. Teraji and Morimoto (2014) explained the mechanism whereby airports in relatively small cities are chosen as hub airports by the model in which two airports compete for the hub position. Kawasaki (2014) studied price discrimination strategy of two competing airports. Czerny et al. (2013) focused on competition between two ports in two countries for demand in a third region. These studies have a problem in which they assume a symmetric network or focus only on one or two airports.

We develop the model with private airports in an asymmetric hub–spoke network to analyze how distance between the hub and spoke airports affects airport charges. In the model, spoke airports locate at an arbitrary distance from the hub and the number of local airports is also arbitrary.

The rest of this chapter is organized as follows. In Section 2.2, we describe the model, which is used to clarify the reason why local airports that are farther from the hubs set their airport fees lower and what affects the discount rate for the transit passengers at hub airports. In Section 2.3, we solve the game among airports and compare the analytical results with some stylized facts described above. In Section 2.4, we derive the welfare effect for each local market and analyse how the distance to the hub affects the welfare loss of each market. In Section 2.5, we suggest the discriminatory pricing policy to improve the social welfare. Finally, Section 2.6 states concluding remarks.

2.2. The Model

Let us consider a situation in which an airline connects $S+1$ airports with a foreign country by forming a hub-spoke network as shown in Figure 2-3.[3] In Figure 2-3, γ_s represents the distance between the hub and each spoke s, and we normalize the distance between the hub and foreign country to 1. Hereafter, we refer to the hub airport as *Airport h*, each local airport as *Airport s* $(s = 1, 2, \ldots, S)$, and *City i* $(i = h \text{ and } 1, 2, , S)$ is the city in which *Airport i* is located. The population of *City i* is represented by n_i and we normalize the population of *City h* to 1, $n_h = 1$.

[3] Long-haul flights from *Airport h* to the foreign county represent flights such as those from Europe to Asia or to the United States.

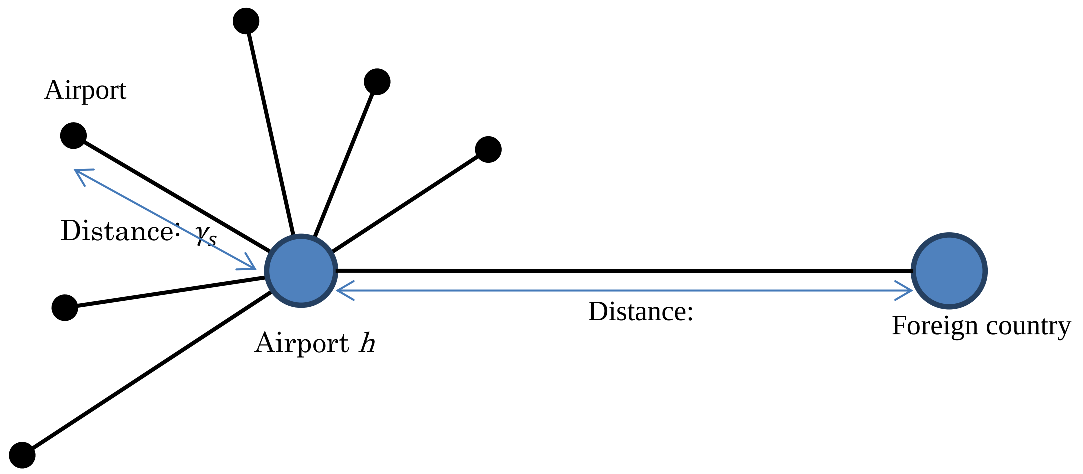

Figure 2-3: Hub–Spoke Network

The economy has three agents: airports, airline, and consumers. The sequence of decisions among these agents is as follows. First, all airports set their airport fees simultaneously to maximize their revenue. Second, the airline sets its fares to maximize its profit. Finally, consumers in each city decide their demand for flights to the foreign country. Hereafter, we trace the decision-making process.

The demand for air services is

$$d_h = 1 - p_h - a_d \tag{1.1}$$

$$d_s = n_s(1 - p_s - a_t - a_s) \quad \text{for } s = 1, 2, \dots S, \tag{1.2}$$

where p_i denotes the airfare. a_d and a_t denote the airport fees of the hub for the departing passengers and for the transit passengers, respectively. We call the former "departing fee" and the latter "transit fee." In Eq. (1.2), a_s is the airport fee of a local airport. Hereafter, we refer to passengers departing from *Airport h* as "hub passengers" and passengers departing from *Airport s* as "local passengers."

The airline creates the hub-spoke network and provides two types of flights, connecting flights between *Airport h* and each local airport, and direct flights between *Airport h* and the foreign country. We assume that the airline's operating cost is proportional to the passenger-kilometer. Specifically, operating cost per passenger is $c\gamma_s$ for the connecting flight and c for the direct flight. The total operating cost is

$$C = cd_h + \sum_{s=1}^{S}(1+\gamma_s)cd_s. \tag{2}$$

The first term is the operating cost for shipping hub passengers and the second term is the operating cost for shipping local passengers. Here, we assume that the airline does not pay airport fees. In reality, while airlines pay airport fees such as landing, aircraft parking, and handling fees, they are shifted onto passengers through the airfare. Therefore, the equilibrium demand and social welfare are given just as functions of total airport fees (= the sum of all the fees levied by airport operators). Therefore, in our model, only passengers pay airport fees. Similar assumptions are used in Oum et al. (1996) and Kawasaki (2014).

Using (2), we obtain the airline's profit as

$$\pi = (p_h - c)d_h + \sum_{s=1}^{S}[p_s - (1+\gamma_s)c]d_s. \tag{3}$$

The first term is the profit from hub passenger and the second term is the profit from spoke passenger. The airline sets its airfare p_i to maximize profit:

$$\max_{p_i} \pi.$$

We obtain airfares from the first-order conditions as follows:

$$p_h = \frac{1 + c - a_d}{2}, \tag{4.1}$$

$$p_s = \frac{1 + (1+\gamma_s)c - a_t - a_s}{2}. \tag{4.2}$$

Substituting these two equations into equations (1), we rewrite the demand as a function of airport fees, a_d, a_t, and a_s:

$$d_h = \frac{1 - c - a_d}{2}, \tag{5.1}$$

$$d_s = \frac{n_s[1 - (1+\gamma_s)c - a_t - a_s)]}{2}. \tag{5.2}$$

Each airport levies airport fees on passengers. Total fee revenue is computed as

$$R_h = a_d d_h + a_t \sum_{s=1}^{S} d_s, \tag{6.1}$$

$$R_s = a_s d_s. \tag{6.2}$$

The first term of (6.1) is the revenue from hub passengers and the second term is from local passengers. We ignore airports' operating cost; therefore, private airports set their airport fees to maximize their fee revenue, that is,

$$\max_{a_i, t_i} R_i.$$

2.3. Equilibrium

This section derives the equilibrium airport fees in the hub-spoke network. Furthermore, we verify the stylized facts given in Figures 2-1 and 2-2; specifically, whether the distance to the hub affects the airport fees of each local airport and whether the hub operator reduces its transit fee as the network size expands. In Subsection 2.3.1, we solve the game among airports, and Subsection 2.3.2 uses this solution to check if the two stylized facts work in our setting.

2.3.1. Equilibrium Airport Fees

Solving each airport's revenue maximizing problem, we obtain the best reaction functions as follows:

$$a_d = \frac{1-c}{2}, \tag{7.1}$$

$$a_t(a_1, \dots, a_s) = \frac{1-c}{2} - \frac{1}{2}\left(c\bar{\gamma} + \frac{\sum_{s=1}^{S} a_s n_s}{\sum_{s=1}^{S} n_s}\right), \tag{7.2}$$

$$a_s(a_t) = \frac{1-(1+\gamma_s)c - a_t}{2}. \tag{7.3}$$

Here, $\bar{\gamma} \equiv \sum_{s=1}^{S} n_s \gamma_s / \sum_{s=1}^{S} n_s$ is the population-weighted average distance between the hub and local airports. See **appendix A** for the derivation of the best responses and equilibrium airport fees. According to equations (7), we obtain Lemma 1:

Lemma 1

The transit fee of the hub and the airport fee of local airports are strategic substitutes.

For local passengers, airport services at the hub and each local airport are complementary goods. Therefore, if one airport increases its fee, the other airport has to decreases its fee.

By solving equations (7), we obtain the equilibrium airport fees as

$$a_d = \frac{1-c}{2}, \tag{7.1}$$

$$a_t = \frac{1-(1+\bar{\gamma})c}{3}, \tag{8.1}$$

$$a_s = \frac{1-c}{3} + \frac{1}{6}c(\bar{\gamma} - 3\gamma_s). \tag{8.2}$$

2.3.2. Pricing Strategies of Private Airports

In this subsection, we discuss pricing strategies by focusing on the distance. We start with airport fees of local airports. Hereafter, *Airport* s' is farther from the hub than *Airport s*, that is, $\gamma_{s'} > \gamma_s$. From (8.2), we obtain

$$\begin{aligned} a_s - a_{s'} &= \frac{c}{6}(\bar{\gamma} - 3\gamma_s) - \frac{c}{6}\left(\bar{\gamma} - 3\gamma_{s'}\right) \\ &= \frac{c}{2}\left(\gamma_{s'} - \gamma_s\right) > 0. \end{aligned}$$

This result is summarized in Proposition 1.

Proposition 1

Airport fees of the local airport decreases as the distance to the hub, γ_s, *increases.*

Demand for connecting flights decreases and becomes more elastic as the distance between a local airport and the hub increases because airfares become higher due to the airline's higher operating cost. Therefore, the local airport lowers its airport fee to boost demand. This result explains the fitted line in Figure 2-2. When the distance to the hub is long, the local airport chooses the lower airport fee, which offsets the higher airfare and increases the demand.

We move to pricing strategies of the hub airport and investigate the discount for transit passengers. According to (7.1) and (8.1), we obtain the ratio of the transit fee to departing fee as follows:

$$\frac{a_t}{a_d} = \frac{2}{3} - \frac{2c}{3(1-c)}\bar{\gamma}. \tag{9}$$

Differentiating (9) with respect to $\bar{\gamma}$, we obtain Proposition 2.

Proposition 2

The ratio of the transit fee to the departing fee decreases as the weighted average distance, $\bar{\gamma}$*, increases.*

The hub lowers its transit fee and compensates for higher airfare of local routes to attract more transit passengers when local airports are located far from the hub. On the other hand, the departing fee is independent from the location pattern of local airports. Therefore, the transit fee gets relatively small compared to the departing fee as the average distance becomes large. Note that in Figure 2-1, the discount ratio of MAD is the lowest among the five largest airports. This can be interpreted as follows. Since MAD locates at the fringe of Europe compared to the other four airports, the operator of MAD discounts the transit fee more than the others to attract more transit passengers from local airports.

2.4. Welfare Analysis

This section clarifies the effect of distance to the hub upon the social welfare for each local route. To deal with this problem, we designate *Route s* as the route from *Airport s* to the foreign country via the hub. We define the social welfare for *Route s* as the gross consumer benefit minus the social cost.

$$W_s = \frac{1}{2}(1 + p_s + a_t + a_s)\, d_s - (1 + \gamma_s)cd_s. \tag{10}$$

The first term is the lower part of the inverse demand function and the second term is the operating cost. The social welfare in the equilibrium is

$$W_s^* = \frac{1}{288}(21X_s + Y)(3X_s - Y)n_s. \tag{11}$$

Here, $X_s = 1 - c - c\gamma_s$ and $Y = 1 - c - c\bar{\gamma}$.

At the optimum, airfare should be equal to the airline's marginal cost, and airport fees should be zero. Therefore, the social welfare in the optimum, W_s^o, is

$$W_s^o = \frac{1}{2}X_s^2 n_s. \tag{12}$$

See **Appendix B** for the derivation of these social welfare functions. The welfare loss is $W_s^o - W_s^*$, and we define the welfare loss ratio on *Route s* as

$$\begin{aligned}\theta_s &\equiv \frac{W_s^o - W_s^*}{W_s^o} \\ &= \frac{1}{144}\left(81 + 18\frac{Y}{X_s} + \frac{Y^2}{X_s^2}\right).\end{aligned} \tag{13}$$

This ratio indicates the degree of market distortion. A large θ_s means large welfare loss and large market distortion.

To analyze the relationship between the welfare loss and the distance, let us compare the two local airports, s and s' $(\gamma_{s'} > \gamma_s)$. From (13), we can state

$$\theta_s - \theta_{s'} = \frac{1}{144}\left[18\left(\frac{1}{X_s} - \frac{1}{X_{s'}}\right)Y + \left(\frac{1}{X_s^2} - \frac{1}{X_{s'}^2}\right)Y^2\right] < 0.$$

Since, $\gamma_{s'} > \gamma_s$, then $X_{s'} = 1 - c - c\gamma_{s'} < X_s = 1 - c - c\gamma_s$; therefore, $\theta_s < \theta_{s'}$. Summarizing this, we obtain Proposition 3.

Proposition 3

The welfare loss ratio, θ_s*, increases as the distance between the hub and local airport,* γ_s*, increases.*

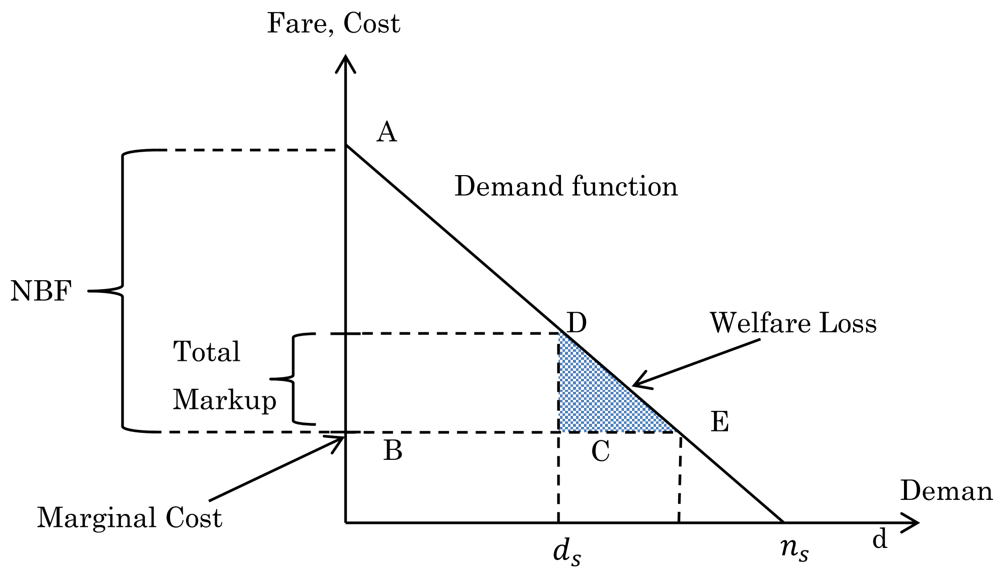

Figure 2-4: Welfare Loss for Route *s*

This result is derived from the hub's transit fee which is identical for all transit passengers. To clarify this mechanism, we define the "Net Benefit of the First trip (NBF_s)" and the "Total Markup (TM_s)." NBF_s captures the net social gain of the first trip along *Route s*, which is computed as the highest willingness to pay (equal to unity) minus marginal cost of the flight operation, $(1+\gamma_s)c$. That is, $NBF_s = 1-(1+\gamma_s)c$. TM_s captures the aggregate private gains of the airline, the hub and *Airport s*: that is,

$$TM_s = [p_s - (1+\gamma_s)c] + a_t + a_s = \frac{1 + a_t + a_s - (1+\gamma_s)c}{2}$$
$$= \frac{1-(1+\overline{\gamma})c}{12} + \frac{9\{1-(1+\gamma_s)c\}}{12} = \frac{Y}{12} + \frac{9X_s}{12}. \qquad (14)$$

In Figure 2-4, the area CDE is the welfare loss and the area ABE is the social welfare in the optimum. Since the slope of the demand curve is unity, according to Figure 2-4, the welfare loss ratio is written as $\theta_s = (TM_s/NBF_s)^2$. While both TM_s and NBF_s decreases in γ_s, the decrease of TM_s is less significant than NBF_s due to the identical transit fee at the hub. Therefore, θ_s is increasing in γ_s.

In this section, we analyzed social welfare for each route under the identical transit fee. Next, we evaluate the welfare effect of the "discriminatory fee scheme" under which the hub can set different transit fees for each route.

2.5. Discriminatory airport fee policy

Proposition 3 shows that the relative welfare loss is increasing with the distance to the hub due to the uniform transit fee at the hub. To avoid the welfare loss due to the uniform transit fee, we consider the case where the hub can set its transit fee for each local route separately according to the demand elasticity. We call this case "discriminatory fee case." In this case, the hub's revenue maximizing problem is reduced to maximize the fee revenue for each route. That is,

$$\max_{a_{t,s}} a_{t,s} d_s.$$

Here, $a_{t,s}$ is the transit fee for *Route s* passengers. The best response is

$$a_{t,s}(a_s) = \frac{1-(1+\gamma_s)c - a_s}{2}.$$

Using the spoke's best response, (7.3), we obtain the transit fee as

$$a_{t,s}^{d} = a_{s}^{d} = \frac{1-(1+\gamma_s)c}{3}.$$

In the discriminatory fee scheme, TM_s^d is computed as:

$$TM_s^d = [p_s - (1+\gamma_s)c] + a_{t,s}^{d} + a_s^d = \frac{5\{1-(1+\gamma_s)c\}}{6} = \frac{5X_s}{6}. \qquad (15)$$

In contrast, the total markup under the uniform fee scheme, TM_s^u, is computed in Eq. (14). In comparison of these two,

$$TM_s^u - TM_s^d = \frac{Y}{12} + \frac{9X_s}{12} - \frac{5X_s}{6} = \frac{c(\gamma_s - \bar{\gamma})}{12}.$$

This indicates that, for the routes where $\gamma_s > \bar{\gamma}$, the discriminatory fee scheme improves the economic welfare. This is because, in these routes, the discriminatory fee scheme results in the airport fee payments reduction[4] and the lower total mark up. In contrast, due to the rise in the airport fee payments, the economic welfare of the routes for $\gamma_s < \bar{\gamma}$ is decreased when the discriminatory fee scheme is introduced.

Next, we focus on change in the welfare loss of the entire network. Because the welfare loss for each route is expressed as the triangle CDE in Figure 2-4, the loss for each route

[4] The differentials in the fees incurred by transit passengers in two cases are computed as:

$$a_t^u - a_{t,s}^d = \frac{1}{3}(\gamma_s - \bar{\gamma})c,$$

$$a_s^u - a_s^d = \frac{1}{6}(\bar{\gamma} - \gamma_s)c.$$

Superscripts u and d indicates the uniform fee and the discriminatory fee cases, respectively. Also note that the fees under the uniform case (with the superscript u) are derived as in Eqs. (8).

is calculated as $n_s TM_s^2/2$. Aggregating the loss for all routes, the differential in the welfare loss of the entire network under the two alternative fee schemes is computed as:[5]

$$\Delta WL = \sum_{s=1}^{S} \frac{n_s \left({TM_s^d}^2 - {TM_s^u}^2 \right)}{2}. \tag{16}$$

If this sign is negative, the discriminatory fee scheme is more efficient than the uniform scheme; that is, the discriminatory fee scheme improves the economic welfare. To obtain a clear result, we assume that all local cities have the same population, that is, $n \equiv n_1 = n_2 = \cdots = n_S$. We rewrite Eq. (16) as:

$$\Delta \mathrm{SW} = \frac{1}{288S} nc\sigma^2 > 0, \tag{17}$$

where σ^2 is the variance of γ_s [see Appendix C for derivation of Eq. (17)]. This result is summarised as follows:

Proposition 4

When all the local cities have an identical population size, the discriminatory fee scheme is more efficient than the uniform scheme in terms of the entire welfare.

[5] Since, under the two alternative fee schemes, the hub passengers incur an identical airfare and airport fee, the loss at the hub airport remains at the same level; therefore, we ignore the change in the loss at the hub.

As shown in Proposition 4, when all the spoke cities have an identical population size, the policy maker can improve social welfare by allowing airports to discriminate passengers in setting airport fees. However in reality, price discrimination is banned in many countries. For example, the EU Airport Charges Directive (2009/12/EC) prohibits differentiated fees to airlines using the same service. In the US, airports are compelled to offer same fees for same service by 2013 FAA's Policy Regarding Airport Rates and Charges. Since these restrictions harm social welfare, we suggest that the discriminatory fee scheme should be introduced based on our results.

2.6. Conclusion

In this chapter, we analyzed airport pricing in an asymmetric hub-spoke network and obtained three results. First, the airport fees of a local airport decreases as the distance to the hub increases. This is because the demand from the local airport gets relatively smaller as the distance between the local and the hub increases, due to the high operating cost and airfare. Second, the ratio of the transit fee to the departing fee diminishes as the weighted average distance increases. Demand of a local route is a decreasing function of the distance. Therefore, the hub lowers its transit fee in attempt to boost the demand for transit services when local airports locate far from the hub at average. Third, the welfare loss ratio increases as the distance between the hub and local airport increases. The mark-up ratio of a long local route is large due to the identical transit fee. According to the large mark-up ratio, the welfare loss ratio also becomes large. Moreover, we showed the possibility that the discriminatory fee scheme improves the social welfare.

We need to extend our model in two aspects. First, we should consider airport groups and alliances among airports. If some airports are in one group or operated by a parent company, airport operators try to maximize the total profit of their group or company. Second, we should establish a model in which network structures are endogenous. It is often observed that some large airports compete for hub positions. Such competitions lead to discount of airport fees. In chapter 3, we tackle the second extension, i.e., endogeneity of the airline networks and analyze competition between airports.

Appendix A: Derivation of best responses

We differentiate (6.1) with respect to a_h and t_h, and the first order conditions for the revenue maximization problem are:

$$\frac{\partial R_h}{\partial a_d} = d_h + a_d \frac{\partial d_h}{\partial a_d} = 0, \tag{A.1}$$

$$\frac{\partial R_h}{\partial a_t} = \sum_{s=1}^{S} d_s + a_t \sum_{s=1}^{S} \frac{\partial d_s}{\partial a_t} = 0. \tag{A.2}$$

Here,

$$\frac{\partial d_h}{\partial a_d} = -\frac{1}{2}. \tag{A.3}$$

We differentiate (6.2) with respect to the total fee, a_s, and the first order condition is

$$\frac{\partial R_s}{\partial a_s} = d_s + a_s \frac{\partial d_s}{\partial a_s} = 0. \tag{A.4}$$

Here,

$$\frac{\partial d_s}{\partial a_s} = \frac{\partial d_s}{\partial a_t} = -\frac{1}{2} n_s. \tag{A.5}$$

We arrange (A.1), (A.2), and (A.5) for a_d, a_t, and a_s using (A.3) and (A.5) and obtain

$$a_d - \frac{1-c}{2} = 0, \tag{A.6}$$

$$\frac{a_t}{2} \sum_{s=1}^{S} n_s + \sum_{s=1}^{S} \frac{a_s n_s}{2} - (1-\mathrm{c}) \sum_{s=1}^{S} n_s + c \sum_{s=1}^{S} \gamma_s n_s = 0, \tag{A.7}$$

$$a_t + a_s - \frac{1-(1+\gamma_s)c}{2} = 0. \tag{A.8}$$

Solving (A.7) for a_t, we obtain

$$a_t = \frac{1-c}{2} - \frac{1}{2}\left(c\bar{\gamma} + \frac{\sum_{s=1}^{S} a_s n_s}{\sum_{s=1}^{S} n_s} \right). \tag{A.9}$$

Here,

$$\bar{\gamma} \equiv \frac{\sum_{s=1}^{S} n_s \gamma_s}{\sum_{s=1}^{S} n_s}.$$

Solving (A.8) for a_s, we obtain

$$a_s = \frac{1-(1+\gamma_s)c - a_t}{2}. \tag{A.10}$$

Appendix B: Derivation of social welfare

(i) The social welfare in the equilibrium

Plugging (1) into (11), we delete d_s and obtain

$$W_s^* = \left[\frac{1}{2}(1+p_s+a_t+a_s) - (1+\gamma_s)c\right](1-p_s-a_s-a_t)n_s. \tag{B.1}$$

Plugging (4.2) into (B.1), we delete p_s and obtain

$$W_s^* = \frac{1}{8}[3-3(1+\gamma_s)c+a_t+a_s][1-(1+\gamma_s)c-a_t-a_s]n_s. \tag{B.2}$$

Plugging (8.1) and (8.3) into (B.2), we delete a_t and a_s and obtain

$$\begin{aligned} W_s^* &= \frac{1}{288}(22-22c-21\gamma_s c - \bar{\gamma}c)(2-2c-3\gamma_s c+\bar{\gamma}c)n_s \\ &= \frac{1}{288}(21X_s+Y)(3X_s-Y)n_s. \end{aligned} \tag{B.3}$$

Here, $X_s = 1-c-c\gamma_s$ and $Y = 1-c-c\bar{\gamma}$

(ii) The social welfare in the optimum condition

Conditions for the optimum are that airfare should be equal to the airline's marginal cost and that airport fees should be zero. Under these conditions,

$$a_d = a_t = a_s = 0, \tag{B.4.1}$$

$$p_s = (1 + \gamma_s)c. \tag{B.4.2}$$

And then, the demand in the optimum is

$$d_s = n_s[1 - (1 + \gamma_s)c]. \tag{B.4.3}$$

Plugging (B.4)s into (11), we obtain the welfare function in the optimum as

$$\begin{aligned} W_s^o &= \frac{1}{2}(1 - c - c\gamma_s)n_s \\ &= \frac{1}{2}X_s^2 n_s. \end{aligned}$$

Appendix C: Comparison of two airport fee schemes

The difference of the social welfare under both schemes is

$$\begin{aligned} \Delta WL &= \frac{1}{2}n\sum_s[(TM_s^d)^2 - (TM_s^u)^2] \\ &= \frac{1}{2}n\sum_s(TM_s^d + TM_s^u)(TM_s^d - TM_s^u). \end{aligned} \tag{C.1}$$

Here,

$$TM_s^d + TM_s^u = \frac{1}{12}(20 - 20c - c\bar{\gamma} - c\gamma_s),$$

$$TM_s^d - TM_s^u = \frac{1}{12}(\bar{\gamma} - \gamma_s).$$

Substituting them into Eq. (C.1) and we obtain

$$\begin{aligned}\Delta WL &= \frac{1}{288}n\sum_s[(20 - 20c - c\bar{\gamma} - c\gamma_s)(\bar{\gamma} - \gamma_s)] \\ &= \frac{1}{288}n\sum_s[c\gamma_s^2 - 20(1-c)\gamma_s - c\bar{\gamma}^2 - 20(1-c)\bar{\gamma}] \\ &= \frac{1}{288}n\left[c\sum_s\gamma_s^2 - 20(1-c)\sum_s\gamma_s - Sc\bar{\gamma}^2 + 20S(1-c)\bar{\gamma}\right]. \qquad (\mathrm{C.2})\end{aligned}$$

Because $n \equiv n_1 = n_2 = \cdots = n_S$, we rewrite the weighted average distance as:

$$\bar{\gamma} = \frac{\sum_s \gamma_s}{S} \Leftrightarrow \sum_s \gamma_s = S\bar{\gamma}.$$

We simplify Eq. (C.2) as:

$$\begin{aligned}\Delta WL &= \frac{1}{288}n\left(c\sum_s\gamma_s^2 - Sc\bar{\gamma}^2\right) \\ &= \frac{1}{288S}nc\left(\frac{\sum_s \gamma_s^2}{S} - \bar{\gamma}^2\right) \\ &= \frac{1}{288S}nc\sigma^2 > 0,\end{aligned}$$

where $\sigma^2 \equiv \left(\frac{\sum_s \gamma_s^2}{S} - \bar{\gamma}^2\right) > 0$ is the variance of γ_s.

Chapter 3

Price Competition of Airports and its Effects on Airline Network

3.1. Introduction

In recent decades, liberalization of the aviation industry has been practiced through airport privatization, airline deregulation, and “Open Skies” agreements. Airport privatization has caused airport operators to focus on the profits from their airports more significantly than those before such privatization while airline deregulation and Open Skies agreements have loosened constraints on carriers’ network choice. Observing these several changes in the aviation industry, Graham (2008) claims that carriers consider low airport charges as a key factor in their decisions regarding the airports to which they will provide flight services. This indicates that airport operators may have incentives to discount their airport charges in order to be selected as a flight destination or a hub airport. In fact, Kuala Lumpur International Airport (KUL) introduced a discount program in which landing fees for new routes and increased frequencies are discounted 100% for three years. This KUL program has a significant effect on the carriers' network choices:[6] for example, in 2013, Turkish Airlines launched direct flight service between KUL and Istanbul instead of the former one-stop service via Bangkok. This shows that operators can induce the carrier to form a favorable network for them by discounting their charges.[7] In this chapter, we focus on the following issues: i) whether airport operators discount their airport charges; ii) if so, when does price competition between airports occurs? By dealing with these questions, we investigate the problem how such discounts and competitions affect network structures.

After the seminal works of Starr and Stinchcombe (1992) and Hendricks et al. (1995), several studies have focused on the carrier's network choice (for example, Brueckner 2004; Kawasaki 2008; Flores-Fillol 2009).[8] More specifically, these papers focused on the carrier's tradeoff between the hub-spoke and point-to-point networks, namely the scale economy of the hub-spoke network (density and distance economies) and the additional operating costs for providing connecting flights. Although Graham (2008)

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[6] Indeed, as a result of this program, KUL has experienced a significant increase in the number of passengers (from 21 million in 2004 to 40 million in 2012), which is much faster than Singapore Changi Airport and New Bangkok International Airport.

[7] Consequently, the price competition among airports is observed in several regions. In East Asia, for example, Narita International Airport (NRT) cut its charges in 2013 to enforce competitive power against Incheon International Airport, which offers lower airport charges to carriers than NRT.

[8] Brueckner (2004) analyzes the topic using three airports and a monopolistic carrier model. The carrier chooses a hub-spoke network when the fixed cost for a flight is high relative to the marginal cost for a seat and when passengers place a high value on flight frequency. Kawasaki (2008) extends the model of Bruechner (2004) by introducing the heterogeneity in value of time among passengers, leisure, and business demands. Flores-Fillol (2009) extends the model by considering the duopoly case and shows that asymmetric equilibria may arise, namely one carrier chooses a point-to-point network while the other chooses a hub-spoke network.

claims that the airport operators' choices are additional key determinants in the network choice of carriers, these papers ignore the behavior of operators. In addition, the pricing policy at airports itself is another topic that is drawing attention (Oum et al. 1996; Brueckner 2002; Pels and Verhoef 2004; Zhang and Zhang 2006; Morimoto and Teraji 2013). These studies that deal with the pricing policy presume the carrier's network is fixed, and focus on its direct effect on the hinterland's welfare. The airport pricing policy, however, may indirectly affect the welfare of its hinterland through the change in the carrier's network.[9] To capture this effect, it is important to focus on competition among airports, and this type of competition has also been studied. Most of studies in this strand (Pels et al. 2000; De Borger and Van Dender 2006; Basso and Zhang 2007; Mun and Teraji 2012) focus on the competition between airports in a relatively small region (for example, airports in a metropolitan area). Therefore, the carrier's network choice, point-to-point or hub-spoke, is not considered. Competition in a relatively large region (for example, airports in multiple countries) is studied in Matsumura and Matsushima (2012) and Czerny et al. (2013). These studies deal with competition between countries for the infrastructure operation, but the carrier is not allowed to choose its network configuration.

[9] Congestion and the carrier's network choice are studied in Fageda and Flores-Fillol (2013). However, they deal with the effect of the carrier's network choice on congestion.

We establish a model that enables us to investigate the interaction between airport competition and the carrier's network choice. Specifically, we focus on multiple airports that are competing in a specific region: for example, the airport competition between Narita International Airport and Incheon International Airport in the East Asian region. The monopoly carrier provides international flight services from a continent, for example, East Asia, to another continent such as the United States or Europe. When providing the service, the carrier chooses one of two networks: i) it directly connects all airports in a region with the final destination (point-to-point) or ii) it directly connects one of the airports in a region (the hub) to the final destination and provides connecting flights between the hub and the other airports (hub-spoke). In the model, the airport operators first set their airport charges and second, the carrier decides its network configuration. Therefore, each operator considers the carrier's network choice when in setting the charges. By employing this model, we deal with the question of how the price competition among airports distorts the carrier's network choice. In addition, through the analysis, we also show the distortion by the private operation of the airports.

The remainder of this chapter is organized as follows. Section 3.2 describes the model while Section 3.3 focuses on the optimal network, which is the reference for the comparison with the equilibrium network. Section 3.4 derives the equilibrium network in which airport operators compete via airport charges, and Section 3.5 evaluates the welfare effect of airport competition by comparing the equilibrium network with the optimal one. Finally, Section 3.6 provides some concluding remarks.

3.2. The Model

3.2.1. The Basic Setting

Suppose that an economy consists of two cities: Cities 1 and 2. Residents in each city travel to the foreign country in another continent using the airport at their residence. We assume that each airport is operated by a private firm, and we call operator i the one who manages Airport i. A monopoly carrier provides the intercontinental air service from these two airports to the foreign country. When providing the intercontinental air service, the carrier makes a network choice (point-to-point or hub-spoke). The carrier also determines which airport would be the hub if it chooses the hub-spoke network. Figure 3-1 summarizes the three possible network configurations. In Figure 3-1, network P is the point-to-point while network H_i corresponds to the hub-spoke case in which Airport i (i = 1, 2) is the hub. Moreover, note that l_{12} and l_{iF} in Figure 3-1 represent the distance between Airports 1 and 2, and the distance from Airport i to the foreign country, respectively. In addition, we assume that $l_{12} < l_{iF}$, and we normalize the distance between Airport 1 and the foreign country to unity, $l_{1F} = 1$.

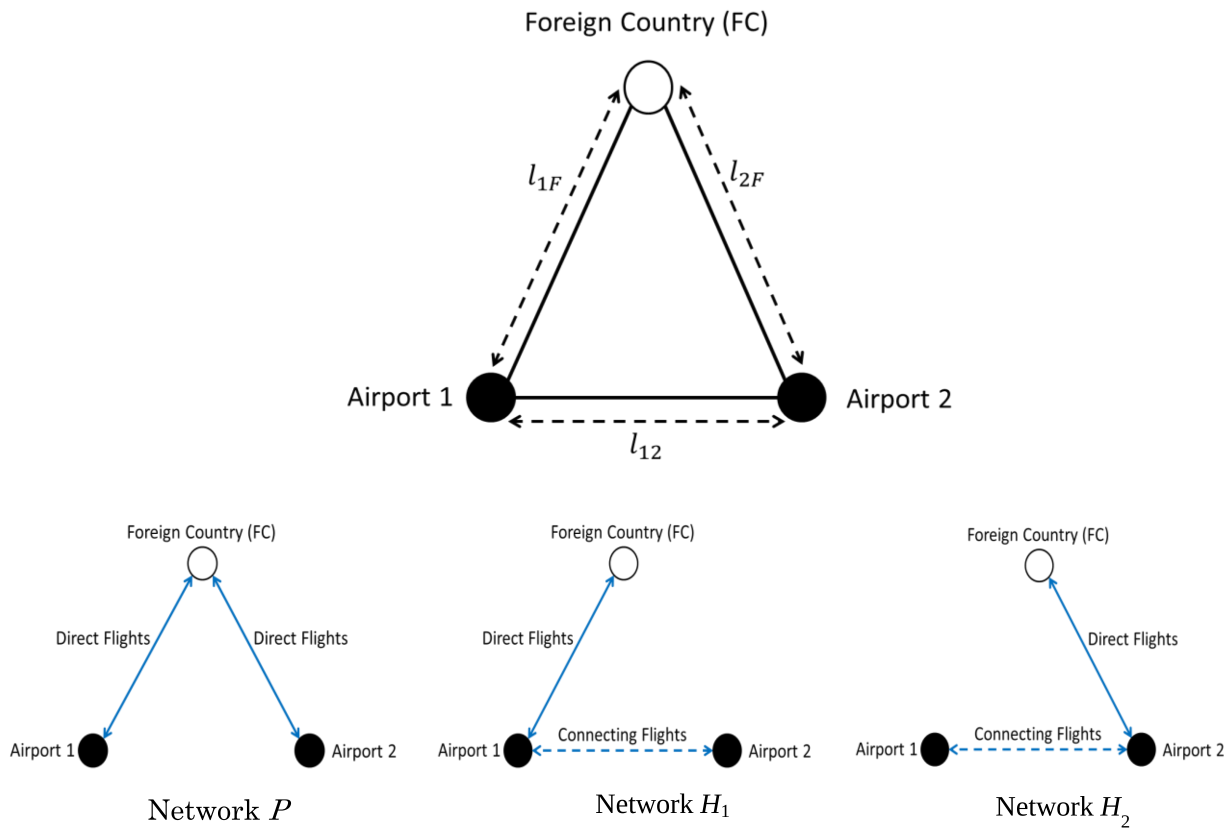

Figure 3-1: Three Alternative Network Configurations

Our model has three types of economic agents, the two airport operators, the monopoly carrier, and households. These three types of agents determine their choices in the following sequence. First, two airport operators simultaneously set their respective airport charges. At the second stage, given the choices of airport operators, the monopoly carrier determines its network configuration, N, and airfares for users at the two airports, p_i. Finally, the households in each city decide whether to travel to the foreign country from the airport near their residence.

We assume that intercontinental air service demand is inelastic. That is, households in each city travel to the foreign country once unless the airfare, p_i, exceeds the reservation price. In addition, all households have a common value of the reservation price, and it is normalized to unity. Therefore, the aggregate demand for the international air service at City i is

$$d_i(p_i) = \begin{cases} n_i & \text{if } p_i \le 1, \\ 0 & \text{otherwise,} \end{cases} \tag{1}$$

where n_i is the population of City i. To simplify the analysis, we normalize the total population of the economy $n_1 + n_2$ to one. In addition, n denotes the population of City 1, and, without loss of generality, we limit our focus on the case where $1 > n > 1/2$. In the following subsections, we describe the carrier's network choice and the behavior of airport operators.

3.2.2. The Carrier

When providing the air service, the carrier must incur three types of costs: the operating cost, the airport charge payment, and the fixed cost for handling the direct flight. We assume that the operating cost is proportional to passenger kilometers and that airport charges are paid on a per-passenger basis. In addition, we assume that the fixed cost is solely generated from the direct flights to the foreign country. This fixed cost can be interpreted as the airport charge at the foreign country or as the cost related to the long haul flights.[10] In summary, the carrier's total cost, $C(N;\mathbf{a})$, under network $N(N = P, H_1, H_2)$ is given by

$$C(P;\mathbf{a}) = \sum_{i=1}^{2} cl_{iF}n_i + \sum_{i=1}^{2} a_i n_i + 2F, \tag{2.1}$$

$$C(H_i;\mathbf{a}) = \left(cl_{iF} + cl_{12}n_j\right) + \left\lfloor a_i\left(1+n_j\right) + a_j n_j \right\rfloor + F, \text{ for } i = 1, 2,\ j \neq i, \tag{2.2}$$

where c, a_i, and F represent the operating cost per passenger kilometer, the airport charge per passenger at i, and the fixed cost for handling the direct intercontinental flights. In Equations (2), the first term of the RHS is the operating cost, the second term is the airport charge payments, and the third term is the fixed cost. Also note that these equations show that the carrier can save the fixed cost by forming a hub-spoke network instead of a point-to-point network since it can reduce the number of routes to the foreign country.

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10 This fixed cost includes the cost for additional crews (pilots and flight attendants) in order to provide a daily flight to each of the long haul routes. For example, Japanese airlines allocate at least two sets of crews for each intercontinental route, such as Tokyo to London and Tokyo to New York City.

Since the market is under a monopoly, the carrier chooses the airfare, p_i, that is equal to the reservation price, $p_i = 1$. Therefore, given the airport charges $\mathbf{a} = (a_1, a_2)$, the carrier determines its network configuration, N ($N = P$, H_1, H_2), in order to maximize its profit, $\pi(N;\mathbf{a})$:

$$\pi(N;\mathbf{a}) = 1 - C(N;\mathbf{a}). \tag{3}$$

Let $N(\mathbf{a})$ denote the carrier's network choice, which is derived according to the following problem:

$$N(\mathbf{a}) = \arg\max_{N} \pi(N;\mathbf{a}). \tag{4}$$

Furthermore, the carrier provides the service at Airport i if the profit at Airport i, $\pi_i(N;\mathbf{a})$, is non-negative.[11] Formally, this condition is written as

$$\pi_i(N;\mathbf{a}) = n_i - C_i(N;\mathbf{a}) \geq 0. \tag{5}$$

Here $C_i(N;\mathbf{a})$ is the total cost for providing the service at Airport i under network N:

$$C_i(P;\mathbf{a}) = C_i(H_i;\mathbf{a}) = cl_{iF}n_i + a_i n_i + F, \tag{6.1}$$

$$C_i(H_j;\mathbf{a}) = (cl_{jF} + cl_{12})n_i + (a_i + 2a_j)n_i, \text{ for } i = 1, 2,\ j \neq i. \tag{6.2}$$

Equations (6) show that in the case of the hub-spoke network, H_i, the carrier allocates the fixed cost of direct flights to the total cost at the hub, $C_i(H_i;\mathbf{a})$. This specification can be interpreted as follows. When choosing a hub-spoke network as its network

[11] Since the demand at each airport is inelastic, the cross subsidy between the routes from the two airports always lowers the carrier's profit.

configuration, the carrier first decides whether to provide the direct flight between the foreign country and its hub. Then, it decides whether to provide the connecting flight from the hub to the spoke airport.

3.2.3. Airport Operators

Each airport operator sets the airport charge in order to maximize the airport charge revenue. Since the airport charges are paid on a per-passenger basis, the airport charge revenue is proportional to the number of users. The number of Airport i ($i = 1, 2$) users, m_i, however, varies with the carrier's network choice, N. To put it differently, we can express the number of Airport i users as a function of the carrier's network choice, N: $m_i = m_i(N)$. The number of Airport i users is equal to the population of its hinterland when the carrier chooses point-to-point ($N = P$) or Airport i as the spoke airport ($N = H_j$): namely, $m_i(P) = m_i(H_j) = n_i$. If the carrier determines Airport i as its hub ($N = H_i$), $m_i(H_i) = n_i + 2n_j = 1 + n_j$ because n_j users from the spoke airport, j, utilize the hub, i, twice: for the arrival of the connecting flights and the departure of the direct international flights.

When setting the airport charge to maximize revenue, each operator considers two conditions. The first condition is Equation (4), the carrier's network choice, $N(\mathbf{a})$. By using $N(\mathbf{a})$ and the number of Airport i users, $m_i(N)$, the revenue of Airport i is computed as

$$R_i\left(a_i, a_j\right) = R_i\left(N\left(\mathbf{a}\right)\right) = a_i m_i\left(N\left(\mathbf{a}\right)\right). \tag{7}$$

The second condition is Equation (5), which states that each operator must assure that the carrier earns a non-negative profit when setting its airport charge. Otherwise, the carrier does not provide the service departing from the airport and the operator cannot earn the revenue.

3.3. The Optimal Network

To evaluate the equilibrium network configuration, we first focus on the optimal network configuration that maximizes the social surplus. The social surplus, $SS(N)$, under each of three networks, N, ($N = P$, H_1, and H_2) is computed as follows:

$$SS\left(P\right) = \sum_{k=1}^{2} n_k\left(1 - p_k\right) + \left[\sum_{k=1}^{2} n_k\left(p_k - cl_{kF} - a_k\right) - 2F\right] + \sum_{k=1}^{2} n_k a_k = 1 - c\sum_{k=1}^{2} n_k l_k - 2F, \tag{8.1}$$

$$SS(H_i) = \sum_{k=1}^{2} n_k (1-p_k) + \left\lfloor \sum_k n_k (p_k - cl_{iF} - a_i) - n_j (cl_{12} + a_1 + a_2) - F \right\rfloor + a_i + n_j \sum_{k=1}^{2} a_k$$
$$= 1 - c(l_{iF} + n_j l_{12}) - F \text{ for } i = 1, 2, \; j \neq i.$$

(8.2)

In Equations (8), the social surplus consists of three components: the consumer surplus, the carrier's profit, and the airport operators' revenue. By summing these three components, the airport charges and airfares are cancelled. In addition, since the reservation price is constant, the optimal network is derived as the network that minimizes the social cost of the air service. Furthermore, throughout this chapter, we consider the case in which the direct flights from Airport 2 generate non-negative social surplus, $F \leq (1-n)(1-c)$.

First, we focus on two hub-spoke networks. In comparison of costs for the service provision between the two networks, H_1 and H_2, Lemma 1 summarizes the condition in which network H_1 assures a lower social cost than H_2:

Lemma 1

Let us denote $\Delta l \equiv l_{1F} - l_{2F} = 1 - l_{2F}$. *Network* H_1 *assures a lower social cost than network* H_2 *if* $\Delta l < l_{12}(2n-1)$; *otherwise, network* H_2 *does.*

Proof:

The difference in the social surplus between networks H_1 and H_2 is computed as follows:

$$SS(H_1) - SS(H_2) = c(l_{2F} - 1) + cl_{12}(2n-1) = -c\Delta l + cl_{12}(2n-1),$$

where $\Delta l = 1 - l_{2F}$. Solving this for Δl, $SS(H_1) > SS(H_2)$ if

$$\Delta l < l_{12}(2n-1).$$

QED

In Lemma 1, the threshold, $l_{12}(2n-1)$, is positive since $n > 1/2$ while $\Delta l = 1 - l_{2F}$ shows the locational advantage of Airport 2 if $\Delta l > 0$. This indicates that from an efficiency perspective, hubbing at Airport 2 is superior to at Airport 1 if Airport 2 has a relatively large locational advantage compared to Airport 1 (that is, $\Delta l > l_{12}(2n-1)$). In contrast, the carrier should utilize Airport 1 as its hub instead of Airport 2 if the two cities are equidistant from the foreign country ($\Delta l = 0$). Since the population of City 2 is smaller than that of City 1, placing the hub at Airport 1 can save the operating cost of connecting flights between the two airports.

In order to derive the optimal network configuration, we compute the threshold of fixed cost, $F = F^O(P, H_i)$ at which

$$SS(P) = SS(H_i).$$

For $F < F^O(P, H_i)$, forming network P saves the social cost; otherwise, it is network H_i.

According to the comparison of social surplus, $F^O(P, H_i)$ is computed as:

$$SS(P) - SS(H_i) = n_j c\left(l_{iF} + l_{12} - l_{jF}\right) - F = 0$$
$$\Leftrightarrow F = F^O(P, H_i) \equiv n_j c\left(l_{iF} + l_{12} - l_{jF}\right) \text{ for } i = 1, 2, j \neq i. \quad (9)$$

By applying Lemma 1 and $F^O(P, H_i)$, the optimal network configuration, N^O, is summarized as follows:

Proposition 1

i) When $\Delta l \leq l_{12}(2n-1)$ *, network* H_1 *is the optimal network configuration if* $F \geq F^O(P, H_1)$ *; otherwise, it is network* P*.*

ii) In contrast, when $\Delta l > l_{12}(2n-1)$*, network* H_2 *is the optimal network configuration if* $F \geq F^O(P, H_2)$ *; otherwise, it is network* P*.*

Proof:

See Appendix A.

In Equation (9), the threshold $F^O(P, H_i)$ is equal to the incremental operating cost at the spoke airport when the network is changed from P to H_i. Therefore, Proposition 1 states that forming the hub-spoke network is efficient if the fixed cost, F, is larger than the incremental operating cost, $F^O(P, H_i)$. In addition, as in Lemma 1, it is efficient for the entire economy to place the hub at Airport 1 if the two airports are equidistant from the foreign country. However, when Airport 2 has a locational advantage (that is, $\Delta l > l_{12}(2n-1)$), placing the hub at Airport 2 becomes the optimal network configuration for $F \geq F^{O}(P, H_2)$.

3.4. The Equilibrium Network

This section addresses how the equilibrium network is determined. Since the operators first determine the airport charges, we solve the game among the carrier and operators through backward induction. Subsection 3.4.1 deals with the carrier's network choice: namely, how the carrier determines its network configuration given the airport charges at the two airports. Subsection 3.4.2 focuses on the behavior of airport operators. In other words, considering the carrier's network choice, this subsection explains how the two operators set the airport charge. Finally, Subsection 3.4.3 describes the equilibrium network configuration.

3.4.1. The Carrier's Choice

As in Equation (4), given the airport charges at the two airports, the carrier determines its network configuration, $N(\mathbf{a})$. When determining the network choice, the carrier solves the following two problems: i) which network maximizes its profit; and ii) given the network, whether to provide the service at each airport. In this subsection, we start with the second problem: that is, given the network choice, *N*, whether to provide the service at each airport. Under each of three alternative networks, N, $(N = P, H_1, H_2)$, the non-negative profit condition at Airport i $(i = 1, 2)$ is given by $\pi_i(N;\mathbf{a}) \geq 0$. Solving these conditions for the airport charge at Airport *i*, a_i,

$$\begin{aligned}&\pi_i(P;\mathbf{a}) = \pi_i(H_i;\mathbf{a}) = n_i(1 - cl_{iF} - a_i) - F \geq 0\\&\qquad\Leftrightarrow a_i \leq \bar{a}_i(P) = \bar{a}_i(H_i) = 1 - cl_{iF} - \frac{F}{n_i} \text{ for } i = 1, 2,\end{aligned} \tag{10.1}$$

$$\begin{aligned}&\pi_i(H_j;\mathbf{a}) = n_i\lfloor 1 - c(cl_{jF} + l_{12}) - 2a_j - a_i \rfloor \geq 0\\&\qquad\Leftrightarrow a_i \leq \bar{a}_i(a_j;H_j) = 1 - c(l_{jF} + l_{12}) - 2a_j \text{ for } i = 1, 2, j \neq i.\end{aligned} \tag{10.2}$$

Equations (10) determine the upper bounds of airport charges for three alternative networks. In other words, network *N* becomes a candidate for the carrier's choice as long as Equations (10) are satisfied. In case of network *P*, for example, the carrier may choose to provide the direct flight service to both airports if each of two airport operators chooses $a_i \leq \bar{a}_i(P)$.

Provided that Equations (10) are satisfied, the carrier determines its network configuration, $N(\mathbf{a})$, according to the comparison of the profits under the three alternative networks. Lemma 2 summarizes the carrier's network choice, $N(\mathbf{a})$.

Lemma 2

The carrier's network choice, $N(\mathbf{a})$, *is determined as follows:*

$$N(\mathbf{a}) = \begin{cases} P & \text{if } \bar{a}_i(P) \geq a_i > \hat{a}_i \text{ for } i = 1,2, \\ H_1 & \text{if } a_1 \leq \min\{\hat{a}_1, \tilde{a}_1(a_2), \bar{a}_1(H_1)\} \text{ and } a_2 \leq \bar{a}_2(a_1; H_1), \\ H_2 & \text{if } a_2 \leq \min\{\hat{a}_2, \tilde{a}_2(a_1), \bar{a}_2(H_2)\} \text{ and } a_1 \leq \bar{a}_1(a_2; H_2), \end{cases} \tag{11}$$

where

$$\hat{a}_i \equiv \frac{F}{2n_j} - \frac{c\left(l_{iF} + l_{12} - l_{jF}\right)}{2} \text{ for } i = 1,2,\ j \neq i, \tag{12.1}$$

$$\tilde{a}_i(a_j) \equiv \frac{n_i a_j}{n_j} + \frac{n_i c\left(l_{jF} + l_{12} - l_{iF}\right) - n_j c\left(l_{iF} + l_{12} - l_{jF}\right)}{2n_j} \text{ for } i = 1,2,\ j \neq i. \tag{12.2}$$

Proof:

See Appendix B.

By using Lemma 2, we hereafter consider the case of $\bar{a}_i(P) > \hat{a}_i$: that is, the carrier always has three alternative networks for candidates of its network choice, Solving this condition, $\bar{a}_i(P) > \hat{a}_i$, for *F*, it is rewritten as follows:

$$\bar{a}_i(P) - \hat{a}_i > 0 \Leftrightarrow F < \frac{n(1-n)\lfloor 2(1-c) + cl_{12} \rfloor}{1+n_j}. \tag{13}$$

Together with the assumption such that $F \leq (1-n)(1-c)$, we denote by $\bar{F}$, the upper bound of the fixed cost:

$$\bar{F} \equiv \min\left\{(1-n)(1-c), \frac{n(1-n)\lfloor 2(1-c)+cl_{12} \rfloor}{1+n}, \frac{n(1-n)\lfloor 2(1-c)+cl_{12} \rfloor}{2-n}\right\}.$$

In summary, hereafter, we derive the equilibrium network configuration in case of $F \le \bar{F}$.

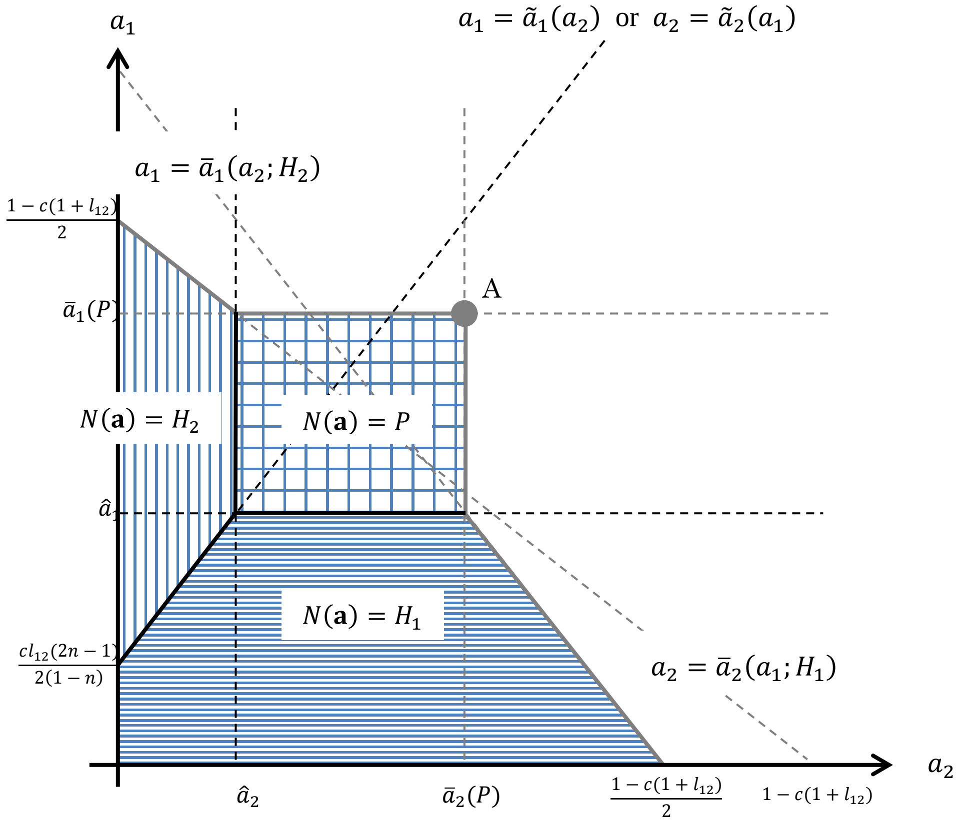

Figure 3-2: Carrier's Network Choice in the Case of $l_{1F} = l_{2F}$

Figure 3-2 summarizes the carrier's network choice in (a_1, a_2) space in the case of $l_{1F} = l_{2F} = 1$ and $\bar{a}_i(P) > \hat{a}_i$. As shown in Figure 3-2, for sufficiently large value of airport charges (that is, $a_1 > \hat{a}_1$ and $a_2 > \hat{a}_2$), the carrier chooses network P. This is because (under this circumstance) the carrier can save the airport charge payment for connecting flights by forming network *P*. In contrast, the carrier chooses one of the two airports as its hub if one operator offers a relatively low airport charge compared to the other airport. For example, the carrier determines network H_1 as its network configuration if the operator of Airport 1 sets the airport charge within the range of $a_1 \leq \hat{a}_1$ and $a_1 \leq \tilde{a}_1(a_2)$.

Lemma 3 summarizes how the change in the parameter values affects the domain of each network in Figure 3-2:

Lemma 3

i) The domains of networks H_1 and H_2 expand as the two airports are located closer or as the fixed cost for the direct flight increases;

ii) The domain of network H_1 expands as the population of City 1 increases;

iii) The domain of network H_2 expands as Airport 2 is located closer to the foreign country.

Proof:

By differentiating Equations (12) with respect to *F*, l_{12}, *n*, and Δl, Lemma 3 is confirmed. For part i),

$$\frac{\partial \hat{a}_i}{\partial l_{12}} = -\frac{c}{2} < 0 \text{ and } \frac{\partial \hat{a}_i}{\partial F} = \frac{1}{2n_j} > 0.$$

For part ii),

$$\frac{\partial \hat{a}_1}{\partial n} = \frac{F}{2(1-n)^2} > 0,\ \frac{\partial \hat{a}_2}{\partial n} = -\frac{F}{2n^2} < 0,\ \text{and } \frac{\partial \tilde{a}_1(a_2)}{\partial n} = \frac{2na_2}{(1-n)^2} + \frac{cl_{12}}{(1-n)^2}.$$

For part iii),

$$\frac{\partial \hat{a}_1}{\partial \Delta l} = -\frac{c}{2} < 0,\ \frac{\partial \hat{a}_2}{\partial \Delta l} = \frac{c}{2} > 0,\ \text{and } \frac{\partial \tilde{a}_1(a_2)}{\partial \Delta l} = -\frac{c}{2(1-n)} < 0.$$

QED

Part i) of Lemma 3 indicates that two parameter values, l_{12} and F, affect the carrier's tradeoff between the point-to-point and hub-spoke networks. Namely, a decrease in the distance between the two airports, l_{12}, expands the domains of H_1 and H_2 because of the reduction in the additional operating costs for connecting flights. An increase in the fixed cost, F, also widens these domains since providing the direct flights at the two airports becomes more costly.

Part ii) of Lemma 3 shows that Airport 1 becomes a more attractive candidate for a hub as the population of City 1 increases. In comparison of networks H_1 and H_2, providing the connecting flight from Airport 2 is less costly than providing it from Airport 1. Furthermore, the increase in the population of City 1 leads to a further reduction in the cost of the connecting flight from Airport 2 since this increase causes a decrease in the population of City 2. Therefore, compared with network P, the disadvantage of choosing network H_1 shrinks. Finally, for part iii) of Lemma 3, note that an increase in $\Delta l = 1 - l_{2F}$ implies that Airport 2 becomes relatively close to the foreign country compared to Airport 1. In this case, it is more likely for the carrier to choose Airport 2 as its hub. This situation is observed in several regions: for example, the "Oneworld" alliance selected Madrid and Helsinki, which are located on the edge of Europe, as the hubs for the Americas and East Asia, respectively.

3.4.2. The Operators' Choices

At the first stage, two operators simultaneously set their airport charges in order to maximize the airport charge revenue:

$$R_i\left(a_i, a_j\right) = a_i m_i\left(N\left(\mathbf{a}\right)\right) \text{ for } i = 1, 2,\ j \neq i.$$

As in Figure 3-2, however, the number of Airport i (i = 1, 2) users, $m_i(N(\mathbf{a}))$, changes discontinuously. That is, for example, suppose that the two airports initially choose $(a_1, a_2) = (\bar{a}_1(P), \bar{a}_2(P))$, point A of Figure 2. Then, the operator of Airport 1 experiences a sudden increase in its users from $m_1 = n$ to $m_1 = n_1 + 2n_2 = 2 - n$ if the operator sets the airport charge $a_1 \le \hat{a}_1$ while no such jump is realized for $\overline{a}_1 > a_1 > \hat{a}_1$ even if the operator cuts its airport charge from $a_1 = \overline{a}_1(P)$. In other words, at point A of Figure 3-2, each operator faces the following problem: whether to discount its airport charge in order to increase its airport users and its revenue.

Therefore, we formulate the operator's problem as follows. Each operator chooses its strategy regarding the airport charge from the following two alternatives. The first strategy is such that, independent from the carrier's network choice, the operator exploits the carrier's direct flight profit at its airport, and we name this strategy the "exploiting strategy." The second strategy is to discount the airport charge in order to attract the carrier to set its airport as the hub, and this strategy is called the "discount strategy." Let us denote by a_i^e and a_i^d the exploiting and the discount airport charges, respectively. Then, the problem for the operator of Airport i is formulated as follows:

$$\max_{a_i \in \left\{a_i^e, a_i^d\right\}} R_i\left(a_i, a_j\right). \tag{14}$$

Furthermore, in order to simplify the analysis, we assume that the two airports are equidistant from the foreign country, $l_{1F} = l_{2F} = 1$.

3.4.2.1. The Exploiting Strategy

We define the exploiting strategy by the airport charge that fully exploits the carrier's direct flight profit at a single airport. In other words, each operator seeks to exercise its market power against the carrier if they employ this particular strategy. When deriving the exploiting airport charge, each operator must consider the carrier's network choice. Under the assumption of Equation (13), however, the carrier chooses network P as its network configuration if two operators simultaneously decide to exploit the carrier's profit. In other words, when choosing to exploit, each operator can earn the maximal revenue if they choose their airport charge so that $\pi_i(P;\mathbf{a})=0$. Therefore, let us denote by a_i^e the exploiting airport charge. It is computed according to $\pi_i(P;\mathbf{a})=0$ as follows:

$$a_i^e = \overline{a}_i\left(P\right) = 1 - c - \frac{F}{n_i} \text{ for } i = 1, 2. \tag{15}$$

3.4.2.2. The Discount Strategy

Each operator can raise their revenue by becoming the carrier's hub thourgh discounting their airport charges instead of playing the exploiting strategy. Let us define by such airport charge, a_i^d, the discount strategy. This strategy, however, does not mean that operators discount until their airport charges become zero since they can earn $a_i^e n_i$ when playing the exploiting strategy. Therefore, the operator discounts its airport charge as long as $a_i(1+n_j) = a_i^e n_i$. According to this relation, we can derive the lower bound of the discount airport charge as

$$\underline{a}_i\left(1+n_j\right) = a_i^e n_i \Leftrightarrow \underline{a}_i = \frac{n_i\left(1-c\right)-F}{1+n_j} \text{ for } i=1,2. \tag{16}$$

The carrier's network choice, $N(\mathbf{a})$, and the parameter values are common knowledge for both operators. Therefore, using the competitor's lower bound of the discount airport charge, $a_j = \underline{a}_j$, in Equation (15), it is easy for each operator to compute the discount airport charge, which assures them to become the carrier's hub. According to Equations (11), (12), and (16), the discount airport charge is computed, as follows:

Lemma 4

The operator of Airport i sets its discount airport charge as

$$a_i^d = \begin{cases} \dfrac{F}{2n_j} - \dfrac{cl_{12}}{2} & \text{if } F < F_i^d, \\ \dfrac{n_i\left(1-c\right)}{1+n_i} - \dfrac{n_i F}{n_j\left(1+n_i\right)} + \dfrac{\left(n_i - n_j\right)cl_{12}}{2n_j} & \text{if } F_i^d \le F, \end{cases} \tag{17}$$

where

$$F_i^d \equiv \frac{2n\left(1-n\right)\left(1-c\right) + cn_i\left(1+n_i\right)l_{12}}{3+n_i} \text{ for } i=1,2.$$

Proof:

It is shown in Appendix C.

3.4.3. The Nash Equilibrium

Table 3-1: Payoff Matrix

Airport 1 \ Airport 2	$a_2 = a_2^e$	$a_2 = a_2^d$
$a_1 = a_1^e$	$R_1\left(a_1^e, a_2^e\right), R_2\left(a_2^e, a_1^e\right)$	$R_1\left(a_1^e, a_2^d\right), R_2\left(a_2^d, a_1^e\right)$
$a_1 = a_1^d$	$R_1\left(a_1^d, a_2^e\right), R_2\left(a_2^e, a_1^d\right)$	$R_1\left(a_1^d, a_2^d\right), R_2\left(a_2^d, a_1^d\right)$

In Subsection 3.4.2, we defined two strategies regarding the airport charge (the exploiting and the discount airport charges), as in Equations (14) and (16). By applying these two types of airport charges in Equation (7), we obtain the payoff matrix, as summarized in Table 3-1 above. Using Table 3-1, the Nash Equilibrium of the operators' game (a_1^*, a_2^*) and the carrier's network choice, $N^* = N(a_1^*, a_2^*)$ are derived, as follows:

Proposition 2

The Nash Equilibrium, (a_1^*, a_2^*, N^*), *is characterized as follows:*

$$\left(a_1^*, a_2^*, N^*\right) = \begin{cases} \left(a_1^e, a_2^e, P\right) & \text{if } F \le \min\left\{\bar{F}_1, \bar{F}_2, \bar{F}\right\}, \\ \left(a_1^d, a_2^e, H_1\right) & \text{if } \bar{F}_1 < F \le \min\left\{\tilde{F}, \bar{F}\right\}, \\ \left(a_1^e, a_2^d, H_2\right) & \text{if } \max\left\{\bar{F}_2, \tilde{F}\right\} < F \le \bar{F}, \end{cases} \tag{18}$$

where

$$\bar{F}_i \equiv \frac{2n(1-n)(1-c) + cl_{12}n_i(1+n_i)}{1+3n_i} \text{ for } i = 1, 2,$$

$$\tilde{F} \equiv -n(1-n)(1-c) + \frac{c\left\lfloor 2 + n(1-n)\right\rfloor l_{12}}{2}.$$

Proof:

See Appendix C.

According to Proposition 2, for a sufficiently low fixed cost, F, the equilibrium network configuration falls into network P while the hub-spoke network, H_1 or H_2, emerges at the equilibrium if the fixed cost is sufficiently large. It is, however, difficult to evaluate the effects on the equilibrium network of other parameters such as the population of City 1, n, and the distance between the two airports, l_{12}. By comparing the thresholds of Equation (18), we obtain the sufficient condition with respect to the population of City

1, n, such that network H_1 is never realized at the equilibrium:

Corollary

The network H_1 never emerges at the Nash Equilibrium if $n \geq 2/3$.

Proof:

See Appendix C.

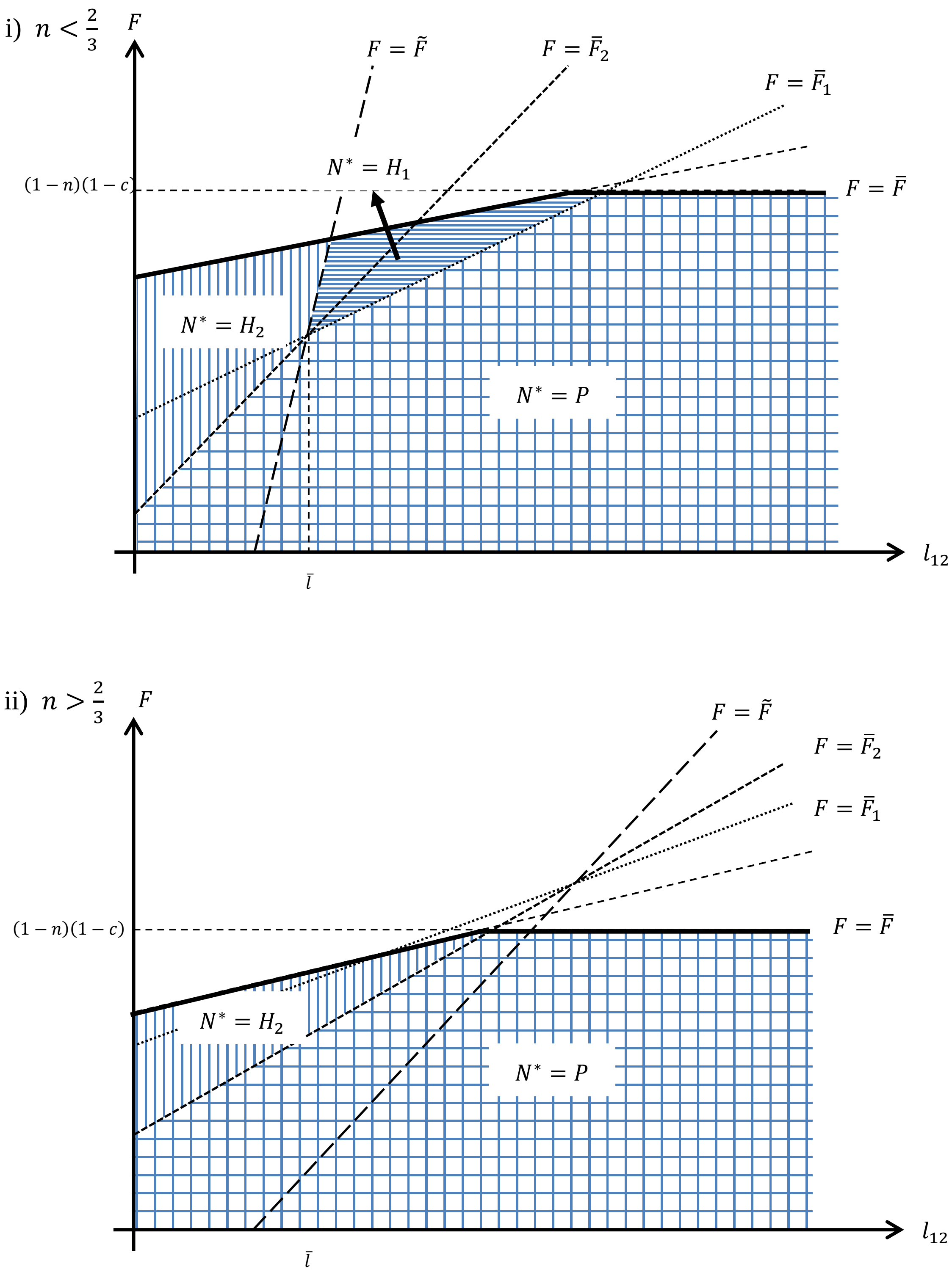

Figure 3-3: Equilibrium Network Configuration, N^*

By using Proposition 2 and the Corollary, we summarize the equilibrium network configuration in (l_{12}, F) space in Figure 3-3. The upper side of Figure 3-3, i), shows the case in which $n < 2/3$ while the lower side, ii), corresponds to the case of $1 > n \geq 2/3$. Let us take a closer look at $n < 2/3$. The upper side of Figure 3-3 shows that the carrier chooses network P as its network configuration when the fixed cost for operating direct intercontinental flights is sufficiently low or when the distance between Airports 1 and 2 is sufficiently large; otherwise, the carrier's network choice becomes hub-spoke. In the case of a hub-spoke network, the carrier may choose one of two airports as its hub. Namely, Airport 2 becomes the carrier's hub if the two airports are relatively close; otherwise, Airport 1 is selected.

Since Airport 2 has a disadvantage in the hinterland demand $(n_2 < n_1)$, the carrier always incurs the larger cost for connecting flights if it chooses Airport 2 as its hub. Let us denote by $\Delta C(H_1, H_2; \mathbf{a})$ the difference in the cost between networks H_1 and H_2. Then,

$$\begin{aligned}\Delta C\left(H_1, H_2; \mathbf{a}\right) &\equiv C\left(H_1; \mathbf{a}\right) - C\left(H_2; \mathbf{a}\right)\\ &= cl_{12}\left(1-n\right) + a_1\left(2-n\right) + a_2\left(1-n\right) - \left[cl_{12}n + a_1 n + a_2\left(1+n\right)\right]\\ &= cl_{12}\left(1-2n\right) + 2\left[a_1\left(1-n\right) - a_2 n\right]. \end{aligned} \tag{19}$$

If the sign of (19) is negative, then the carrier chooses Airport 1 as its hub; otherwise, Airport 2 is selected. Since the first term, $cl_{12}(1-2n)$, is negative for $n > 1/2$, Airport

2 must discount its airport charge so that the difference in airport charges between the two airports offsets the gap in the cost, $cl_{12}(1-2n)$, if it wants to become the carrier's hub. Furthermore, this gap is monotonically decreasing in l_{12}; therefore, Airport 2 must discount more as the distance between the two airports, l_{12}, increases. The upper side of Figure 3-3 indicates that the operator of Airport 2 can increase its revenue by discounting its airport charges when the two airports are close. However, as the distance between the two airports increases, the loss due to the discount outweighs the gain from becoming the hub; therefore, Airport 2 stops discounting.

In the case of $1 > n \geq 2/3$,[12] in contrast, the lower side of Figure 3-3 shows that the carrier always chooses Airport 2 as its hub if it sets a hub-spoke network configuration. This is due to the difference in the gain of becoming the hub between the two airports. In order to capture this gain, let us define by ρ_i the ratio of Airport i users between networks H_i and H_j:

$$\rho_1 = \frac{m_1(H_1)}{m_1(H_2)} = \frac{2-n}{n} = \frac{2}{n} - 1, \tag{20.1}$$

[12] One might think that for $(1-n)(1-c) > F \geq \bar{F}$, which we ignore in the analysis, network H_1 may appear as the equilibrium network configuration. However, network H_1 may not be realized for $(1-n)(1-c) > F \geq \bar{F}$ because of the following two reasons. First, the dominance of network H_2 against H_1 is attributed to the difference in the population size rather than the size of the fixed cost or the distance between the two airports. Second, within the domain of $(1-n)(1-c) > F \geq \bar{F}$, the two airports are close to one another; therefore, operator 2's loss from discounting is not significant, as argued above.

$$\rho_2 = \frac{m_2\left(H_2\right)}{m_2\left(H_1\right)} = \frac{1+n}{1-n} = \frac{2}{1-n} - 1. \tag{20.2}$$

Note that ρ_1 is decreasing in the population of City 1, *n*, and for $1 > n \geq 2/3$, at most, $\rho_1 = 2$, whereas ρ_2 is increasing in *n*, and for $1 > n \geq 2/3$, at least, $\rho_2 = 5$. This indicates that Airport 1 receives a smaller gain from applying the discount strategy than Airport 2 does when becoming the carrier's hub. Furthermore, the gain of Airport 1 decreases as its hinterland demand, *n*, expands. Therefore, the Corollary and ii) of Figure 3-3 indicate that, in the case of $1 > n \geq 2/3$, the operator of Airport 1 stops discounting since its gain is quantitatively small.

3.5. Discussion

In this section, we address the question of how a private airport operator's behavior can distort the carrier's network choice. In order to simplify the analysis, we focus on the case in which the two airports are equidistant from the foreign country. In such a case, although network H_1 always dominates H_2 from the efficiency since $\Delta l = 0 < cl_{12}(2n-1)$, as in Lemma 1, the carrier may choose H_2 as its network configuration according to Proposition 2. This is because the operator of Airport 2 receives a larger gain, ρ_2, from becoming the carrier's hub than that of Airport 1, ρ_1:

$$\rho_2 > 3 > \rho_1 \text{ for } 1 > n > \frac{1}{2}.$$

This indicates that the operator of Airport 2 is more willing to discount its airport charge than Airport 1. As a result, for some sets of parameter values, offering the discounted airport charge attracts the carrier to Airport 2 and as a result, it becomes the carrier's hub. This is observed in several regions: for example, in East Asia, airports in relatively small cities such as Kuala Lumpur and Seoul offer relatively low airport charges, and they have larger connections with cities in other continents than those in relatively large cities such as Bangkok and Tokyo.

Other than the realization of network H_2, Proposition 3 shows that the private operation of airports disturbs the formation of a hub-spoke network:

Proposition 3

Network P is more often observed at the equilibrium than at the optimum.

Proof:

See Appendix D.

In order to provide the intuition behind this proposition, we compare the carrier's cost between the hub-spoke network, H_i, and network P:

$$\begin{aligned}\Delta C(P,H_i;\mathbf{a}) &\equiv C(P;\mathbf{a})-C(H_i;\mathbf{a})\\ &= c+\sum_{k=1}^{2}a_k n_k+2F-\left[c\left(1+l_{12}n_j\right)+a_i\left(1+n_j\right)+a_j n_j+F\right]\\ &= F-cl_{12}n_j-2a_i n_j.\end{aligned} \tag{21}$$

Equation (21) shows the carrier's tradeoff: namely, the carrier prefers network P if the sign of Equation (21) is negative and network H_i, otherwise. Since externalities, such as airport congestion, are absent in our model, at the optimum, airport charge is equal to zero while under the private operation, the airport charge is positive. This means that, at the equilibrium, the carrier must incur the additional airport charge for utilizing the hub, Airport i, as well as the cost for the connecting flight. As a result, because of the positive airport charge, network P is more easily observed at the equilibrium than at the optimum.

Figure 3-3 summarizes the comparison of the equilibrium and the optimal network configurations in the case of $l_{1F}=l_{2F}=1$ and $n<2/3$. According to Figure 3-3, we can confirm the distortion of the private airport operation on the carrier's network choice, as explained in this section. That is, within the domain A of Figure 3-4, due to the competition between the two airports, the equilibrium network configuration is network H_2 while the optimum is H_1. The domain B corresponds to Proposition 3; namely, because of the private operation of airports, the carrier chooses network P instead of H_1 at the equilibrium.

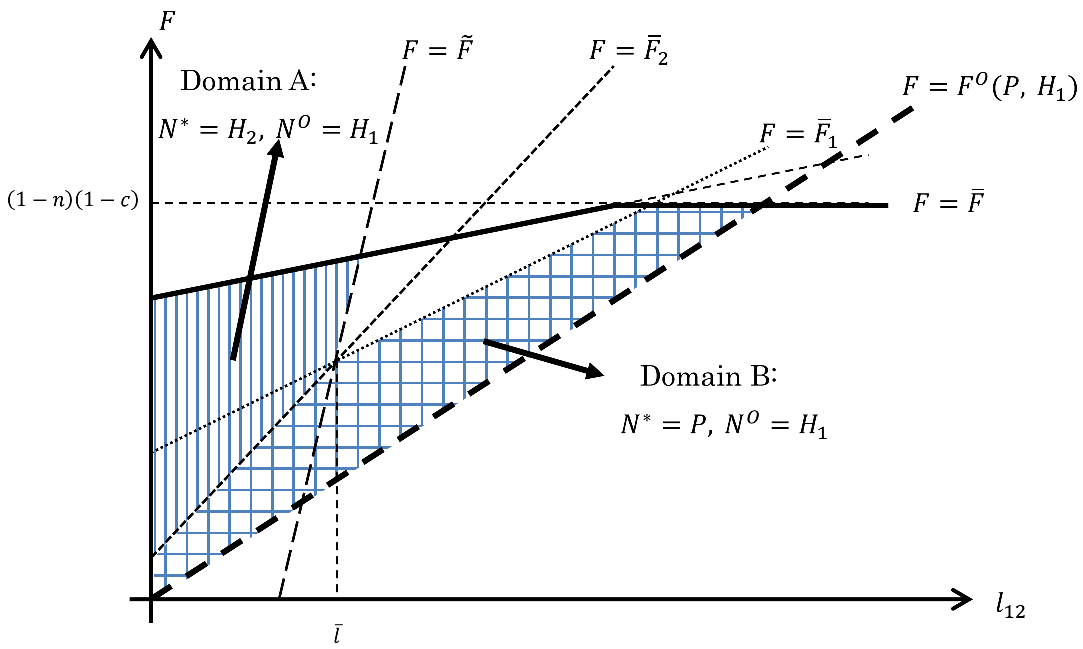

Figure 3-4: Equilibrium vs. the Optimum

3.6. Conclusion

In this chapter, we focused on the question of how price competition among airports affects the carrier's network choice. In order to address this question, we constructed a model in which the behaviors of both the carrier and airport operators were considered. By using this model, two types of network configurations were derived: the optimal and the equilibrium network configurations. At the optimum, airports at relatively small cities may become the carrier's hub when they have the locational advantage against those of large cities; otherwise, hubbing at airports in large cities is efficient. Conversely, at the equilibrium, airports at relatively small cities may become the carrier's hub even if they have no locational advantage. This is because operators of airports at small cities are willing to discount their airport charge since they receive relatively large gains from connecting flights from their spoke nodes. In addition to this effect, the private operation itself also distorts the carrier's choice. Namely, the market power of airport operators leads the carrier to choose a point-to-point network instead of a hub-spoke one.

Finally, we suggest topics for future research. First, in order to maintain analytical tractability, we omit the costs of user's transit and airport operation. However, introducing these two factors may change operators' behaviors under price competition. Therefore, it is necessary to extend our model by introducing these two factors. In addition, since we have ignored air service demand among the hub airport and spoke nodes, our results overstate the inefficiency of the private operation. Namely, this type of extension (introducing the air service demand among the hub airport and spoke nodes) reinforces the carrier's benefit of hubbing; thus, the inefficiency of private operation may be mitigated. It is also necessary to introduce airport congestion into the model since several hub airports experience severe congestion. This addition is useful for considering how the price competition affects airport congestion as well as the carrier's network choice.

Appendix A: The Optimal Network Configuration

Proposition 1

i) When $\Delta l \le l_{12}(2n-1)$ *, network* H_1 *is the optimal network configuration if* $F \ge F^O\left(P, H_1\right)$*; otherwise, it is network P.*

ii) In contrast, when $\Delta l > l_{12}(2n-1)$*, network* H_2 *is the optimal network configuration if* $F \ge F^O\left(P, H_2\right)$*; otherwise, it is network P.*

Proof:

The thresholds are derived as follows:

$$SS\left(P\right) - SS\left(H_i\right) = n_j c\left(l_{iF} + l_{12} - l_{jF}\right) - F = 0 \text{ for } i = 1, 2,\ j \neq i. \tag{A.1}$$

Solving this for *F*,

$$F = F^O\left(P, H_1\right) = c\left(1-n\right)\left(l_{12} + 1 - l_{2F}\right) = c\left(1-n\right)\left(l_{12} + \Delta l\right), \tag{A.2}$$

$$F = F^O\left(P, H_2\right) = cn\left(l_{12} - l_{2F} + 1\right) = cn\left(l_{12} - \Delta l\right). \tag{A.3}$$

By comparing these thresholds, we obtain the following relation:

$$F^O\left(P, H_1\right) - F^O\left(P, H_2\right) = c\left\lfloor \Delta l - \left(2n-1\right) l_{12} \right\rfloor. \tag{A.4}$$

(A.4) indicates that if $\Delta l \le l_{12}(2n-1)$, then $F^O(P, H_1) - F^O(P, H_2) \le 0$. Suppose that

$\Delta l \le l_{12}(2n-1)$ is satisfied. In such a situation, $SS(H_2) \le SS(H_1)$ holds according to Lemma 1. Therefore, in the case of $F > F^O(P, H_2)$, together with the definition of $F^O(P, H_i)$, we have $SS(P) < SS(H_2) < SS(H_1)$. In contrast, for $F \le F^O(P, H_2)$, it is easy to derive the optimal network configuration by simply using the definition $F^O(P, H_i)$. In the case of $\Delta l > l_{12}(2n-1)$, we can derive the optimal configuration using a similar argument for $\Delta l \le l_{12}(2n-1)$.

QED

Appendix B: The Carrier's Network Choice at the Equilibrium

Lemma 2

The carrier's network choice, $N(\mathbf{a})$, *is determined as follows:*

$$N(\mathbf{a}) = \begin{cases} P & \text{if } \bar{a}_i(P) \ge a_i > \hat{a}_i \text{ for } i = 1, 2, \\ H_1 & \text{if } a_1 \le \min\{\hat{a}_1, \tilde{a}_1(a_2), \bar{a}_1(H_1)\} \text{ and } a_2 \le \bar{a}_2(a_1; H_1), \\ H_2 & \text{if } a_2 \le \min\{\hat{a}_2, \tilde{a}_2(a_1), \bar{a}_2(H_2)\} \text{ and } a_1 \le \bar{a}_1(a_2; H_2), \end{cases} \tag{11}$$

where

$$\hat{a}_i \equiv \frac{F}{2n_j} - \frac{c(l_{iF} + l_{12} - l_{jF})}{2} \text{ for } i = 1, 2,\ j \ne i, \tag{12.1}$$

$$\tilde{a}_i(a_j) \equiv \frac{n_i a_j}{n_j} + \frac{n_i c(l_{jF} + l_{12} - l_{iF}) - n_j c(l_{iF} + l_{12} - l_{jF})}{2n_j} \text{ for } i = 1, 2,\ j \ne i. \tag{12.2}$$

Proof:

$N(\mathbf{a})$ is derived through the comparison of profits, $\pi(N;\mathbf{a})$, under the three alternative network configurations. First, suppose that the carrier chooses network P as its network configuration. Since $N(\mathbf{a})=P$, according to Equation (4), the following must hold:

$$\pi(P;\mathbf{a})-\pi(H_i;\mathbf{a})=F-cn_j\left(l_{iF}+l_{12}-l_{jF}\right)-2n_ja_i>0 \text{ for } i=1,2,\ j\neq i.$$

Solving this for a_i, we obtain the following:

$$\pi(P;\mathbf{a})>\pi(H_i;\mathbf{a})\Leftrightarrow a_i>\hat{a}_i\equiv\frac{F}{2n_j}-\frac{c\left(l_{iF}+l_{12}-l_{jF}\right)}{2} \text{ for } i=1,2,\ j\neq i. \quad \text{(B.1)}$$

Together with Equation (10.1), the carrier sets network P as its network configuration if:

$$\bar{a}_i\left(P\right)\geq a_i>\hat{a}_i \text{ for } i=1,2. \quad \text{(B.2)}$$

In the case of $N(\mathbf{a})=H_i$,

$$\pi(P;\mathbf{a})-\pi(H_i;\mathbf{a})=F-cn_j\left(l_{iF}+l_{12}-l_{jF}\right)-2n_ja_i\leq 0 \text{ for } i=1,2,\ j\neq i,$$

$$\pi(H_j;\mathbf{a})-\pi(H_i;\mathbf{a})=n_ic\left(l_{jF}+l_{12}-l_{iF}\right)-n_jc\left(l_{iF}+l_{12}-l_{jF}\right)+2\left[a_in_j-a_jn_i\right]\leq 0 \text{ for } i=1,2,\ j\neq i.$$

The former holds if and only if $a_i\leq\hat{a}_i$. Solving the latter relation for a_i, we obtain

$$\pi\left(H_i;\mathbf{a}\right)\geq\pi\left(H_j;\mathbf{a}\right)$$

$$\Leftrightarrow a_i\leq\tilde{a}_i\left(a_j\right)\equiv\frac{n_i a_j}{n_j}+\frac{n_i c\left(l_{jF}+l_{12}-l_{iF}\right)-n_j c\left(l_{iF}+l_{12}-l_{jF}\right)}{2n_j}\text{ for } i=1,2,\ j\neq i. \tag{B.3}$$

According to Equations (10.1), (10.2), (B.1), and (B.3), the carrier's choice becomes H_i if:

$$a_i\leq\min\left\{\hat{a}_i,\tilde{a}_i\left(a_j\right),\bar{a}_i\left(H_i\right)\right\}\text{ and } a_j\leq\bar{a}_j\left(a_i;H_i\right)\text{ for } i=1,2,\ j\neq i. \tag{B.4}$$

By using Equations (B.2) and (B.3), the carrier's network choice is determined as in Equation (11).

QED

Also note that, under the assumption, $F\leq\bar{F}$, Equation (11) is rewritten as follows:

$$N\left(\mathbf{a}\right)=\begin{cases}P & \text{if } \bar{a}_i\left(P\right)\geq a_i>\hat{a}_i \text{ for } i=1,2,\\ H_1 & \text{if } a_1\leq\min\left\{\hat{a}_1,\tilde{a}_1\left(a_2\right)\right\}\text{ and } a_2\leq\bar{a}_2\left(a_1;H_1\right),\\ H_2 & \text{if } a_2\leq\min\left\{\hat{a}_2,\tilde{a}_2\left(a_1\right)\right\}\text{ and } a_1\leq\bar{a}_1\left(a_2;H_2\right).\end{cases} \tag{B.5}$$

Appendix C: The Discount Strategy and the Nash Equilibrium

First, we derive the discount airport charge, as in Lemma 4:

Lemma 4

The operator of Airport i sets its discount airport charge as

$$a_i^d = \begin{cases} \dfrac{F}{2n_j} - \dfrac{cl_{12}}{2} & \text{if } F \le F_i^d, \\ \dfrac{n_i(1-c)}{1+n_i} - \dfrac{n_i F}{n_j(1+n_i)} + \dfrac{(n_i - n_j)cl_{12}}{2n_j} & \text{if } F > F_i^d, \end{cases} \tag{17}$$

where

$$F_i^d \equiv \frac{2n(1-n)(1-c) + cn_i(1+n_i)l_{12}}{3+n_i} \text{ for } i = 1, 2.$$

Proof:

Under the discount strategy, the operator must discount its airport charge unless it succeeds in taking the hub position in the carrier's network. According to Lemma 2, if the operator of Airport *i* wants to become the carrier's hub, then its airport charge, a_i, must satisfy the following relation:

$$a_i \le \hat{a}_i \equiv \frac{F}{2n_j} - \frac{cl_{12}}{2}, \tag{C.1}$$

$$a_i \le \tilde{a}_i(a_j) \equiv \frac{n_i a_j}{n_j} + \frac{(n_i - n_j)cl_{12}}{2n_j}. \tag{C.2}$$

Note that (C.2) depends on the competitor's airport charge, a_j. Therefore, for any possible value of the competitor's airport charge, the discount charge of Airport *i* should assure that Airport *i* becomes the carrier's hub. As explained in Subsection 4.2, the competitor *j* discounts its airport charge at most $a_j = \underline{a}_j$. Applying this to (C.2),

$$a_i = \tilde{a}_i(\underline{a}_j) = \frac{n_i(1-c)}{1+n_i} - \frac{n_i F}{n_j(1+n_i)} + \frac{(n_i - n_j)cl_{12}}{2n_j}. \tag{C.3}$$

(C.3), however, does not necessarily imply the condition (C.1). Therefore, by comparing (C.3) and $\hat{a}_i$, we obtain the threshold as follows:

$$\begin{aligned}\hat{a}_i - \tilde{a}_i\left(\underline{a}_j\right) &= \frac{F}{2n_j} - \frac{cl_{12}}{2} - \frac{n_i\left(1-c\right)}{1+n_i} + \frac{n_i F}{n_j\left(1+n_i\right)} - \frac{\left(n_i - n_j\right)cl_{12}}{2n_j} \\ &= \frac{\left(3+n_i\right)F}{2n_j\left(1+n_i\right)} - \frac{n_i\left(1-c\right)}{1+n_i} - \frac{cl_{12}}{2n_j} \geq 0 \\ &\Leftrightarrow F \leq F_i^d \equiv \frac{2n\left(1-n\right)\left(1-c\right) + cn_i\left(1+n_i\right)l_{12}}{3+n_i}. \end{aligned} \tag{C.4}$$

QED

In order to derive each operator's best response, it is important to derive the number of each airport users under the four possible sets of the airport charges. In case of $(a_1, a_2) = (a_1^e, a_2^e)$, the number of each airport users is equal to the population of the hinterland since $a_i^e > \hat{a}_i$; therefore, $N(a_1^e, a_2^e) = P$. Lemma 5 summarizes the carrier's network choice when $(a_1, a_2) = (a_1^d, a_2^e)$ or $(a_1, a_2) = (a_1^e, a_2^d)$ while Lemma 6 shows the network choice in case of $(a_1, a_2) = (a_1^d, a_2^d)$.

Lemma 5

Suppose that operator i chooses the discount strategy while operator j chooses the exploiting strategy (*that is,* $a_i = a_i^d$ *and* $a_j = a_j^e$). *In such a case, the carrier sets its hub at airport i, which offers the discount airport charge.*

Proof:

Suppose that operator 1 chooses the discount strategy while operator 2 plays the exploiting strategy (that is, $(a_1, a_2) = (a_1^d, a_2^e)$). We check whether $(a_1, a_2) = (a_1^d, a_2^e)$ satisfies the following two conditions for $N(a_1^d, a_2^e) = H_1$:

$$a_1^d \leq \min\left\{\hat{a}_1, \tilde{a}_1\left(a_2^e\right)\right\}, \tag{C.5}$$

$$a_2^e \leq \bar{a}_2\left(a_1^d; H_1\right). \tag{C.6}$$

We first take a closer look at the RHS of (C.5). By the calculation (or Figure 2), it is shown that $\hat{a}_1 = \tilde{a}_1(\hat{a}_2)$. Furthermore, since $\tilde{a}_1{}'(a_2) > 0$ and $a_2^e > \hat{a}_2$, the RHS of (C.5) is $\min\{\hat{a}_1, \tilde{a}_1(a_2^e)\} = \hat{a}_1$. The discount strategy of Airport 1 is given by $a_1^d = \min\{\hat{a}_1, \tilde{a}_1(\underline{a}_2)\}$; therefore, in case of $(a_1, a_2) = (a_1^d, a_2^e)$, (C.5) is automatically satisfied. For the RHS of (C.6),

$$\bar{a}_2\left(\hat{a}_1; H_1\right) = 1 - c - \frac{F}{1-n} = \bar{a}_2\left(P\right) = a_2^e.$$

Furthermore, since $a_1^d = \min\{\hat{a}_1, \tilde{a}_1(\underline{a}_2)\}$ and $a_2{}'(a_1; H_1) < 0$, (C.6) is also automatically satisfied when $(a_1, a_2) = (a_1^d, a_2^e)$. By using a similar argument for the case of $(a_1, a_2) = (a_1^e, a_2^d)$, we can show $N(a_1^e, a_2^d) = H_2$.

QED

Lemma 6

Suppose that both operators choose the discount strategy, namely $(a_1, a_2) = (a_1^d, a_2^d)$. *In such a case, the carrier's network choice is*

$$N\left(a_1^d, a_2^d\right) = \begin{cases} H_1 & \text{if } \max\left\{\tilde{F}, \bar{F}_1\right\} < F, \\ H_2 & \text{if } \bar{F}_2 < F < \tilde{F}, \\ H_1 \text{ or } H_2 & \text{otherwise,} \end{cases} \tag{C.7}$$

where

$$\bar{F}_i \equiv \frac{2n(1-n)(1-c) + cl_{12}n_i(1+n_i)}{1+3n_i} \text{ for } i = 1, 2,$$

$$\tilde{F} \equiv -n(1-n)(1-c) + \frac{c\lfloor 2+n(1-n)\rfloor l_{12}}{2}.$$

Proof:

As in Lemma 4, the discount airport charge of operator *i* depends on the fixed cost, F_i^d.

We define $\underline{F}^d$ and $\bar{F}^d$ as:

$$\underline{F}^d \equiv \min\left\{F_1^d, F_2^d\right\},$$

$$\bar{F}^d \equiv \max\left\{F_1^d, F_2^d\right\}.$$

Hereafter, we derive the carrier's network choice, $N(a_1^d, a_2^d)$, for the following three situations: i) $F \leq \underline{F}^d$; ii) $\bar{F}^d < F$; iii) $\underline{F}^d < F \leq \bar{F}^d$. For $F \leq \underline{F}^d$, each of the two operators chooses $a_i^d = \hat{a}_i$. In such case, network H_i (i = 1, 2) becomes the carrier's choice if:

$$\hat{a}_i \leq \min\left\{\hat{a}_i, \tilde{a}_i\left(\hat{a}_j\right)\right\}, \tag{C.8}$$

$$\hat{a}_j \leq \bar{a}_j\left(\hat{a}_i; H_i\right). \tag{C.9}$$

First, since, by the calculation (or Figure 2), $\hat{a}_i = \tilde{a}_i(\hat{a}_j)$, (C.8) is automatically satisfied.

In addition, (C.9) is also satisfied for $F \leq \underline{F}^d$:

$$\bar{a}_j\left(\hat{a}_i;H_i\right)=1-c\left(1+l_{12}\right)-2\hat{a}_i=1-c-\frac{F}{n_j}=\bar{a}_j\left(P\right)=a_j^e>\hat{a}_j. \tag{C.10}$$

Therefore, the two hub-spoke networks, H_1 and H_2, remain the candidates for the carrier's network choice:

$$N\left(a_1^d,a_2^d\right)=H_1 \text{ or } H_2 \text{ if } F<\underline{F}^d. \tag{C.11}$$

In case of $\bar{F}^d<F$, $a_i^d=\tilde{a}_i(\underline{a}_j)$. Under this circumstance, network H_i (i = 1, 2) becomes the carrier's network choice if:

$$\tilde{a}_i\left(\underline{a}_j\right)\le\min\left\{\hat{a}_i,\tilde{a}_i\left(\tilde{a}_j\left(\underline{a}_i\right)\right)\right\}, \tag{C.12}$$

$$\tilde{a}_j\left(\underline{a}_i\right)\le\bar{a}_j\left(\tilde{a}_i\left(\underline{a}_j\right);H_i\right). \tag{C.13}$$

Let us start with the condition (C.13). Note that, for $\bar{F}^d<F$, we have $\tilde{a}_i(\underline{a}_j)<\hat{a}_i$. Together with this, since $a_j'(a_i;H_i)<0$ and $\bar{a}_j(\hat{a}_i;H_i)=\bar{a}_j(P)=a_j^e>\hat{a}_j$,

$$\tilde{a}_j\left(\underline{a}_i\right)\le\hat{a}_j<\bar{a}_j\left(\hat{a}_i;H_i\right)\le\bar{a}_j\left(\tilde{a}_i\left(\underline{a}_j\right);H_i\right). \tag{C.14}$$

Therefore, (C.13) is satisfied for $\bar{F}^d<F$, and now we consider the condition (C.12). Since $\tilde{a}_i(\underline{a}_j)<\hat{a}_i$ for $\bar{F}^d<F$, we need to derive the condition at which $\tilde{a}_i(\underline{a}_j)\le\tilde{a}_i(\tilde{a}_j(\underline{a}_i))$ holds. By using Equations (12.2) and (17),

$$\tilde{a}_i\left(\tilde{a}_j\left(\underline{a}_i\right)\right)=\frac{n_i}{n_j}\times\tilde{a}_j\left(\underline{a}_i\right)+\frac{cl_{12}\left(n_i-n_j\right)}{2n_j}=\frac{n_i\left(1-c\right)}{1+n_j}-\frac{F}{1+n_j}=\frac{n_ia_i^e}{1+n_j}=\underline{a}_i. \tag{C.15}$$

Hence, the comparison of $\tilde{a}_i(\underline{a}_j)$ and $\tilde{a}_i(\tilde{a}_j(\underline{a}_i))$ is equivalent to that of $\tilde{a}_i(\underline{a}_j)$ and $\underline{a}_i$:

$$\tilde{a}_1\left(\underline{a}_2\right)-\underline{a}_1=-\frac{n\left(2n-1\right)\left(1-c\right)}{\left(1+n\right)\left(2-n\right)}-\frac{\left(2n-1\right)F}{\left(2-n\right)\left(1-n\right)\left(1+n\right)}+\frac{\left(2n-1\right)cl_{12}}{2\left(1-n\right)}\leq 0$$

$$\Leftrightarrow F\geq\tilde{F}\equiv -n\left(1-n\right)\left(1-c\right)+\frac{\left(2-n\right)\left(1+n\right)cl_{12}}{2}, \tag{C.16}$$

$$\tilde{a}_2\left(\underline{a}_1\right)-\underline{a}_2=\frac{\left(1-n\right)\left(2n-1\right)\left(1-c\right)}{\left(2-n\right)\left(1+n\right)}+\frac{\left(2n-1\right)F}{n\left(2-n\right)\left(1+n\right)}-\frac{\left(2n-1\right)cl_{12}}{2n}\leq 0$$

$$\Leftrightarrow F\leq\tilde{F}\equiv -n\left(1-n\right)\left(1-c\right)+\frac{\left(2-n\right)\left(1+n\right)cl_{12}}{2}. \tag{C.17}$$

According to the conditions (C.16) and (C.17), $\tilde{a}_1(\underline{a}_2)\leq\tilde{a}_1(\tilde{a}_2(\underline{a}_1))$ and $\tilde{a}_2(\underline{a}_1)\geq\tilde{a}_2(\tilde{a}_1(\underline{a}_2))$ for $F\geq\tilde{F}$; therefore, network H_1 becomes the carrier's network choice. For $F\leq\tilde{F}$, the carrier chooses H_2 since $\tilde{a}_1(\underline{a}_2)\geq\tilde{a}_1(\tilde{a}_2(\underline{a}_1))$ and $\tilde{a}_2(\underline{a}_1)\leq\tilde{a}_2(\tilde{a}_1(\underline{a}_2))$. In summary, for $\bar{F}^d<F$,

$$N\left(a_1^d,a_2^d\right)=\begin{cases}H_1 \text{ if } F>\bar{F}^d \text{ and } F\geq\tilde{F},\\ H_2 \text{ if } F>\bar{F}^d \text{ and } F\leq\tilde{F}.\end{cases} \tag{C.18}$$

Finally, we derive the carrier's network choice in case of $\underline{F}^d<F\leq\bar{F}^d$. Suppose that $\underline{F}^d=F_1^d$ and $\bar{F}^d=F_2^d$. In this case, $(a_1^d,a_2^d)=(\tilde{a}_1(\underline{a}_2),\hat{a}_2)$. The carrier chooses H_1 as its network if:

$$\tilde{a}_1\left(\underline{a}_2\right)\leq\min\left\{\hat{a}_1,\tilde{a}_1\left(\hat{a}_2\right)\right\}, \tag{C.19}$$

$$\hat{a}_2\leq\bar{a}_2\left(\tilde{a}_1\left(\underline{a}_2\right);H_1\right). \tag{C.20}$$

Since $\hat{a}_1=\tilde{a}_1(\hat{a}_2)$ and $\underline{F}^d=F_1^d$, (C.18) holds with the strict inequality for $F_1^d<F\leq F_2^d$ according to Lemma 4. (C.19) is also satisfied according to Equation (C.10). Therefore, network H_1 remains a candidate for the carrier's choice for

$F_1^d < F \le F_2^d$. For this domain, we also need to check whether the carrier chooses H_2. This is the case if:

$$\hat{a}_2 \le \min\left\{\hat{a}_2, \tilde{a}_2\left(\tilde{a}_1\left(\underline{a}_2\right)\right)\right\}, \tag{C.21}$$

$$\tilde{a}_1\left(\underline{a}_2\right) \le \bar{a}_1\left(\hat{a}_2; H_1\right). \tag{C.22}$$

As in Equation (C.14), the condition (C.22) holds with the strict inequality. For the condition (C.21), by using (C.15),

$$\begin{aligned} \hat{a}_2 - \underline{a}_2 &= \frac{F}{2n} - \frac{cl_{12}}{2} - \frac{(1-n)(1-c)-F}{1+n} \le 0 \\ \Leftrightarrow F &\le \frac{2n(1-n)(1-c)+cl_{12}n(1+n)}{1+3n} = \frac{2n(1-n)(1-c)+cl_{12}n_1(1+n_1)}{1+3n_1} = \bar{F}_1. \end{aligned}$$

In comparison of $\bar{F}_1$ and F_1^d, we have $\bar{F}_1 > F_1^d$ since $1+3n < 3+n$. Therefore, for $F \le \bar{F}_1$, the carrier may choose network H_2 as its network configuration. In summary, in case of $F_1^d < F \le F_2^d$,

$$N\left(a_1^d, a_2^d\right) = \begin{cases} H_1 \text{ or } H_2 & \text{if } \underline{F}^d = F_1^d < F \le \bar{F}_1, \\ H_1 & \text{if } \bar{F}_1 < F \le \bar{F}^d = F_2^d. \end{cases} \tag{C.23}$$

In case of $F_2^d < F \le F_1^d$, a similar argument is applied; therefore, the network choice is derived as

$$N\left(a_1^d, a_2^d\right) = \begin{cases} H_1 \text{ or } H_2 & \text{if } \underline{F}^d = F_2^d < F \le \bar{F}_2, \\ H_2 & \text{if } \bar{F}_2 < F \le \bar{F}^d = F_1^d, \end{cases} \tag{C.24}$$

where

$$\bar{F}_2 = \frac{2n(1-n)(1-c)+cl_{12}(1-n)(2-n)}{4-3n} = \frac{2n(1-n)(1-c)+cl_{12}n_2(1+n_2)}{1+3n_2}.$$

By summarizing these conditions, (C.11), (C.18), (C.23), and (C.24), we obtain (C.7).

QED

By using Lemma 5, we obtain each operator's best response against the competitor's exploiting strategy as follows:

Lemma 7

Suppose that the competitor chooses the exploiting strategy. Each operator's best response against the competitor's strategy is

$$a_1^* = \begin{cases} a_1^d \text{ if } \bar{F}_2 \le F \le \min\left\{\tilde{F}, \bar{F}\right\}, \\ a_i^e \text{ if } F < \bar{F}_2 \text{ and } \tilde{F} < F, \end{cases} \tag{C.25}$$

$$a_2^* = \begin{cases} a_2^d \text{ if } \max\left\{\bar{F}_1, \tilde{F}\right\} \le F \le \bar{F}, \\ a_2^e \text{ if } F < \max\left\{\bar{F}_1, \tilde{F}\right\}, \end{cases} \tag{C.26}$$

where

$$\bar{F}_i \equiv \frac{2n(1-n)(1-c) + cl_{12}n_i(1+n_i)}{1+3n_i} \text{ for } i = 1, 2,$$

$$\tilde{F} \equiv -n(1-n)(1-c) + \frac{c\lfloor 2+n(1-n)\rfloor l_{12}}{2}.$$

Proof:

Suppose that the competitor *j* chooses $a_j = a_j^e$. Then, by using Lemma 5, the difference in the payoffs is computed as

$$R_i\left(a_i^d, a_j^e\right) - R_i\left(a_i^e, a_j^e\right) = a_i^d\left(1+n_j\right) - a_i^e n_i. \tag{C.27}$$

By using the definition of $\underline{a}_i$, (C.27) is rewritten as

$$a_i^d\left(1+n_j\right)-a_i^e n_i=\left(a_i^d-\underline{a}_i\right)\left(1+n_j\right).$$

Therefore, in this case, the sign of $(a_i^d-\underline{a}_i)$ determines whether the discount strategy becomes the best response against the competitor's exploiting strategy. According to Equations (16) and (17),

$$\hat{a}_i-\underline{a}_i=\frac{\left(1+3n_j\right)F}{2n_j\left(1+n_j\right)}-\frac{cl_{12}}{2}-\frac{n_i\left(1-c\right)}{1+n_j}\geq 0\Leftrightarrow F\geq\frac{2n\left(1-n\right)\left(1-c\right)+cl_{12}n_j\left(1+n_j\right)}{1+3n_j}=\bar{F}_j,\tag{C.28}$$

$$\begin{aligned}\tilde{a}_1\left(\underline{a}_2\right)-\underline{a}_1&=-\frac{n\left(2n-1\right)\left(1-c\right)}{\left(1+n\right)\left(2-n\right)}-\frac{\left(2n-1\right)F}{\left(2-n\right)\left(1-n\right)\left(1+n\right)}+\frac{\left(2n-1\right)cl_{12}}{2\left(1-n\right)}\geq 0\\&\Leftrightarrow F\leq\tilde{F}\equiv -n\left(1-n\right)\left(1-c\right)+\frac{\left(2-n\right)\left(1+n\right)cl_{12}}{2},\end{aligned}\tag{C.29}$$

$$\begin{aligned}\tilde{a}_2\left(\underline{a}_1\right)-\underline{a}_2&=\frac{\left(1-n\right)\left(2n-1\right)\left(1-c\right)}{\left(2-n\right)\left(1+n\right)}+\frac{\left(2n-1\right)F}{n\left(2-n\right)\left(1+n\right)}-\frac{\left(2n-1\right)cl_{12}}{2n}\geq 0\\&\Leftrightarrow F\geq\tilde{F}\equiv -n\left(1-n\right)\left(1-c\right)+\frac{\left(2-n\right)\left(1+n\right)cl_{12}}{2}.\end{aligned}\tag{C.30}$$

Together with Equation (17) and the assumption, $F\leq\bar{F}$, each operator's best response, a_i^*, against the competitor's exploiting strategy is derived as Equations (C.25) and (C.26).

QED

Finally, Lemma 8 summarizes each operator's best response against the competitor's discount strategy.

Lemma 8

Suppose that the competitor chooses the discount strategy. Each operator's best response against the competitor's strategy is always the exploiting strategy.

Proof:

Due to the discontinuous change in the number of airport users, we derive each operator's best response against the competitor's discount strategy according to the following process. First, we focus on the best response of operator i in case of $N(a_1^d, a_2^d) = H_i$, and then, we solve the problem of operator i in case of $N(a_1^d, a_2^d) = H_j$.

In case of $N(a_1^d, a_2^d) = H_i$, the difference in the payoff is:

$$R_i\left(a_i^d, a_j^d\right) - R_i\left(a_i^e, a_j^d\right) = a_i^d\left(1+n_j\right) - a_i^e n_i = \left(a_i^d - \underline{a}_i\right)\left(1+n_j\right).$$

Therefore, we can apply the same argument as in the proof of Lemma 7, and the best response is identical to Equations (C.25) and (C.26). However, according to Lemma 6,

$$N\left(a_1^d, a_2^d\right) = H_1 \text{ if } \max\left\{\tilde{F}, \bar{F}_1\right\} < F,$$

$$N\left(a_1^d, a_2^d\right) = H_2 \text{ if } \bar{F}_2 < F < \tilde{F}.$$

Hence, by using (C.25) and (C.26), we need to derive the best response against the competitor's discount strategy of operator 1 for $\max\{\tilde{F}, \bar{F}_1\} < F$, and that of operator 2 for $\bar{F}_2 < F < \tilde{F}$. In case of operator 1, for this domain, $\tilde{F} \le \max\{\tilde{F}, \bar{F}_1\}$, according to (C.25), its best response is always the exploiting, $a_1^* = a_1^e$. For $\bar{F}_2 < F < \tilde{F}$, as shown in (C.26), the best response of operator 2 is also the exploiting since $\tilde{F} \le \max\{\tilde{F}, \bar{F}_1\}$.

In the case of $N(a_1^d, a_2^d) = H_j$, the difference in the payoff between the two strategies is

$$R_i\left(a_i^d, a_j^d\right) - R_i\left(a_i^e, a_j^d\right) = \left(a_i^d - a_i^e\right)n_i.$$

The best response is determined by the sign of $a_i^d - a_i^e$. However, under our setup, for $F \le F_i^d$, $a_i^d = \hat{a}_i < a_i^e$. In addition, for $F > F_i^d$, since $\hat{a}_i \ge \tilde{a}_i(\underline{a}_j)$ according to Lemma 4, $a_i^e > \tilde{a}_i(\underline{a}_j)$. Therefore, each operator's best response against the discount strategy is always the exploiting strategy, i.e., $a_i^* = a_i^e$ if $a_j = a_j^e$.

QED

By using Lemmas 5, 6, 7, and 8, we obtain Proposition 2.

Proposition 2

The Nash Equilibrium, (a_1^*, a_2^*, N^*), *is characterized as follows*:

$$\left(a_1^*, a_2^*, N^*\right) = \begin{cases} \left(a_1^e, a_2^e, P\right) & \text{if } F < \min\left\{\bar{F}_1, \bar{F}_2, \bar{F}\right\}, \\ \left(a_1^d, a_2^e, H_1\right) & \text{if } \bar{F}_2 \le F \le \min\left\{\tilde{F}, \bar{F}\right\}, \\ \left(a_1^e, a_2^d, H_2\right) & \text{if } \max\left\{\bar{F}_1, \tilde{F}\right\} \le F \le \bar{F}, \end{cases} \tag{18}$$

where

$$\bar{F}_i \equiv \frac{2n(1-n)(1-c) + cl_{12}n_i(1+n_i)}{1+3n_i} \text{ for } i = 1, 2,$$

$$\tilde{F} \equiv -n(1-n)(1-c) + \frac{c\left\lfloor 2 + n(1-n)\right\rfloor l_{12}}{2}.$$

Proof:

According to Lemma 8, each operator always plays the exploiting strategy if its competitor chooses the discount strategy. Therefore, by using Lemma 7, in the case where one of the two operators plays the discount strategy, the equilibrium airport charges are derived as follows:

$$\left(a_1^*, a_2^*\right) = \begin{cases} \left(a_1^d, a_2^e\right) \text{ if } \bar{F}_2 \le F \le \min\left\{\tilde{F}, \bar{F}\right\}, \\ \left(a_1^e, a_2^d\right) \text{ if } \max\left\{\bar{F}_1, \tilde{F}\right\} \le F \le \bar{F}. \end{cases} \tag{C.31}$$

In either case of (C.31), as in Lemma 6, the equilibrium network configuration, N^*, falls into H_1 if $(a_1^*, a_2^*) = (a_1^d, a_2^e)$ and into H_2 if $(a_1^*, a_2^*) = (a_1^e, a_2^d)$.

In the case of $F < \min\{\bar{F}_1, \bar{F}_2\}$, both operators have no incentives to discount. Therefore, the equilibrium airport charges are $(a_1^*, a_2^*) = (a_1^e, a_2^e)$. As in Lemma 8, furthermore, since $a_i^e > \hat{a}_i$, the equilibrium network becomes *P*.

QED

Finally, we state the Corollary, which summarizes the condition where network H_1 emerges at the equilibrium.

Corollary

The network H_1 never emerges at the Nash Equilibrium if $n \ge 2/3$.

Proof:

Let us begin by focusing on the threshold, $\bar{F}$:

$$\bar{F} \equiv \min\left\{(1-n)(1-c), \frac{n(1-n)\lfloor 2(1-c)+cl_{12}\rfloor}{1+n}, \frac{n(1-n)\lfloor 2(1-c)+cl_{12}\rfloor}{2-n}\right\}.$$

Since $n > 1/2$,

$$\frac{n(1-n)\lfloor 2(1-c)+cl_{12}\rfloor}{1+n} < \frac{n(1-n)\lfloor 2(1-c)+cl_{12}\rfloor}{2-n} \quad \because 2-n < \frac{3}{2} < 1+n.$$

Furthermore,

$$(1-n)(1-c) - \frac{n(1-n)\left[2(1-c)+cl_{12}\right]}{1+n} = \frac{(1-n)^2(1-c) - cl_{12}n(1-n)}{1+n} < 0$$
$$\Leftrightarrow l_{12} > x_A \equiv \frac{(1-n)(1-c)}{cn}.$$

That is,

$$\bar{F} = \begin{cases} (1-n)(1-c) & \text{if } l_{12} > x_A, \\ \dfrac{n(1-n)\left[2(1-c)+cl_{12}\right]}{1+n} & \text{otherwise.} \end{cases}$$

According to Proposition 2, network H_1 is realized at the equilibrium if the following condition is satisfied:

$$\bar{F}_2 \le F \le \min\left\{\tilde{F}, \bar{F}\right\}.$$

Through a comparison of the upper thresholds, we obtain

$$(1-n)(1-c) - \tilde{F} = (1+n)(1-n)(1-c) - \frac{cl_{12}(1+n)(2-n)}{2} < 0 \Leftrightarrow l_{12} > x_B \equiv \frac{2(1-n)(1-c)}{c(2-n)},$$

$$\frac{n(1-n)\left[2(1-c)+cl_{12}\right]}{1+n}-\tilde{F}=\frac{2n(1-n)(3+n)(1-c)-cl_{12}\left(2+2n^2+n-n^3\right)}{2(1+n)}<0$$

$$\Leftrightarrow l_{12}>x_C\equiv\frac{2n(1-n)(3+n)(1-c)}{c\left(-n^3+2n^2+n+2\right)},$$

Since we have assumed that $n \geq 2/3$, evaluating the three thresholds, x_A, x_B, and x_C, at $n = 2/3$,

$$x_A\Big|_{n=\frac{2}{3}}=x_B\Big|_{n=\frac{2}{3}}=x_C\Big|_{n=\frac{2}{3}}=\frac{1-c}{2c},$$

$$\frac{\partial x_A}{\partial n}\bigg|_{n=\frac{2}{3}}=-\frac{9(1-c)}{4c}<\frac{\partial x_B}{\partial n}\bigg|_{n=\frac{2}{3}}=-\frac{9(1-c)}{8c}<\frac{\partial x_C}{\partial n}\bigg|_{n=\frac{2}{3}}=-\frac{171(1-c)}{176c}<0.$$

These imply that for $n > 2/3$, $x_A < x_B < x_C$. Therefore, for $n > 2/3$, the upper threshold is given by

$$\min\left\{\tilde{F},\bar{F}\right\}=\begin{cases}\tilde{F} & \text{if } l_{12}<x_B,\\ (1-n)(1-c) & \text{otherwise.}\end{cases} \tag{C.32}$$

Finally, we compare the upper threshold (C.32) with the lower, $\bar{F}_2$:

$$\tilde{F}-\bar{F}_2=-\frac{(2-n)\left\lfloor 6n(1-n)(1-c)-cl_{12}\left(2+3n-n^2\right)\right\rfloor}{8-6n}>0\Leftrightarrow l_{12}<x_D\equiv\frac{6n(1-n)(1-c)}{c\left(2+3n-n^2\right)},$$

$$(1-n)(1-c)-\bar{F}_2=-\frac{(1-n)\left\lfloor(5n-4)(1-c)-cl_{12}(2-n)\right\rfloor}{4-3n}>0\Leftrightarrow l_{12}<x_E\equiv\frac{(5n-4)(1-c)}{c(2-n)}.$$

Again, by evaluating these three thresholds, x_B, x_D, and x_E, at $n = 2/3$,

$$x_B\big|_{n=\frac{2}{3}} = x_D\big|_{n=\frac{2}{3}} = x_E\big|_{n=\frac{2}{3}} = \frac{1-c}{2c},$$

$$\frac{\partial x_E}{\partial n}\bigg|_{n=\frac{2}{3}} = -\frac{27(1-c)}{8c} < \frac{\partial x_B}{\partial n}\bigg|_{n=\frac{2}{3}} = -\frac{9(1-c)}{8c} < \frac{\partial x_D}{\partial n}\bigg|_{n=\frac{2}{3}} = -\frac{9(1-c)}{16c} < 0.$$

These relations indicate that for $n > 2/3$, $x_E < x_B < x_D$. By using the definitions of x_k (k = B, D, E), we obtain the following relations among the fixed cost thresholds, $\bar{F}_2, \tilde{F}$, and $(1-n)(1-c)$:

$$(1-n)(1-c) \geq \bar{F}_2 > \tilde{F} \text{ for } x \leq x_E,$$

$$\bar{F}_2 > (1-n)(1-c) \geq \tilde{F} \text{ for } x_E < x \leq x_B,$$

$$\bar{F}_2 \geq \tilde{F} > (1-n)(1-c) \text{ for } x_B < x \leq x_D,$$

$$\tilde{F} > \bar{F}_2 > (1-n)(1-c) \text{ for } x_D < x.$$

QED

Appendix D: The Equilibrium vs. the Optimum

Proposition 3

Network P is more often observed at the equilibrium than at the optimum.

Proof:

At the equilibrium, network P emerges if $F \leq \min\{\bar{F}_1, \bar{F}_2, \bar{F}\}$ while at the optimum, it is the case if $F \leq F^O(P, H_1)$. By comparing these thresholds,

$$(1-n)(1-c)-F^{O}(P,H_1)=(1-n)\lfloor(1-c)-cl_{12}\rfloor>0$$
$$\Leftrightarrow l_{12}<y_A\equiv\frac{1-c}{c},\qquad\text{(D.1)}$$

$$\bar{F}_1-F^{O}(P,H_1)=\frac{2n(1-n)(1-c)-cl_{12}(1+n-4n^2)}{1+3n}>0$$
$$\Leftrightarrow l_{12}<y_B\equiv\frac{2n(1-n)}{(1+n-4n^2)}\times y_A,\qquad\text{(D.2)}$$

$$\bar{F}_2-F^{O}(P,H_1)=\frac{2\lfloor n(1-n)(1-c)-cl_{12}(1-n)^2\rfloor}{4-3n}>0$$
$$\Leftrightarrow l_{12}<y_C\equiv\frac{n}{1-n}\times y_A,\qquad\text{(D.3)}$$

$$\frac{n(1-n)\lfloor 2(1-c)+cl_{12}\rfloor}{1+n}-F^{O}(P,H_1)=\frac{2n(1-n)(1-c)-cl_{12}(1-n)}{1+n}>0$$
$$\Leftrightarrow l_{12}<y_D\equiv\frac{2n}{1-n}\times y_A.\qquad\text{(D.4)}$$

First, note that for (D.2), $\bar{F}_1>F^{O}(P,H_1)$ is always satisfied if $1+n-4n^2<0$, i.e., $1>n>(1+\sqrt{17})/8$. Otherwise, the signs of these relations are dependent on the value of l_{12}. In order to prove Proposition 3, we focus on the coefficients of thresholds in (D.2), (D.3), and (D.4). According to the computation,

$$\frac{2n(1-n)}{(1+n-4n^2)}=1+\frac{(2n-1)(n+1)}{1+n-4n^2}>1\text{ for }n<\frac{1+\sqrt{17}}{8}\Leftrightarrow y_A<y_B\text{ for }n<\frac{1+\sqrt{17}}{8},$$

$$\frac{n}{1-n}>1\Leftrightarrow y_A<y_C,$$
$$\frac{2n}{1-n}>1\Leftrightarrow y_A<y_D.$$

These indicate that as long as $(1-n)(1-c)>F^{O}(P,H_1)$, the equilibrium threshold of network P always exceeds $F^{O}(P,H_1)$.

QED

Chapter 4

The Effects of Airline Competition on Flight Schedules and the Social Welfare

4.1. Introduction

Deregulation in aviation industry is intended to promote competition through new entries, which is expected to lower airfares and thereby raise the social welfare. In Japan, deregulation removed restrictions on entry, and four airlines started to flight services in 1996 and 1997. In the US, Department of Justice rejected American Airlines to merge US airway at first.

However, competition affects not only airfares but also flight schedules. Table 4-1 shows time tables for a monopolistic route (Tokyo-Toyama) and a competitive route (Tokyo-Kushiro). As can be seen in this table, flights depart at almost same intervals in the former route. In contrast, in the latter, departure times of two airlines (ANA and JAL) tend to be close to each other. This might be due to competition of Hotelling type to attract passengers whose desired departure times are distributed on the time axis. In this case, total scheduling delay cost (hereafter, SDC) in competitive routes would be higher than that in monopolistic ones. If this effect is significant, promoting entries may result in efficiency loss. In this chapter, we focus on the scheduling effect of competition. Some positive aspects of monopoly have been pointed out. Bruckner and Spiller [1991] introduced the economy of density. The higher traffic density allows the use of larger, more efficient aircrafts and this effect leads to lower cost per passenger-mile on dense route. Bruckner [2002] and Silva and Verhoef [2013] showed that airlines which have large share at their hub airports internalize congestion. Mayer and Sinai [2003] and Santos and Robin [2010] empirically showed that flight delays are lower at highly concentrated airports because the airline internalizes congestion.

Previous researches ignored flight schedules and SDC was given directly while SDC is linked with scheduling strongly. Brueckner [2004], Kawasaki [2012], Alderighi, Cento, Nijkamp and Rietveld [2005] and Flores-Fillol [2009] treated flight frequency as one of components of generalized cost ($\mathrm{GC} = \mathrm{airfare} + 1/\mathrm{frequency}$). These models implicitly assume that all flights are at even interval and SDC is the inverse of frequency.

The purpose of this paper is to present the condition where monopoly is better than competition and contribute to establishment of anti-trust policies. Competition has two effects, that is, price effect and scheduling effect. The former effect increases demand and improve social welfare, which is shown as the left path in Figure 4-1. It has been pointed out traditionally and is the basis of anti-trust policies. The latter effect raises SDC and decreases demand, and then harms social welfare. It depends on the trade-off between the effects which monopoly or competition is better in term of social welfare.

This chapter is organized as follows. Section 4.2 is the empirical part in which we verify that competition changes flight schedules and raise SDC by introducing un-evenness index. In section 4.3, we estimate the decrement of airfares by competition and the demand function to justify the theoretical model. Section 4.4 is the theoretical part. We establish the model based on empirical regressions to derive the condition where monopoly is more desirable than competition. Finally, section 4.5 concludes.

Tokyo-Toyama		Tokyo-Kushiro	
Dep. Time	Airline	Dep. Time	Airline
6:40	ANA	7:40	ANA
9:45	ANA	8:10	JAL
13:40	ANA	11:20	ANA
15:35	ANA	12:30	JAL
18:25	ANA	17:00	ANA
19:50	ANA	17:50	JAL

Table 4-1: Flight schedules for monopolistic and competitive routes

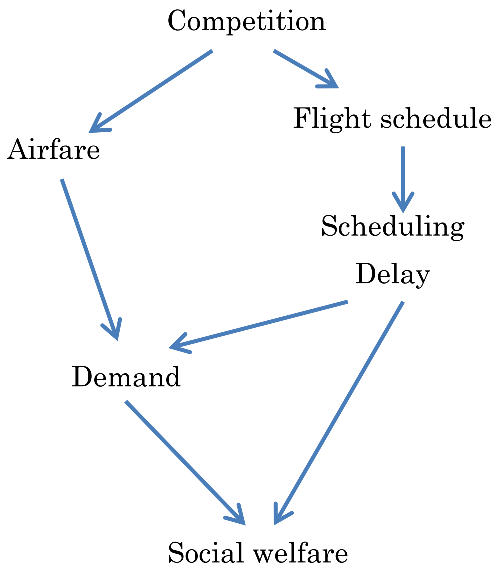

Figure 4-1: Effect paths of competition to social welfare

4.2. Flight Schedules and Scheduling Delay Cost

In this section, we show empirical methodology to provide an evidence that flight schedules of monopolistic routes are at more even interval than competitive routes. First, to measure scheduling delay, we construct new variables based on intervals of air schedule and we define the metric which captures "un-evenness" of the air schedule using the variables. Second, we present the research design which connects schedule distortion and competition. Then, we discuss the data for empirical analysis. Finally, we derive the fact which supports our hypothesis aforementioned by the simple regression model.

4.2.1. Scheduling Delay and Un-evenness Index

Scheduling delay (hereafter, SD) is defined as the time difference between the desired departing time and actual flight schedule. We assume that all airports are operated from 6:00 through 21:00, that is, total business time of each airport is up to 900 minutes. This assumption is quite natural because most airports can be operated in this time range due to agreements with local residents or aviation policies. It is also note we could construct a circler timeframe by connecting 6:00 and 21:00. This implies that, for each route, departing times are arranged along the circle's perimeter with 900 minutes. Then we denote actual intervals between flights as $\{Int_j\,; j = 1,2,\cdots,f\}$, where f is its frequency. In addition, passengers' desired departure time is assumed to be continuous uniformly distribution across the perimeter. Figure 4-2 shows an example of intervals and scheduling delay for a route with three services.

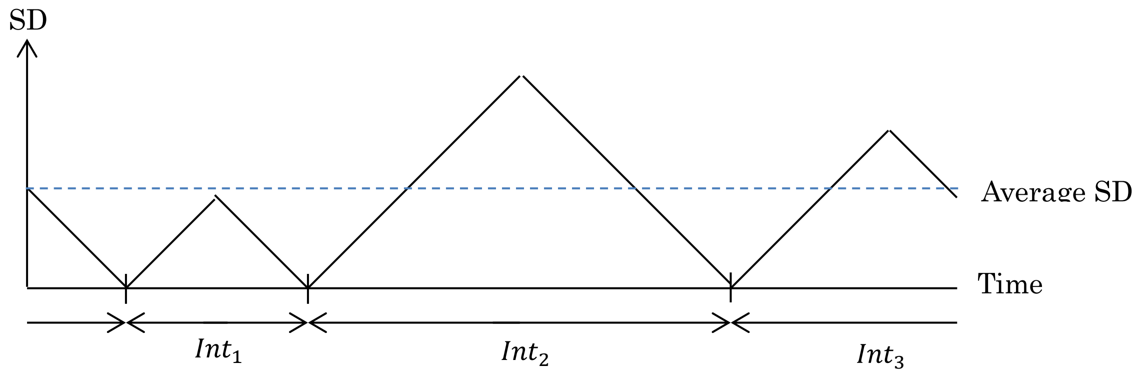

Figure 4-2: Flight intervals and Scheduling delay

Then, for a given route, we calculate the average of SD, which is equal to the average height of all triangles:

$$SD_i = \frac{\sum_{j=1}^{f} Int_j^2}{4\sum_{j=1}^{f} Int_j} = \frac{\sum_{j=1}^{f} Int_j^2}{3600}$$

where i denotes route. This metric is minimized when actual departing times are set at regular intervals, which we define minimum SD as follows:

$$SD_i^{min} = \frac{900}{4f} = \frac{225}{f}$$

It is note that, by definition, SD_i increases as the time schedule becomes uneven. Together these SD metrics, we could construct the new measure which represents how the time schedule is distorted relative to the minimized case, that is, “unevenness”. The most fundamental methodology is calculating how many times the actual SD value is larger than minimum SD value. Thus, for a given route, we define the SD metric divided by its minimum value as the unevenness index:

$$Index_i \equiv \frac{SD_i}{SD_i^{min}} \tag{1}$$

It is straightforward that this index is more than or equal to one for all routes, particularly as the degree of the distortion of flight schedule relative to optimal scheduling becomes larger, reflecting it, the index becomes larger. Since this index could capture the scheduling distortion by the standardized way for all routes, we employ it as a basis for analysis.

4.2.2. Un-evenness and Competition

To clarify the rigorous relationship between calculated unevenness index and competition among airlines, we introduce the simple regression model. To identify the competition and monopoly, we construct the dummy variable $Multi\_Dummy_i$, which is equal to one in the case with competition (i.e., more than or equal to two airlines) and zero otherwise. Then, we regress the unevenness index on the dummy variable:

$$Index_i = \alpha_0 + \alpha_1 \times Multi_{Dummy_i} + \varepsilon_i \tag{2}$$

where ε_i is an error term. If the competition leads to increase in scheduling distortion, coefficient α_1 must be positive. Negative estimate indicates the opposite. It should be considered that whether or not unevenness index depends on only competitive status. However, the airline schedule is rarely affected by other factors including the capacity of airplanes or the distance. We also could define the number of airlines as the explanatory variable instead of dummy variable, but all results remains to be unchanged. Therefore this simple reduced formulation could capture the causal effect of competition on unevenness of air scheduling.

4.2.3. Data

We briefly describe the data. We focus on all Japanese domestic routes with two or more flights in a day and 50,000 or more passengers per year. 85 routes[13] meet these

[13] In order to focus on urban area rather than airports themselves, we integrate multi airports in same region. While there are alternative definitions, we consider urban employment area in Japan in 2005 defined by Kanemoto (2005). For instance, Kansai international airport, Itami (Osaka) airport, and Kobe airport are all in the Osaka area in terms of urban employment based data. Thus, we combine

conditions. We use the timetables published on September 1 in 2011 to calculate scheduling delays.

4.2.4. Results

Using the data, we could take a first look on the relationship between distorted air scheduling and competition. For example, the un-evenness index is 1.12 in Tokyo-Toyama route which is monopolistic route, while the value of competitive Tokyo-Kushiro route is 1.22. (See table 4-1 for the timetables of these routes.) To check our hypothesis that the competition leads to un-even schedule, we estimate the regression model above and derive the main result:

$$\widehat{Index_i} = \underset{(9.25)}{0.436} \times \boldsymbol{I}(\text{Number of Airlines } \geq 2) + \underset{(32.28)}{1.121}$$

---

these airport and routes arriving and departing at these airports are regarded as a single route. Other areas are Tokyo area (including Narita airport and Haneda airport), Nagoya area (including Chubu international airport and Nagoya airport), Sapporo area (including Chitose airport and Sapporo Tamaoka airport), and Fukuoka area (including Fukuoka airport and Kita-Kyusyu airport).

where $\widehat{Index_i}$ is estimator of unevenness index and I is an indicator function. The numbers in a parenthesis show t value of coefficients. Strongly positive value and significance of the coefficient for competition imply that monopoly leads to more equalized schedules, while competition deteriorates them. This finding underpins our hypothesis. We conclude with the derived fact:

Fact

If competition status changes from monopoly to competition, the unevenness of air schedule becomes larger.

4.3. Preparation

This section provides empirical analysis on air demand and airfare. While plenty of previous literatures analyze the determinants of them, we still need parameters needed for theoretical analysis in the later section. Particularly, we focus on the demand and the relationship between competition and airfare. We first provide the data and the research design for it, the model of Ordinary Least Squares (OLS) estimation, then estimate it using Japanese data.

4.3.1. Regression Model

For air demand, we estimate the following linear regression:

$$x_i = \beta_0 + \beta_1 Generalized\ cost_i + \beta_2\ Distance_i + \epsilon_i \tag{3}$$

where x_i is the relative demand size, $Generalized\ cost_i$ is generalized cost calculated for each route and $Distance_i$ is the distance of each route. ϵ_i is error term. For our purpose, coefficient β_1 captures how scheduling delay has impact on the air demand.

For airfare, we estimate the following linear equation:

$$Fare_i = \gamma_0 + \ \gamma_1\ Multi\_Dummy_i + \gamma_2 Distance_i + \gamma_3 New_{Dummy_i} + u_i \tag{4}$$

where $Fare_i$ is cut-rate airfare and $Multi\_Dummy_i$ is the same variable in section 4.2. u_i is error term. In addition, we add New_Dummy_i which is equal to one if the focal route is operated only by new airlines and zero otherwise. Because, in Japan, newly companies set the airfare lower than existing companies to attract more passengers, we control the effect. Among the coefficients, γ_1 captures how competition directly affects airfare. By definition, note that distance directly affect demand and indirectly affect through generalized cost. Therefore we have to consider multicollinearity problem.

However, except for perfect multicollinearity, estimators satisfy consistency and efficiency. In fact, correlation between distance and fare is strictly lower than one, thus OLS estimator is BLUE. For our purpose, we emphasize the preferable feature of estimator to avoid the misspecification problem.

4.3.2. Data

Most data for airfares and demand is cross section data in 2010 obtained from *Survey of services conducted by specified Japanese air carrier*, *Survey of services conducted by Japanese air carrier other than specified Japanese air carrier*, and *Airline origin and destination survey* conducted by Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

We here define some variables for OLS estimation. First, population in each urban employment area (i.e., potential demand) is computed as the summation of population in each municipality constructing it. Given them, actual relative flight demand size for each route is defined by the actual number of passengers divided by population of urban employment areas linked by the route. This enables us to adjust demand size in terms of potential demand size. On the other hand, for each route, we calculate its airfare by averaging reported airfare taking account of discount. In fact, most passengers pay cut-rate price; for example, if a passenger reserve a seat 2 weeks advanced, she pay discounted price. To do this, we compute the average airfare with weighting the number of passengers who pay the discounted price. Thus we define the cut-rate airfare as an explained variable instead of a regular price. For other explanatory variables, distance is the cruising distance reported in the survey and its unit is kilometer. Generalized cost is calculated following previous studies. Generalized cost is defined as summation of airfare and scheduling delay cost. We compute the scheduling delay cost by multiplying scheduling delay SD_i by value of scheduling delay, which is equal to 10.9 Yen per minute in line with Tseng, Ubbels and Verhoef [2005].

4.3.3. Results

Table 4-2 shows the results of regression presented above. All coefficients are strongly significant. It is apparently showed that air demand decreases when generalized cost increases. This implies that scheduling delay cost has negative (indirect) impact on demand. For airfare, competition between multiple airlines sufficiently decreases its airfare. Combining these results and fact in section 2 could support our main idea that competition has negative impact on demand through distortion of time schedule, on the other hand, it decreases airfare, which leads to positive effect on demand. Also note that other results including the impacts of distance and newly airline are quite natural and in line with previous literatures.

In the next section, based on the empirical results, we provide theoretical explanation for our idea.

Each entry reports OLS estimator	Demand size	Airfare
Generalized Cost	- 0.00000683	
	(-4.19)	
Distance	0.000143	15.645
	(5.06)	(18.77)
Multi Dummy		-1724.10
		(-3.40)
New Dummy		-8240.49
		(-5.22)
Constant	0.0926	12757.57
	(3.83)	(19.41)
Adjusted R^2	0.2203	0.8188
Observations	85	85

Table 4-2: Estimation of demand size and airfare

4.4. Theoretical Analysis

In this section, we analyze how competition affect the social welfare based on the results of the empirical part. We clarify the condition in which monopoly is better than competition in terms of the social welfare. At first, we introduce the model which represents the effect of competition on the SDC and the airfare.

4.4.1. Model

As shown in (1), the average scheduling delay is calculated as

$$s = s^{min} i = k f^{-1} i. \tag{5}$$

k is a positive constant and f represents the frequency. Based on regression (2), we formulate un-evenness index as

$$i^m = a_0 \tag{6.1}$$

$$i^c = a_0 + a_1 \tag{6.2}$$

$$\Delta i = a_1 \tag{6.3}$$

The subscripts m and c stand for monopoly and competition, respectively. Δ indicates the difference between competition and monopoly. a_0 and a_1 are corresponding to α_0

and α_1 in the regression equation (2) respectively. (6.3) indicates that competition leads to more un-even schedule by a_1. Using equations (6) on un-evenness of the schedule, we rewrite scheduling delay as

$$s^m = a_0 k f^{-1} \tag{7.1}$$

$$s^c = (a_0 + a_1) k f^{-1} \tag{7.2}$$

$$\Delta s = a_1 k f^{-1}. \tag{7.3}$$

We formulate the airfare as

$$p^m = b_o \tag{8.1}$$

$$p^c = b_o - b_1 \tag{8.2}$$

$$\Delta p = -b_1 \tag{8.3}$$

b_o and b_1 are corresponding to $\beta_0 + \beta_2 Distance + \beta_3 New\_Dummy$ and $-\beta_1$ in regression equation (3) respectively. (8.3) indicates that competition leads to lower airfare by b_1.

We assume the linear demand function as

$$x = c_0 - c_1 p - c_2 s. \tag{9}$$

Here, the generalized cost is $p + c_2/c_1 \cdot s$ and c_2/c_1 is value of scheduling delay[14]. c_0 and c_1 are corresponding to $\gamma_0 + \gamma_2 Distance$ and $-\gamma_1$ in equation (4) respectively.

[14] According to Tseng, Ubbels and Verhoef [2005], Value of Scheduling Delay is 4.6566€/hour. We convert it to Yen by $1€ = 140¥$ and obtain c_2/c_1 is 10.9 Yen per minute.

Using equations (8) and (9), we obtain the demand functions for monopolistic and competitive cases.

$$x^m = c_0 - b_o c_1 - a_0 c_2 k f^{-1} \tag{10.1}$$

$$x^c = c_0 - (b_o - b_1) c_1 - (a_0 + a_1) c_2 k f^{-1} \tag{10.2}$$

$$\Delta x = b_1 c_1 - a_1 c_2 k f^{-1} \tag{10.3}$$

The first term in (10.3) is the decrement of the airfare and the second term is the increment of SD by competition.

We assume three assumptions as following.

Assumption 1:

The airfare in monopolistic case is higher than the increment of SDC.

$$b_0 > a_1 c_1^{-1} c_2 k f^{-1} \Leftrightarrow p^m > c_2/c_1 \cdot \Delta s$$

$p^m = 28{,}402$ and $c_2/c_1 \cdot \Delta s = 214$ when $Distance = 1{,}000$, $New\_Dummy = 0$ and $f = 5$. Therefore, this assumption is acceptable.

Assumption 2:

In monopolistic case, the demand is positive even if SDC gets double.

$$c_0 - b_0 c_1 - 2 a_0 c_2 k f^{-1} > 0 \Leftrightarrow x^m > c_2 s^m$$

$x^m = 0.0373$ and $c_2 s^m = 0.0037$ when $Distance = 1{,}000$, $New\_Dummy = 0$ and $f = 5$. Therefore, this assumption is acceptable.

Assumption 3:

We set the lower bound of f as

$$\underline{f} \equiv c_0^{-1} c_2 (2a_0 + a_1) k$$

$\underline{f} = 0.1908$ when $Distance = 1{,}000$ and $New\_Dummy = 0$. Frequency should be two or larger so that competition can occur. Therefore, this assumption is acceptable.

4.4.2. Discussion

In this subsection, we analyze the effects of competition on the demand and the social welfare focusing on the frequency. Differentiating (7.3) with respect to f, we obtain Lemma 1

Lemma 1

As the flight service becomes frequent, the increment in SD by competition becomes small.

$$\frac{\partial \Delta s}{\partial f} = -d_1 k f^{-2} < 0$$

Flight intervals are short for high frequency route, therefore the increment in SD is small while the flight schedule gets un-even by competition.

We differentiate (10.3) with respect to f and obtain Lemma 2.

Lemma 2

As the flight service becomes frequent, the increment in demand becomes large.

$$\frac{\partial \Delta x}{\partial f} = {a_1}^{-1} a_2 d_1 k f^{-2} > 0$$

The first term in the right hand side of Eq. (10.3) is the decrement of the airfare and the second term is the increment of SDC. The former independents of frequency while the latter is decreasing function of frequency. Therefore, the change in the generalized cost by competition also decreases in frequency.

We analyze the social welfare. We define the welfare as the social benefit minus social cost. The former is consumers' benefit from their flights and it is depicted as the lower part of the invers demand function. The latter is SDC which is taken by consumers and we ignore the operating cost of airlines.

We define two effects of competition, namely, "demand effect" and "SD effect". "Demand effect" is the improvement of the social welfare by the increase in demand due to the decreasing in the airfare by competition. This effect is shown as the square BEFG in Figure 4-3 and $\Delta SW_D \equiv \frac{1}{2}(GC^m + GC^c - 2{c_1}^{-1}c_2 s^c)\,\Delta x$. "SD effect" is the decrement of the social welfare by the increase in SDC. This effect is depicted as the square ABCD and $\Delta SW_S \equiv {c_1}^{-1}c_2\Delta s\cdot x$.

The change in the social welfare is $\Delta SW \equiv \Delta SW_D - \Delta SW_S$ and it depends on the trade-off between two effects which monopoly or competition is better in term of the social welfare.

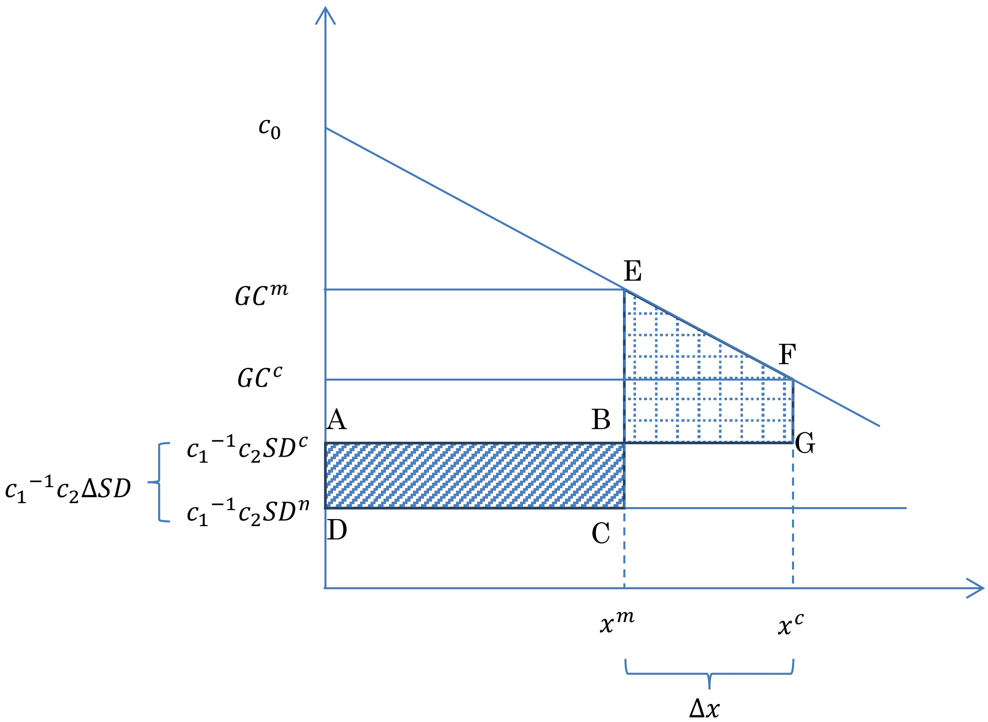

Figure 4-3: "Demand effect" and "SD effect"

We calculate the values of both effects by using equations (7), (8) and (10).

$$\Delta SW_D = \frac{1}{2}\{2b_0 - b_1 - a_1 {c_1}^{-1} c_2 k f^{-1}\}(b_1 c_1 - a_1 c_2 k f^{-1}) \tag{11.1}$$

$$\Delta SW_S = a_1 {c_1}^{-1} c_2 k f^{-1}(c_0 - b_0 c_1 - a_0 c_2 k f^{-1}) \tag{11.2}$$

We differentiate (11)s with respect to f and obtain Lemma 3.

Lemma 3-1

As the flight service becomes frequent, the improvement in social welfare by demand effect is large.

Proof:

$$\frac{\partial \Delta SW_D}{\partial f} = a_1 c_2 k f^{-2}(b_0 - a_1 c_1^{-1} c_2 k f^{-1})$$

According to assumption 1, $b_0 - a_1 c_1^{-1} c_2 k f^{-1} > 0$ and then $\partial \Delta SW_D / \partial f > 0$.

(Q.E.D.)

As shown in Lemma 2, the increment of demand is large for routes with high frequency, so demand effect is large when the number of flights is large.

Lemma 3-2

As the flight service becomes frequent, welfare loss by SD effect becomes small.

Proof:

$$\frac{\partial \Delta SW_S}{\partial f} = -a_1 c_1^{-1} c_2 k f^{-2}(c_0 - b_0 c_1 - 2a_0 c_2 k f^{-1})$$

According to assumption 2, $c_0 - b_0 c_1 - 2a_0 c_2 k f^{-1} > 0$. Therefore, $\partial \Delta SW_S / \partial f < 0$.

(Q.E.D.)

As shown in Lemma 1, the increment of SDC is small for route with high frequency, SD effect is small when the number of flight is large.

Finally, we analyze the relationship between the total effect and frequency. Using (11), we rewrite the total effect as

$$\Delta SW = \Delta SW_D - \Delta SW_S$$

$$= \frac{1}{2}(2a_0 + a_1) a_1 c_1^{-1} c_2^2 k^2 f^{-2} - a_1 c_0 c_1^{-1} c_2 k f^{-1} + A,$$

where, $A \equiv \frac{1}{2}(2b_0 - b_1) b_1 c_1 = \frac{1}{2}(p^m + p^c) b_1 c_1 > 0.$

Lemma 4

As the flight service becomes frequent, change in social welfare by competition is large.

Proof:

$$\frac{\partial \Delta SW}{\partial f} = a_1 c_0 c_1^{-1} c_2 k f^{-3} \{f - (2a_0 + a_1) c_0^{-1} c_2 k\}$$

According to assumption 3, $f > \underline{f} = (2a_0 + a_1) c_0^{-1} c_2 k$. Therefore, $\partial \Delta SW / \partial f > 0$.

(Q.E.D.)

Lemma 4 indicates $\Delta SW(f)$ is increasing in the area $f > \underline{f}$ as depicted in Figure 4-4. $\Delta SW(f)$ is minimum at $f = \underline{f}$ and maximum value is A when $f \to \infty$. We summarize results and obtain

(i) When $\Delta SW\left(\underline{f}\right) < 0$, the solution f^* exists and

$$\Delta SW < 0 \quad if \quad \underline{f} < f < f^*,$$

$$\Delta SW > 0 \quad if \quad f^* < f.$$

(ii) When $\Delta SW\left(\underline{f}\right) > 0$,

$$\Delta SW > 0 \quad \text{for all} \quad f > \underline{f}$$

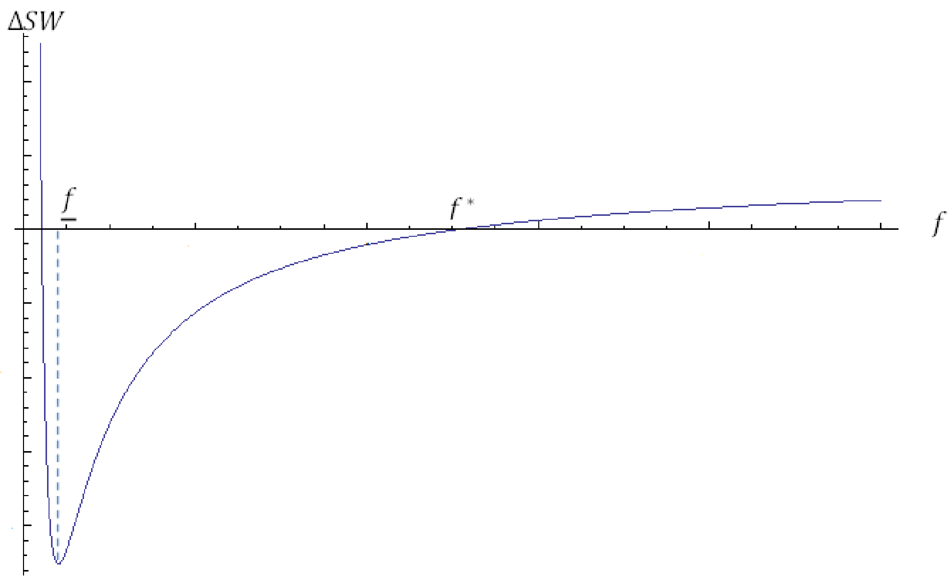

Figure 4-4: Change in the social welfare and frequency

From the form of $\Delta SW(f)$, we obtain

Proposition

When $\Delta SW\left(\underline{f}\right) < 0$ *and* $\underline{f} < f < f^*$*, monopoly is better than competition in terms of the social welfare.*

For low frequency routes, SD increases largely by competition as shown in Lemma 1 and demand increases only a little or decreases as shown in Lemma 2. Therefore, monopoly is better than competition for low frequency routes.

4.5. Conclusion

In empirical part, we showed that competition leads to un-even flight schedule. In theoretical part, we showed that monopoly is better than competition for routes with low frequency. SD effect is large when the number of flights is small because SDC for low frequency routes is large even in monopolistic case. On the other hand, the demand effect is small for low frequency routes. Therefore, the SD effect overwhelms the demand effect for low frequency routes.

We have two tasks for the future. First, we should consider airline networks. Hub-Spoke networks have been adopted by airlines widely after the deregulation and open skies, and then many passengers make transit at the hub. Second, it is also important to extend our empirical analysis to other countries and international market although we focused on only Japanese domestic market in this chapter.

Chapter 5

Conclusion

5.1. Summary

This thesis has proposed different models to answer various research questions concerned with air-transportation market. We have suggested some implications to which policy makers refer when they make decision on deregulation and privatization. In Chapter 2 and 3, we focused on the distortion caused by the pricing strategy of the private airports, and in Chapter 4, we dealt with the condition in which the airline competition improves the social welfare. The summary and main results in each chapter are following.

In Chapter 2, we established the model with arbitrary location of airports and population in each city, but the exogenous flight network. We investigated the airport pricing strategies of private airports and suggested the discriminatory pricing policy. At first, we found that a local airport far from the hub set its fee low. This is because passengers who depart from such airport pay high airfare, and the airport has to lower its fee to boost the flight demand. Second, the hub airport discounts its transit fee when the weighted average distance is long. By the low transit fee, the hub airport collects transit passengers from distant local airports. Third, the welfare loss caused by markup of the airports and airline is serious for routes with long connection flight due to the identical transit fee. Finally, we showed that the social welfare under the discriminatory transit fee system is higher than the one under the identical transit fee system. Therefore, we suggested that the policy maker should allow airports to set different transit fees route by route.

In Chapter 3, we treated the route structure as endogenous to study the relationship between the airports' pricing strategies and the airline's network choice. To achieve this purpose, we develop the model with three-stage game. At first, two airports choose a strategy from the alternatives, i.e., exploiting strategy and discount strategy. Next, the airline chooses its flight network from point-to-point or hub-spoke. Finally, consumers decide whether they travel the foreign country or not. Comparing networks in optimal and equilibrium, we showed two results. First, the relatively small airport can be chosen as the hub airport in equilibrium, but which never occurs in optimal. This is because the small airport discounts its airport fee aggressively to obtain transit passengers from the large city. However, this is inefficient because passengers from the large city are compelled to transfer. Second, point-to-point network is more likely to be realized in equilibrium than in optimal. Private airports set their fees higher than their marginal cost (zero in the model). Therefore, the airline chooses point-to-point to avoid paying airport fees twice at the hub airport. Our results imply that both too high and low airport fees lead to distortions of the flight network. To correct these distortions, we suggested the policy implication that both the under and upper limit regulations on airport fees are needed.

In Chapter 4, we analyzed the condition where monopoly is better than competition in terms of the social welfare. Using Japanese domestic flight data, Section 4.2 showed empirically that airline competition leads to more un-even flight schedules. Section 4.4, the theoretical part, pointed out two effects of competition, i.e., "demand effect" and "SD effect". The demand effect, which is positive on the social welfare, is large when the number of flight is large. On the other hand, the SD effect, which has negative impact, is small when the flight services are frequent. Integrating these results, we suggested that the policy maker should introduce competition only for routes with frequent flight services.

5.2. Topics for the Further Research

We have various new topics to research because air-transport industry is in the dynamic movement and the industrial structure is changing at a rapid pace. The largest change is emergence of Low Cost Carriers (LCC) which provides cheap flight services. Most previous researches suppose traditional full service carriers (FSC) in their models. However, LCCs have grown in recent decades and share 24 % of whole air-transport market as of 2011. Especially, 87% of domestic flight services are provided by LCCs in Philippines [CAPA, 2013]. Some papers have dealt with LCCs. For example, Dobruszkes [2006] investigated flight network of LCCs in European market, and Graham and Vowles [2006] analyzed the relationship between FSCs and LCCs. However, we have more rooms to study this new market taking account of characteristics of LCCs (e.g., single aircraft type, point-to-point services, frequent use of secondary airports etc.).

Another topic which should be researched is airport consolidations. Since mid-1990s, airport alliances and airport holding companies have been formed. For example, Schiphol Group has 100% stocks of three airports in the Netherlands and 19% of Brisbane Airport in Australia, and operates John F. Kennedy International Airport's Terminal 4. Maquarie Airports, which was found by the investment fund, holds stocks of airports in Australia, Belgium, Denmark and the UK [Forsyth et al., 2011]. At the present time, the main purpose of airport consolidations is sharing "know-hows".

However, integrations of management can leads to change in the strategic relationship. On one hand, if airports in a same region engage in an alliance, airport fees might rise due to regional monopoly. On the other hand, a group of airports which serve the same O&D market might lower airport fees to avoid "double markup". Although the recent wave of airport consolidation, its effects haven't been investigated yet sufficiently.

In addition to these new topics, we should apply our theoretical models for empirical analysis. Although the results shown in this thesis have significant implications, we aren't sure that our results still hold in reality. Therefore, we should check the robustness of our models and results empirically.

References

Air Transport Action Group, "Aviation Benefits Beyond Borders", 2014.

Alderighia, M., A. Cento, P. Nijkamp and P. Rietveld, "Network competition—the coexistence of hub-and-spoke and point-to-point systems", *Journal of Air Transport Management,* Vol. 11 (5), pp. 328-334, 2005.

Averch, H. and L. Johnson, "Behavior of the Firm Under Regulatory Constraint", *American Economic Review*, Vol. 52 (5), pp. 1052-1069, 1962.

Ball, M., C. Barnhart, M. Drenser, K. Neels., A. Odoni, E. Perterson, L. Sherry, A. Trani and B. Zou, "Total Delay Impact Study: A Comprehensive Assessment of the Costs and Impacts of Flight Delay in the United States", *NEXTOR*, 2010. (Available at www.isr.umd.edu/NEXTOR/rep2010.html)

Basso, L.J., "Airport deregulation: Effects on pricing and capacity", *International Journal of Industrial Organization*, Vol. 26, pp. 1015-1031, 2008.

Basso, L.J. and A. Zhang, "Congestible facility rivalry in vertical structures", *Journal of Urban Economics,* Vol. 61(2), pp. 218–237, 2007.

Bel, G. and X. Fegada, "Factors explaining charges in European airports: Competition, market size, private ownership and deregulation", *Journal of Regulatory Economics*, Vol. 37, pp. 142-161, 2010.

Brueckner, J.K., “Airport Congestion when carriers have market power”, *American Economic Review*, Vol. 92 (5), pp. 1357-1375, 2002.

Brueckner, J.K., “Network Structure and Airline Scheduling”, *The Journal of Industrial Economics*, Vol. 52, pp. 291–312, 2004.

Bruckner, J.K., “Internalization of airport congestion: A network analysis”, *International Journal of Industrial Organization*, Vol. 23 (7-8), pp. 599-614, 2005.

Brueckner, J.K. and P.T. Spiller, “Competition and mergers in airline networks”, *International Journal of Industrial Organization*, Vol. 9, pp. 323-342, 1991.

Brueckner, J.K., and P.T. Spiller, “Economics of traffic density in the deregulated airline industry”, *Journal of Law and Economics*, Vol. 37, pp. 379-415, 1994.

CAPA – Center for Aviation, “Lccs in Asia Pacific”, *ICAO/CAAC LCC Symposium*, 2013.

Carlin, A. and R.E. Park, “Marginal cost pricing of airport runway capacity”, *American Economic Review*, Vol. 60, pp. 310-319, 1970.

Czerny, A.I., “Public versus private airport behavior when concession revenues exist”, *Working Paper, WHU – Otto Beisheim School of Management*, 2012.

Czerny, A.I., F. Höffler and S. Mun “Port competition and welfare effect of strategic Privatization”, *EWI Working Paper*, No. 13/13, 2013

Czerny, A.I. and A. Zhang, "How to mix per-flight and per-passenger based airport charges", *Transportation Research Part A*, No.71, pp. 77–95, 2015.

Daniel, J.I., "Congestion pricing and capacity of large hub airports: A bottleneck model with stochastic queues", *Econometrica*, Vol. 63, pp. 327-370, 1995.

De Borger, B., and K. Van Dender, "Prices, capacities and service levels in a congestible Bertrand duopoly", *Journal of Urban Economics*, Vol. 60(2), pp. 264–283, 2006.

Dobruszkes, F., "An analysis of European low-cost airlines and their networks", *Journal of Transport Geography*, Vol. 14(4), pp. 249-264, 2006.

Fageda, X. and R. Flores-Fillol, "Airport congestion and airline network structure", *mimeo*, 2013.

Flores-Fillol, R., "Airline competition and network structure", *Transportation Research Part B*, Vol. 43, pp. 966–983, 2009.

Forsyth, P., H.M. Niemeier and H. Wolf, "Airport alliances and mergers – Structural change in the airport industry?", *Journal of Air Transport Management*, Vol. 17(1), pp. 49-56, 2011.

Graham, A., "Managing Airports – an International Perspective", Butterworth-Heinemann, *Oxford, the United Kingdom*, 2008.

Graham, A. and T.M. Vowles, "Carriers within Carriers: A Strategic Response to Low -

cost Airline Competition", *Transport Reviews*, Vol. 26(1), pp. 105-126, 2006.

Hendricks, K., M. Piccione and G. Tan, "The economics of hubs: the case of monopoly", *Review of Economic Studies*, Vol. 62(1), pp. 83-99, 1995.

International Air Transport Association, "Annual Review 2014", 2014.

International Civil Aviation Organization, < http://www.icao.int/Pages/freedomsAir.aspx >, Accessed on 8th December 2015.

Kawasaki, A., "Network effects, heterogeneous time value and network formation in the airline market", *Regional Science and Urban Economics,* Vol. 38(4), pp. 388–403, 2008.

Kawasaki, A., "Hub location with scheduling effects in a monopoly airline market", *The Annals of Regional Science*, Vol. 49, pp. 805-819, 2012.

Kawasaki, A., "Uniform or discriminatory pricing in the international hub airport", *The 4th Asian Seminar in Regional Science*, 2014.

Levine, M.E, "Landing fees and the airport congestion problem", *Journal of Law and Economics*, Vol. 12, pp. 79-108, 1969.

Liebert, V. and H.-M. Niemeier, "Benchmarking of airports – a critical assessment", Paper presented at 12th *World Conference on Transportation Research*, July 2010, Lisbon, Portugal.

Matsumura, T. and N. Matsushima, "Airport privatization and international competition", *Japanese Economic Review*, Vol. 63(4), pp. 431–450, 2012.

Mayer, C., and N. Sinai, "Why do airlines systematically schedule their flights to arrive late?", *The Wharton School, University of Pennsylvania*, 2003.

Morimoto, Y. and Y. Teraji, 'The airport pricing in the hub-spoke network,' *Tezukayama RIEB Discussion Paper Series*, No. 3, 2013.

Müller, J., T. Ülkü and Z. Živanović, "Privatization, restructuring and its effects on performance: A comparison between German and British airports", *German Airport Performance*, Paper No. 16, 2009.

Mun, S. and Y. Teraji, "The organization of multiple airports in a metropolitan area", *Journal of Transport Economics and Policy*, Vol. 46(2), pp. 221-237, 2012.

Oum, T.H., N. Adler and C. Yu, "Privatization, corporatization, ownership forms and their effects on the performance of the world's major airports", *Journal of Air Transport Management*, Vol. 12, pp. 109-121, 2006.

Oum, T.H., C. Yu and X. Fu, "A comparative analysis of productivity performance of the world's major airports", *Journal of Air Transport Management*, Vol. 9, pp. 285-297, 2003.

Oum, T.H., A. Zhang and Y. Zhang, "A note on optimal airport pricing in a hub-and-spoke system", *Transportation Research Part B,* No.30, pp. 11–18, 1996.

Pels, E., P. Nijkamp and P. Rietveld, "Airport and airline competition for passengers departing from a Large Metropolitan Area", *Journal of Urban Economics,* Vol. 48(1), pp. 29–45, 2000.

Pels, E. and E.T. Verhoef, "The economics of airport congestion pricing", *Journal of Urban Economics*, No.55, pp. 257–277, 2004.

Perelman, S. and T. Serebrisky, "Measuring the technical efficiency of airport in Latin America", *World Bank Working Paper* 5339, 2010.

Santos, G. and M. Robin, "Determinants of delays at European airports", *Transportation Research Part B*, Vol. 44, pp. 392–403, 2010.

Silva, H.E. and E.T. Verhoef, "Optimal pricing of flights and passengers at congested airports and the efficiency of atomistic charges", *Journal of Public Economics*, Vol. 106, pp. 1–13, 2013.

Silva, H.E., E.T. Verhoef and V.A.C. van den Berg, "Airline route structure competition and network policy", *Transportation Research Part B,* Vol.67, pp. 320–343 ,2014.

Starr, R.M. and M.B. Stinchcombe, "Efficient transportation routing and natural monopoly in the airline industry: an economic analysis of hub-spoke and related systems", *UCSD Economics Department Discussion Paper*, No. 92-25, 1992.

Teraji, Y. and Y. Morimoto, "Price competition of airports and its effect on the airline network", *Economics of Transportation*, No.3, pp. 45–57, 2014.

Tseng, Ubbels and Verhoef, "Value of time, schedule delay and reliability", *ERSA conference papers*, 2005

Yang, H. and A. Zhang, "Impact of regulation on transport infrastructure capacity and service quality", *Journal of Transport Economics and Policy*, Vol. 46, pp. 415-430, 2012.

Zhang, A. and A.I. Czerny, "Airports and airlines economics and policy: An interpretive review of recent research", *Economics of Transportation*, Vol.1 (1–2), pp. 15-34, 2012.

Zhang, A. and Y. Zhang, "Airport charges and capacity expansion: Effects of concession and privatization", *Journal of Urban Economics,* Vol. 53, pp. 53-75, 2003.

Zhang, A. and Y. Zhang, "Airport capacity and congestion when carriers have market power", *Journal of Urban Economics,* Vol. 60, pp. 229–247, 2006.