Tezukayama RIEB Discussion Paper Series No. 6

Price Competition of Airports and Airline Network

TERAJI, Yusuke
Faculty of Economics, Tezukayama University

MORIMOTO, Yu
Graduate School of Economics, Kyoto University

September 2013

Tezukayama University
Research Institute for Economics and Business
7-1-1 Tezukayama, Nara 631-8501, Japan

Price Competition of Airports and Airline Network

TERAJI, Yusuke and MORIMOTO, Yu

Abstract:

This paper deals with the price competition of airports, and its effect on the airline (carrier) network. We construct the model which has following features: i) the carrier can choose its network configuration, point-to-point or hub-spoke; ii) airport operators compete in airport charge by taking into account the carrier's choice. By using this model, we address the question how the airport competition affects the carrier's network choice. It is shown that the price competition distorts the carrier's network choice in following two manners: i) it disturbs the carrier to choose hub-spoke network instead of point-to-point; ii) it makes the carrier chose an airport at a relatively small city as the hub of network.

Keywords: Airport Competition, Network Choice, Hub-Spoke, Point-to-Point

1. Introduction

After deregulations of airline markets in the United States and Europe, carriers can freely choose their network configuration. Most of major network carriers in these regions have adopted the hub-spoke network instead of the point-to-point. When choosing the hub-spoke network, it is important for a carrier to decide which airport to be its hub. In case of Singapore, for example, several carriers such as Singapore Airlines and British Airways utilize Singapore Changi Airport as their hubs.[1] Their choices are due to the locational advantages of Singapore. Namely, it is centrally located in Southeast Asia, and between Europe and Australia. Furthermore, there exist significant

[1] Until the end of March, 2013, Qantas also used this airport as its international hub. However, it switched its hub to Dubai in the UAE in April, 2013.

demands for air trip service between Europe and Singapore and for the one between Australia and Singapore as well as between Europe and Australia. Therefore, carriers can enjoy the traffic density economies when choosing Changi as their hubs.

In some cases, carriers choose airports at relatively small cities as their hub. Furthermore, it seems that the locational advantages of these airports are insignificant or ambiguous compared to their neighboring airports. For example, in West Coast, United Airlines utilizes San Francisco International Airport as its hub for Far East and Delta Airlines chooses Seattle even though these two cities are smaller than Los Angeles.[2] This might be explained by the difference in the airport charge; namely, per passenger basis, airport charge at Los Angeles is about twice as high as those at San Francisco and Seattle.[3] From the other viewpoint, this can be interpreted that airports at small cities discount their airport charges in order to attract carriers to choose them as the hub.

It is also often observed that airports in a region compete in price. For example, in 2012, two airports in Japan, Narita and Kansai, have discounted the airport charge for international flights. This is because these airports are located further away from Tokyo than Tokyo International Airport (Haneda) is. Since they have smaller hinterland

---

[2] At San Francisco, United provides direct flights to ten cities in Far East; Delta connects five East Asian cities with Seattle.

[3] This calculation is based on the following assumptions: each carrier provides a flight by using B777-200; its capacity is 268 seats; the loading factor is 70 percent. By using Airport, ATC & Fuel Charges Monitor (IATA 2013), the charge per passenger at each airport is computed as follows: at Los Angeles, 29 dollars; at San Francisco, 16 dollars; at Seattle, 19 dollars.

demand for air trip services than Haneda, in order to raise their revenues, it is important for them to attract carriers to provide connection flights from other regions by discounting the airport charges.[4] To put it differently, airports at relatively small cities may take more aggressive attitude toward the price competition among airports within a region since the revenue from connection flights is more significant. In this paper, we address the question how the price competition among airports affects the carrier's network choice. We also investigate the welfare effect of the price competition from a qualitative perspective. In addition, it is analytically shown that the price competition induces the carrier to choose the airport at relatively small city as its hub.

Reflecting current changes in the carriers' network configuration, several literatures deal with the carrier's network choice. In the monopoly setting, Starr and Stinchcombe (1992), Hendricks et al. (1995), Brueckner (2004) and Kawasaki (2008) address the question when the carrier chooses the hub-spoke network.[5] Flores-Fillol (2009) extends the model by introducing the competition between carriers. In more general setting,

---

[4] As well as the discount in the landing fee, Kansai International Airport offers several discount menus for carriers such as the off-peak and the promotional discounts. As a result of these discount menus, several airlines start to provide the service between Kansai and other airports. Especially, Peach Aviation chooses Kansai as its hub.

[5] The difference among them is mainly attributed to the formulation of the density economy. Namely, in Starr and Stinchcombe (1992) and Hendricks et al. (1995), the density economy is represented by a reduction in the average operating cost through an increase in the number of passenger. In contrast, as well as the density economy in these two studies, Brueckner (2004) introduces another source of the density economy by including the schedule delay cost for passengers. In this setting, an increase in flight reduces the generalized cost, and expands the demand; therefore, it enhances the density economy. Kawasaki (2008) extends Brueckner (2004) by introducing the heterogeneity in value of time among users.

Mori (2012) studies the network formation of a transport firm. As in Mori (2012), these literatures focus on the tradeoff of hubbing strategy for carriers. When choosing the hubbing strategy, each carrier can enjoy two types of scale economy, density and distance economies, while it needs to incur the additional operating costs for providing connection flights between the hub and spoke nodes. These literatures, however, solely focus on carrier's choice, and the operators' choices or the pricing at airports is out of consideration.

The pricing policy at airports itself is another topic drawing an attention (Oum et al. (1996), Brueckner (2002), Pels and Verhoef (2004), Zhang and Zhang (2006), Morimoto and Teraji (2013)). These literatures dealing with the pricing policy presume the carrier's network and focus on its direct effect on the hinterland's welfare.[6] The pricing policy, however, may indirectly affect the welfare of its hinterland through the change in the carrier's network.[7] In order to capture this effect, it is important to concern about the competition among airports, and this type of competition is also studied in literatures. Most of literatures in this strand (Pels et al. (2000), De Borger and Van Dender (2006), Basso and Zhang (2007), Mun and Teraji (2012)) focus on the

[6] Most of literatures focus on the single congested airport case (Brueckner (2002), Pels and Verhoef (2004), Zhang and Zhang (2006)). In contrast, Oum et al. (1996) deal with the pricing at airports in the hub-spoke system. Morimoto and Teraji (2013) extend the model of Oum et al. (1996) by introducing the two-sidedness of airport operation: namely, each airport serves to both carriers and users.

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

competition between airports in a small region (for example, a metropolitan area); therefore, the carrier's network choice, point-to-point or hub-spoke, is not considered. The competition in a relatively large region (for example, multiple countries) is studied in Matsumura and Matsushima (2012) and Czerny et al. (2013). These literatures focus on the competition between countries for the infrastructure operation, but the carrier is not allowed to choose its network configuration.

We extend a multiple-airport model in Matsumura and Matsushima (2012) in two perspectives: first, we allow the monopoly carrier to choose its network configuration; second, we limit our focus on the case where each airport is under the separate private operation. When serving to airports, the carrier can choose one of two networks: i) it directly connects all airports with the final destination (point-to-point); ii) it directly connects one of airports with both the final destination and the rest of them (hub-spoke). If the carrier chooses the hub-spoke network, it faces the tradeoff between the saving in fixed costs for direct flights[8] to the final destination and additional operating cost for connection flights between the hub and spoke nodes. Since the airport charge is included in the additional operating cost, each airport operator can induce the carrier to form their desired network by choosing the airport charge appropriately. In other words, there exists a possibility such that operators compete in price in order to attract the

[8] This may include the costs for ground sites, administration, and ticketing and promotion.

carrier. By using this model, we address the question how the price competition distorts the carrier's network choice.

The rest of the paper is organized as follows. Section 2 describes the model, and Section 3 explains the optimal network, which is the reference for the evaluation of the equilibrium network. Section 4 derives the equilibrium network in which airport operators compete in the airport charge. This section also investigates the welfare effect of the airport competition by comparing the equilibrium network with the optimal one. Finally, Section 5 states some concluding remarks.

2. The Model

2.1. The Basic Setting

Suppose an economy which is consisted from two cities, Cities 1 and 2. Residents in each city travel to the foreign country by 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. The monopoly carrier provides the international air trip service from these two airports to a foreign country. When providing the international air trip service, the carrier makes the network choice, point-to-point or hub-spoke. The carrier also determines which airport to be the hub if it chooses the hub-spoke network. Figure 1 summarizes the three possible network configurations. In Figure 1, network P indicates the point-to-point while network H_i corresponds to the case where Airport i (i=1, 2) is the hub. Also note that l_{12} and l_{iF} in Figure 1 respectively represent the distance between Airports 1 and 2, and the distance from Airport i to the foreign country. In addition, we assume that $l_{12} < l_{iF}$.

<<FIGURE 1: ABOUT HERE>>

The sequence of decisions is as follows: first, two airport operators simultaneously set airport charges. At the second stage, given choices of airport operators, the monopoly carrier determines its network configuration, N, and airfares for users at two airports, p_i. Finally, households in each city decide whether to travel to the foreign country from the airport at their residence.

We assume that the international air trip demand is inelastic: that is, households in each city travel to the foreign country once unless the airfare, p_i, exceeds the reservation price. We assume that all households have an identical value of the reservation price, and it is normalized to one. Therefore, the aggregate demand for the international air trip service at City i is:

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

where n_i is the population of City i. In order to simplify the analysis, we normalize the total population of the economy $n_1 + n_2$ to one. In addition, we denote by n the population of City 1 and limit our focus on the case where $1 > n > 1/2$. Since the market is under the monopoly, the carrier chooses the airfare equal to the reservation price: that is, $p_i = 1$. In the following subsections, we describe the carrier's network choice and the behavior of airport operators.

2.2. The Carrier

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, $\pi(N;\mathbf{a})$. It is shown that the individual demand for international air trip service is inelastic, and that the carrier sets the airfare equal to the reservation price, $p_i = 1$. Therefore, the carrier's profit, $\pi(N;\mathbf{a})$, is given by:

$$\pi(N;\mathbf{a}) = \sum_i \left[n_i - C_i(N;\mathbf{a}) \right], \tag{2}$$

where $C_i(N;\mathbf{a})$ is the total cost for market i under network N:

$$C_i(P;\mathbf{a}) = C_i(H_i;\mathbf{a}) = c l_{iF} n_i + a_i n_i + F, \tag{3.1}$$

$$C_i(H_j;\mathbf{a}) = c(l_{iF} + l_{12}) n_i + (2a_j + a_i) n_i. \tag{3.2}$$

The total operation cost for serving at Airport i is consisted from three components: the operating cost for flights, the airport charge payments, and the fixed cost for handling direct flights. The first term of the RHS in Equations (3) captures the operating costs for flights. It is assumed to be proportional to passenger-kilometer, and the operating cost per passenger-kilometer is denoted by c. The second term shows the airport charge payment by the carrier. Since the carrier must pay at an airport for both departing and arriving, in case of network H_j, airport charge per passenger is $2a_j + a_i$ while in case of other networks, airport charge per passenger is a_i. Finally, F represents the fixed cost for handling direct flights.

Summing Equations (3), the carrier's total cost under each of three networks is computed as:

$$C\left(P;\mathbf{a}\right)=\sum_k\left(cl_{kF}+a_k\right)n_k+2F,$$

$$C\left(H_i;\mathbf{a}\right)=\left(cl_{iF}+a_i\right)+\left(cl_{12}+a_1+a_2\right)n_j+F,\ \text{for } i=1,2,\ j\neq i.$$

These equations show the carrier's tradeoff. Namely, if the carrier chooses the hub-spoke network, H_1 or H_2, the carrier can save the fixed cost, F, while it must incur the additional operating cost for connection flights between the hub and the spoke airport. Also note that between two types of network, point-to-point and hub-spoke, the airport charge payment varies. In other words, the carrier's network choice is dependent on the airport charges. Let us denote by $N(\mathbf{a})$ the carrier's network choice, then it suffices:

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

2.3. Airport Operators

Each operator sets the airport charge in order to maximize the revenue. The revenue of operator i is given by:

$$R_i(P) = R_i(H_j) = a_i n_i \text{ and } R_i(H_i) = a_i(1 + n_j) \text{ for } i = 1, 2,\ j \neq i. \quad (5)$$

When setting the airport charge, each operator takes into account two conditions. The first condition is such that each airport operator must make consideration on the carrier's network choice, $N(\mathbf{a})$. Furthermore, since the carrier's network choice is dependent on airport charges at two airports, each operator can induce the carrier's network to be favorable for them by setting its airport charge appropriately. The second condition is such that the carrier must earn the non-negative profit at each airport. Otherwise, the carrier does not utilize the airport, and the operator cannot earn the revenue. We denote by $\pi_i(N;\mathbf{a})$ the carrier's profit at Airport i. Then, it is specified as follows:

$$\pi_i(P;\mathbf{a}) = \pi_i(H_i;\mathbf{a}) = \left[1 - (cl_{iF} + a_i)\right] n_i - F, \quad (6.1)$$

$$\pi_i(H_j;\mathbf{a}) = \left[1 - (cl_{jF} + a_j) - (cl_{12} + a_1 + a_2)\right] n_i. \quad (6.2)$$

3. The Optimal Network

In order to evaluate the equilibrium network configuration, we first focus on the optimal network configuration which 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:

$$SS(P) = \sum_k n_k (1 - p_k) + \left[\sum_k n_k (p_k - cl_k - a_k) - 2F \right] + \sum_k n_k a_k = 1 - c \sum_k n_k l_{kF} - 2F, \tag{7.1}$$

$$\begin{aligned} SS(H_i) &= \sum_k n_k (1 - p_k) \\ &+ \left[\sum_k n_k (p_k - cl_{iF} - a_i) - n_j (cl_{12} + a_1 + a_2) - F \right] \\ &+ a_i + n_j (a_1 + a_2) = 1 - c \left(l_{iF} + n_j l_{12} \right) - F \text{ for } i = 1, 2,\ j \neq i. \end{aligned} \tag{7.2}$$

In Equations (7), the social surplus is consisted from three components, the consumer surplus, the carrier's profit, and the airport charge revenue. Summing these three components, the airport charges are cancelled. Furthermore, since the reservation price is constant, the optimal network is defined as the network minimizing the cost for the international air trip service provision.

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

Lemma 1

Network H_1 assures the 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:

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

where $\Delta l = l_{1F} - l_{2F}$. 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 $n > 1/2$. This implies that, from the welfare perspective, the carrier should utilize Airport 1 as its hub instead of Airport 2 if two cities are equidistant from the foreign country. This is due to the difference in the population between two cities. Namely, 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 connection flights between 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, network H_i. By using Lemma 1 and $F^O(P, H_i)$, the optimal network configuration, N^O, is summarized in Proposition 1:

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, 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, network P.*

Proof:

The thresholds are derived as follows:

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

Solving this for *F*,

$$F = F^O\left(P, H_i\right) = n_j c\left(l_{iF} + l_{12} - l_{jF}\right). \tag{8}$$

QED

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

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 by the backward induction. Subsection 4.1 deals with the carrier's network choice: how the carrier determines its network configuration given the airport charges at two airports. Subsection 4.2 focuses on the behavior of airport operators. Namely, taking into consideration the carrier's network choice, this subsection explains how two operators set the airport charge. Subsection 4.3 describes the equilibrium network configuration. Finally, in Subsection 4.4, we discuss the mechanism behind the equilibrium network configuration, and investigate the welfare effect of the price competition through the comparison with the optimal network configuration.

4.1. The Carrier's Choice

As in Eq. (4), given the airport charges at two airports, the carrier determines its network configuration, $N(\mathbf{a})$. In comparison of profits under three alternative networks, we derive the carrier's network choice as in Lemma 2.

Lemma 2

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

$$N(\mathbf{a}) = \begin{cases} P & \text{if } a_i > \hat{a}_i \text{ for } i = 1, 2, \\ H_1 & \text{if } a_1 \le \hat{a}_1 \text{ and } a_1 \le \tilde{a}_1(a_2), \\ H_2 & \text{if } a_2 \le \hat{a}_2 \text{ and } a_2 < \tilde{a}_2(a_1), \end{cases} \tag{9}$$

where

$$\hat{a}_i \equiv \frac{F}{2n_j} - \frac{c\left(l_{iF} + l_{12} - l_{jF}\right)}{2} \text{ for } i = 1, 2, \ j \ne i, \tag{10.1}$$

$$\tilde{a}_i\left(a_j\right) \equiv \frac{n_i a_j}{n_j} + \frac{n_i c\left(l_{jF} + l_{12} - l_{iF}\right) - n_j c\left(l_{iF} + l_{12} - l_{jF}\right)}{2n_j} \text{ for } i = 1, 2, \ j \ne i. \tag{10.2}$$

Proof:

It is easily derived from the comparison of Equations (2) and (3).

QED

Figure 2 summarizes the carrier's network choice in (a_1, a_2) space in case of $l_{1F} = l_{2F} = 1$. As shown in Figure 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 connection flights by forming network *P*. In contrast, the carrier chooses one of two airports as its hub if that operator offers 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 $a_1 \le \hat{a}_1$ and $a_1 \le \tilde{a}_1(a_2)$.

<<FIGURE 2: ABOUT HERE>>

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

Lemma 3

i) The domains of networks H_1 *and* H_2 *expand as 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 (9) with respect to *F*, l_{12}, *n*, and Δl, it is confirmed. For part i) of Lemma 3,

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

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

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

According to the part ii) of Lemma 3, Airport 1 becomes more attractive place for the hub as the population of City 1 increases. In comparison of networks H_1 and H_2, providing the connection flight from Airport 2 is less costly than providing from Airport 1. Furthermore, the increase in the population of City 1 leads to the reduction in the cost of connection flight from Airport 2 because this increase causes the decrease in that of City 2; therefore, comparing with network P, the disadvantage of choosing network H_1 shrinks. Finally, for the part iii) of Lemma 3, notice that an increase in $\Delta l = l_{1F} - l_{2F}$ implies that Airport 2 becomes relatively close to the Foreign Country compared to Airport 1. In such case, it is more likely for the carrier to choose Airport 2 as its hub. This situation is observed in several regions: for example, Delta chooses Narita as its East Asian hub to the United States.

4.2. The Operators' Choices

At the first stage, two operators simultaneously set airport charges. Since operators take into account the carrier's network choice, $N(\mathbf{a})$, they can induce the carrier's network choice by setting airport charge appropriately. In this paper, we assume that operators' strategies are discrete; namely, each operator discounts its airport charge in order to become the carrier's hub, or exploits the carrier's profit at its airport. The first type of strategy is named *discount strategy* while the second type, *exploiting strategy*. This subsection describes two strategies, and derives the condition such that each operator plays discount strategy instead of exploiting. In order to simplify the analysis, we assume that two airports are equidistant from the foreign country, and the distance is normalized to unity: that is, $l_{1F} = l_{2F} = 1$. In addition, we consider the case where $F < (1-n)(1-c)$, and we assume that parameter values suffice the condition such that for some sets of airport charges. Under these two assumptions, the carrier may choose network *P* as its network configuration.

4.2.1. The Exploiting Strategy

The exploiting strategy aims at setting the airport charge to exploit the carrier's profit at an airport instead of becoming the carrier's hub. Therefore, by its definition, the exploiting airport charge, a_i^e, is equal to the level at which the carrier's profit at Airport *i* equals to zero. Since without competing with the other operator, at least, each operator can exploit the carrier's profit at its airport under network *P*, the exploiting airport charge is computed according to the relation, $\pi_i(P;\mathbf{a}) = 0$: namely,

$$a_i^e = 1 - c - \frac{F}{n_i} \text{ for } i = 1, 2. \tag{11}$$

By choosing $a_i = a_i^e$, operator *i* can earn the revenue, $a_i^e n_i$, without competing with the other operator *j*. To put it differently, the revenue, $a_i^e n_i$, is a reference point for operator *i* when deciding whether to compete.

4.2.2. The Discount Strategy

The discount strategy, in contrast, aims at reducing the airport charge in order to become the carrier's hub. Prior to characterizing this strategy, we first check the operator's incentive to discount the airport charge. As in Figure 2, operator *i* (*i*=1, 2) must discount its airport charge below $\hat{a}_i$ if it wants to become the carrier's hub. In other words, operator *i* has an incentive to cut its airport charge if:

$$\hat{a}_i\left(1+n_j\right) > a_i^e n_i.$$

Solving this for the fixed cost, *F*, we obtain Lemma 4, which summarizes the condition where operator *i* has an incentive to play the discount strategy:

Lemma 4

Operator i (*i*=1, 2) *discounts its airport charge if*:

$$F > F_i \equiv \frac{2n_i n_j(1-c) + cn_j\left(1+n_j\right)l_{12}}{1+3n_j}. \tag{12}$$

Lemma 4 indicates that, if $F < F_j$, operator *j* has no incentives to discount its airport charge from a_j^e; therefore, for $F < F_j$, operator *i* becomes the carrier's hub if it sets the discount airport charge, $a_i^d = \hat{a}_i$. However, for $F_j < F$, two operators have incentives to cut their airport charges, and the price competition is realized. Under this circumstance, in order to become the carrier's hub, each operator has to choose its airport charge by taking into account two conditions: i) the operator has to choose the level so that its competitor cannot cut the airport charge anymore; ii) it also must set the level so that the carrier choose its airport as the hub. The condition i) states that, when setting the discount airport charge, each operator chooses the level by taking into account the competitor's lower bound airport charge. Since each operator can earn the revenue, $a_j^e n_j$, without discounting, the lower bound of the airport charge for operator *j*, $\underline{a}_j$, is computed as follows:

$$a_j\left(1+n_i\right) = a_i^e n_i \Leftrightarrow \underline{a}_j = \frac{n_j a_j^e}{1+n_i} = \frac{n_j\left(1-c\right)}{1+n_i} - \frac{F}{1+n_i}. \tag{13}$$

The condition ii) indicates that the discount charge should be the level at which the carrier choose Airport *i* as its hub. In other words, according to Proposition 2, operator *i* must set its discount airport charge, a_i^d, equals to $\tilde{a}_i(a_j)$; otherwise, it cannot become the carrier's hub. Therefore, by using (10.2) and (13), the discount airport charge, a_i^d, in case of $F_j < F$ is computed as follows:

$$\tilde{a}_i\left(\underline{a}_j\right)=\frac{n_i\underline{a}_j}{n_j}+\frac{\left(n_i-n_j\right)cl_{12}}{2n_j}=\frac{n_i\left(1-c\right)}{1+n_i}-\frac{n_iF}{n_j\left(1+n_i\right)}+\frac{\left(n_i-n_j\right)cl_{12}}{2n_j}.$$

In summary, the discount airport charge is given by:

$$a_i^d=\begin{cases}\dfrac{F}{2n_j}-\dfrac{cl_{12}}{2} & \text{if } F<F_j,\\ \dfrac{n_i\left(1-c\right)}{1+n_i}-\dfrac{n_iF}{n_j\left(1+n_i\right)}+\dfrac{\left(n_i-n_j\right)cl_{12}}{2n_j} & \text{if } F_j<F.\end{cases} \tag{14}$$

4.3. The Nash Equilibrium

In Subsection 4.2, we have defined two strategies on the airport charge, the exploiting and the discount airport charges, as in Equations (12) and (14). This subsection describes the Nash Equilibrium of the operators' game, (a_i^*, a_j^*, N^*), and characterizes the equilibrium network configuration. As in Eq. (14), the discount airport charge is dependent on the fixed cost. We derive the Nash Equilibrium under each of three cases such as: i) $F \le F_i$; ii) $F_i < F < F_j$; and iii) $F_j < F$. In case i), both operators have no incentives to play the discount strategy instead of the exploiting strategy as in Lemma 4. Therefore, under this circumstance, the Nash Equilibrium is characterized by $(a_1^*, a_2^*, N^*) = (a_1^e, a_2^e, P)$.

In case ii), Lemma 4 indicates that operator *i* has an incentive to play the discount strategy while operator *j* employs the exploiting strategy. Hence, the Nash Equilibrium is attained at $a_i^* = a_i^d$, $a_j^* = a_j^e$, and $N^* = H_i$. In order to characterize the Nash

Equilibrium in case ii), however, it is necessary to clarify the relation of thresholds, F_1 and F_2. Through exercising simple calculation on Eq. (12), we obtain Lemma 5, which summarizes the relation between F_1 and F_2:

Lemma 5

i) The gradient of F_2 *with respect to* l_{12} *is steeper than that of* F_1;

ii) The intercept of F_2 *with respect to* l_{12} *is smaller than that of* F_1.

Lemma 5 indicates that there exists a threshold distance, $l_{12} = \bar{l}$, at which $F_1 = F_2$; furthermore, $F_1 > F_2$ if $l_{12} < \bar{l}$ while $F_1 < F_2$ otherwise. This implies that the case ii) is characterized by $F_2 < F \leq F_1$ if $l_{12} \leq \bar{l}$, and the Nash Equilibrium is attained at $(a_1^*, a_2^*, N^*) = (a_1^e, a_2^d, H_2)$; if $l_{12} > \bar{l}$, in contrast, the case ii) is given by $F_1 < F \leq F_2$, and $(a_1^*, a_2^*, N^*) = (a_1^d, a_2^e, H_1)$.

Lemma 5 is interpreted as follows. Due to the small population of its hinterland, it is attractive for operator 2 to become the carrier's hub. At the same time, however, it is more costly for the carrier to choose H_2 network than H_1 since it has to provide more connection flights. This implies that operator 2 must subsidize more than operator 1 to recover the carrier's cost of connection flight, and this loss increases as the distance between two airports increases. Therefore, operator 2 is more willing to discount than operator 1 if two airports are located close to each other; as a result, network H_2 is realized. In contrast, operator 2 becomes less willing than operator 1 if two airports are located further away from each other since t the subsidy has a significant negative impact on the revenue; consequently, network H_1 is attained.

Finally, under case iii), $F_j < F$, where there exists a possibility such that both operators may have incentives to discount their airport charges in order to become the carrier's hub. In such situation, we need to check whether each operator sets the discount airport charge, (14). Lemma 6 summarizes the condition where each operator plays the discount strategy:

Lemma 6

Suppose that $F > F_j = \max\{F_1, F_2\}$. *Then, operator* 1 *plays the discount strategy if* $F \leq \tilde{F}$ *while operator* 2 *plays if* $F \geq \tilde{F}$ *where*

$$\tilde{F} = -n(1-n)(1-c) + \frac{c\left[2+n(1-n)\right]l_{12}}{2}. \tag{15}$$

Proof:

Operator *i* plays the discount strategy if:

$$a_i^d\left(1+n_j\right) \geq a_i^e n_i. \tag{A.1}$$

Since $F > F_j = \max\{F_1, F_2\}$, according to (14), the discount airport charge is given by:

$$a_i^d = \frac{n_i(1-c)}{1+n_i} - \frac{n_i F}{n_j(1+n_i)} + \frac{\left(n_i - n_j\right)cl_{12}}{2n_j}. \tag{A.2}$$

Plugging (12) and (A.2) into (A.1), and solving for the fixed cost, we obtain the threshold $F = \tilde{F}$ at which Eq. (A.1) holds with the equality.

QED

According to Lemma 6, in case iii), the Nash Equilibrium is characterized by the following: if $F \leq \tilde{F}$, $(a_1^*, a_2^*, N^*) = (a_1^d, a_2^e, H_1)$; otherwise, $(a_1^*, a_2^*, N^*) = (a_1^e, a_2^d, H_2)$.

According to the argument exercised above, we can characterize the Nash Equilibrium of the operators' game. Prior to summarizing the equilibrium network configuration, however, it is necessary to characterize the sets of parameter values which we consider. First, since we have assumed $a_i^e > \hat{a}_i$, the following condition should be satisfied:

$$a_1^e > \hat{a}_1 \Leftrightarrow F < \overline{F}_1 = \frac{n(1-n)\left[2(1-c)\right]}{2-n} + \frac{cn(1-n)l_{12}}{2-n}, \qquad (16.1)$$

$$a_2^e > \hat{a}_2 \Leftrightarrow F < \overline{F}_2 = \frac{n(1-n)\left[2(1-c)\right]}{1+n} + \frac{cn(1-n)l_{12}}{1+n}. \qquad (16.2)$$

Since $n > 1/2$, $a_i^e > \hat{a}_i$ if $F < \overline{F}_2$. In addition, in order to assure that the carrier provides the direct flight at Airport 2, $F < (1-n)(1-c)$. For the case where $F < \min\{(1-n)(1-c), \overline{F}_2\} = \overline{F}$, Proposition 2 summarizes the Nash Equilibrium:

Proposition 2

Suppose that $F < \min\{(1-n)(1-c), \overline{F}_2\} = \overline{F}$. *The Nash Equilibrium,* (a_1^*, a_2^*, N^*), *is characterized as follows*:

$$\left(a_1^*, a_2^*, N^*\right) = \begin{cases} \left(a_1^e, a_2^e, P\right) & \text{if } F \le \min\left\{F_1, F_2, \bar{F}\right\}, \\ \left(a_1^d, a_2^e, H_1\right) & \text{if } F_1 < F \le \min\left\{\tilde{F}, \bar{F}\right\}, \\ \left(a_1^e, a_2^d, H_2\right) & \text{if } \max\left\{F_2, \tilde{F}\right\} < F \le \bar{F}. \end{cases} \tag{17}$$

4.4. Discussion

In this subsection, we give some intuition behind the equilibrium network configuration, N^*, summarized in Proposition 2. In addition, we compare the equilibrium network configuration with the optimum, and investigate the welfare effect of the price competition between airports. Figure 3 shows the equilibrium network configurations for $n < 2/3$ and for $n > 2/3$. The left figure corresponds to the case where $n < 2/3$ while the right figure is the case where $n > 2/3$. In either case, as the fixed cost of decreases or as the distance between two airports increases, the equilibrium configuration changes from the hub-spoke into the point-to-point. Since these two changes diminish the carrier's net benefit of hubbing, each operator must discount more in order to become the carrier's hub; therefore, operators give up becoming the carrier's hub through the discount strategy.

Let us start with taking a closer look at the case of $n < 2/3$. In this case, Airport 2 becomes the carrier's hub if the distance between two airports, l_{12}, is small while Airport 1 becomes the carrier's hub if the distance is relatively large. As explained in Subsection 4.3, this change is caused from the difference in the operator's loss of subsidizing the carrier. That is, since hubbing at Airport 2 imposes the larger cost of connection flight operation on the carrier, operator 2 must discount its airport charge more than operator 1. Furthermore, as the distance increases, the loss of discounting becomes more significant; consequently, network H_2 is never realized for $l_{12} > \bar{l}$. In case of $n > 2/3$, in contrast, network H_1 is never realized. Since operator 2 faces relatively small hinterland demand, the revenue of operator 2 under network *P*, $a_2^e(1-n)$, is small; therefore, the lower bound of operator 2's airport charge is sufficiently low. This implies that operator 1 has to discount its airport charge more if it wants to become the carrier's hub. Figure 3, however, shows such discount harms the welfare of operator 1; therefore, network H_1 is never realized.

<<FIGURE 3: ABOUT HERE>>

The result of $n > 2/3$ seems strange in the sense such that City 1 cannot become the carrier's hub even though its population is more than twice as large as that of City 2. This result may stem from the following two setups, omitting the user's transit cost and the cost of airport operation.[9] The introduction of the user's cost of transit may alter

[9] One might think that for $(1-n)(1-c) > F \geq \bar{F}_2$, 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 $(1-n)(1-c) > F \geq \bar{F}_2$ 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 fixed cost or the distance between two airports. Second, within the domain of $(1-n)(1-c) > F \geq \bar{F}_2$, two airports are close to each other; therefore, operator 2's loss of discounting is not significant as argued in Subsection 4.3.

network H_2 dominance in case of $n > 2/3$. The transit cost lowers the operator's airport charge for connection flights since users at the spoke airports becomes less willing to pay for the air trip service. Furthermore, the ratio of such users at Airport 2 is larger than at Airport 1. Therefore, operator 2 has to discount more to become the carrier's hub; for large transit cost, it may give up employing the discount strategy. The introduction of airport operation cost also may affect network H_2 dominance. The airport operation cost puts the fixed lower bound of airport charge while, in current setting, the lower bound varies with the population of hinterland. For some value of the operation cost, this cost binds the lower bound airport charge of operator 2. Since operator 2 becomes less competitive, operator 1 may take the discount strategy in order to become the carrier's hub.

<<FIGURE 4: ABOUT HERE>>

Finally, we compare the equilibrium and the optimal network configurations in case of $l_{iF} = 1$. Figure 4 compares two network configurations in case of $n < 2/3$. As shown in Figure 4, the airport price competition distorts the carrier's choice in two ways; i) it disturbs the carrier to form hub-spoke network instead of point-to-point; ii) it may make Airport 2 become the carrier's hub at the equilibrium even though Airport 2 has no locational advantage. The difficulty in the transition from point-to-point to hub-spoke is attributed to the positive airport charge. Under the positive airport charge, it is more costly for the carrier to form hub-spoke instead of point-to-point. In contrast, the benefit of forming hub-spoke is identical between the equilibrium (positive airport charge) and the optimum (zero airport charge); therefore, at the equilibrium, the carrier tends to choose network P instead of H_i. The realization of network H_2 at the equilibrium is due to the relatively aggressive attitude of operator 2 toward the competition. Since operator 2 can enjoy the larger gain from connection flights when becoming the carrier's hub, it offers the discount airport charge more easily than operator 1 if two airports are relatively close to each other. Therefore, the carrier is induced to choose Airport 2 as its hub.

5. Conclusion

In this paper, we have dealt with the question how the price competition among airports affects the carrier's network choice. In order to address this question, we have constructed the model where behaviors of both the carrier and airport operators are considered. By using this model, it is derived two types of network configuration, 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 at relatively large cities; otherwise, hubbing at airports in large cities is efficient. In contrast, 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 relatively small cities are willing to discount their airport charge since they receive relatively large gain from connection flights from their spoke nodes. According to the comparison of two network configurations, the optimum and the equilibrium, it is shown that the price competition distorts the carrier's network choice in following two ways: i) it disrupts the carrier to choose hub-spoke instead of point-to-point; ii) it induces the carrier to choose airports at relatively small cities as its hub even if they have no locational advantage.

Finally, we suggest topics for the future research. First, in order to keep the analytical tractability, we omit the costs of user's transit and airport operation; however, as argued in Section 4, introducing these two factors may change operators' behaviors in price competition. Therefore, it is necessary to extend our model by introducing these two factors. In addition, since we ignore the air trip service demand among the hub airport and spoke nodes, our result overstates the inefficiency of the price competition. This is because this extension reinforces the carrier's benefit of hubbing; therefore, the inefficiency of price competition may be mitigated. It is also necessary to introduce the airport congestion into the model. Since several hub airports experience severe congestion, it is useful to consider how the price competition affects the airport congestion as well as the carrier's network choice.

Reference

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

J. K. Brueckner, 2004, ‘Network Structure and Airline Scheduling,’ *The Journal of Industrial Economics*, Vol. 52(2), pp. 291–312.

J. K. Brueckner, 2002, ‘Airport Congestion When Carriers Have Market Power,’ *The American Economic Review,* Vol. 92(5), pp. 1357-1375.

A. Czerny, Hoffler, F, and Mun, S., 2013, ‘Port competition and welfare effect of strategic privatization,’ *EWI Working Paper*, No. 13/13

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

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

R. Flores-Fillol, 2009, ‘Airline competition and network structure,’ *Transportation Research Part B: Methodological*, Vol. 43(10), pp. 966–983.

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

IATA, “*Airport, ATC & Fuel Charges Monitor*,” 1 Aug., 2013, <http://aafcm.iata.org>.

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

T. Matsumura and Matsushima, N., 2012, ‘Airport privatization and international competition,’ *Japanese Economic Review*, Vol. 63(4), pp. 431–450.

T. Mori, 2012. ‘Increasing returns in transportation and the formation of hubs,’ *Journal of Economic Geography*, vol. 12(4), pp. 877-897.

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

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

T. H. Oum, Zhang, A., and Zhang, Y. 1996, ‘A note on optimal airport pricing in a hub-and-spoke system,’ *Transportation Research Part B: Methodological*, vol. 30(1), pp.11–18.

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

E. Pels and E. T. Verhoef, 2004, ‘The economics of airport congestion pricing,’ *Journal* *of Urban Economics,* Vol. 55, pp. 257–277.

R. M. Starr and Stinchcombe, M. B., 1992, '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.

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

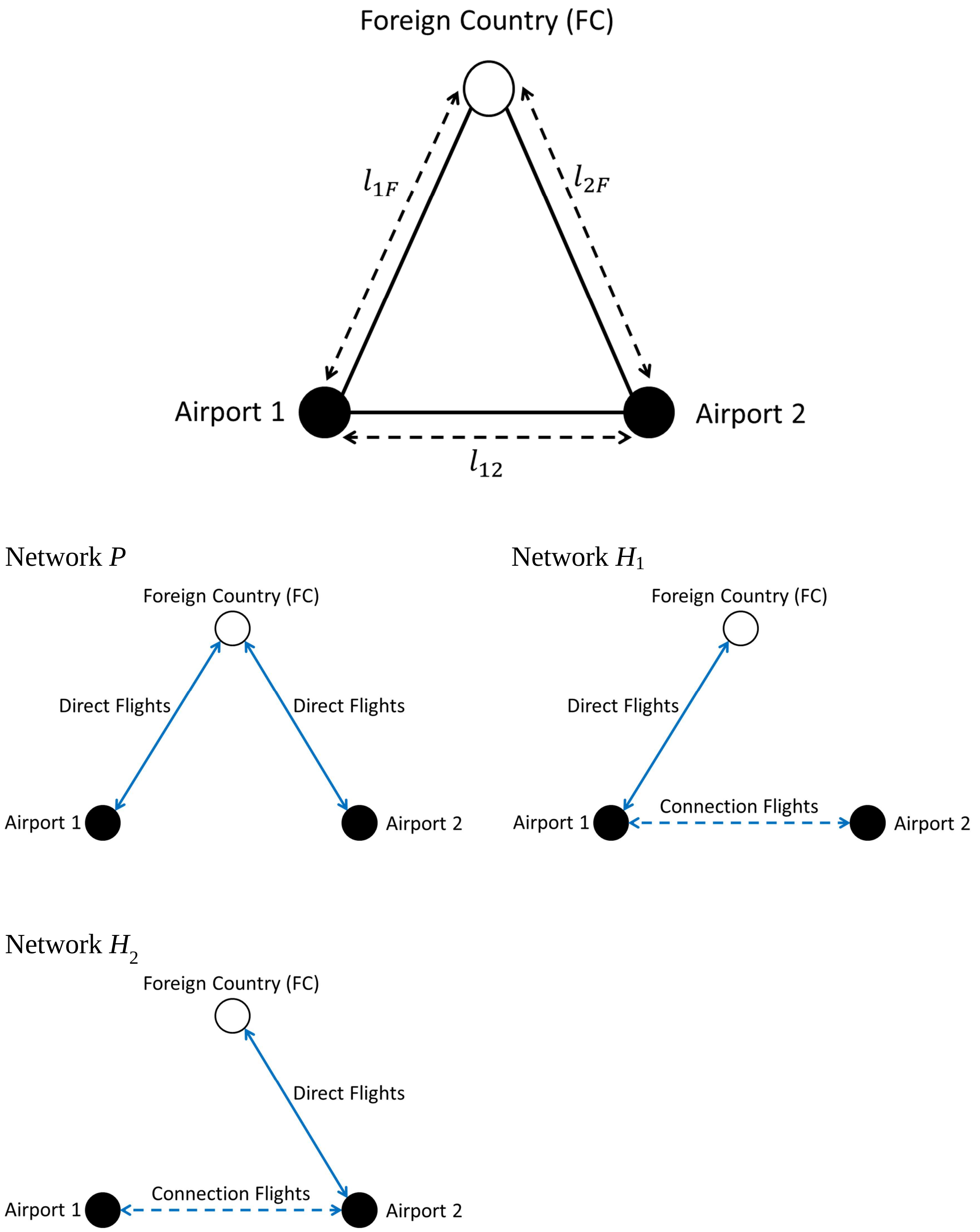

Figure 1: Three Alternative Network Configurations

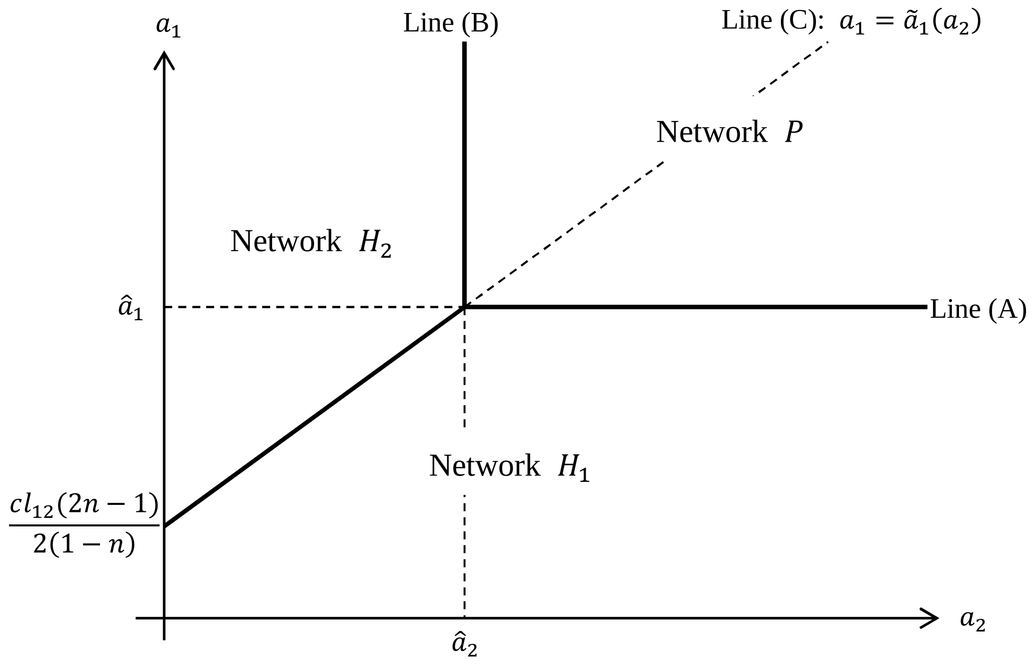

Figure 2: The Carrier's Network Choice in Case of $l_{1F} = l_{2F}$

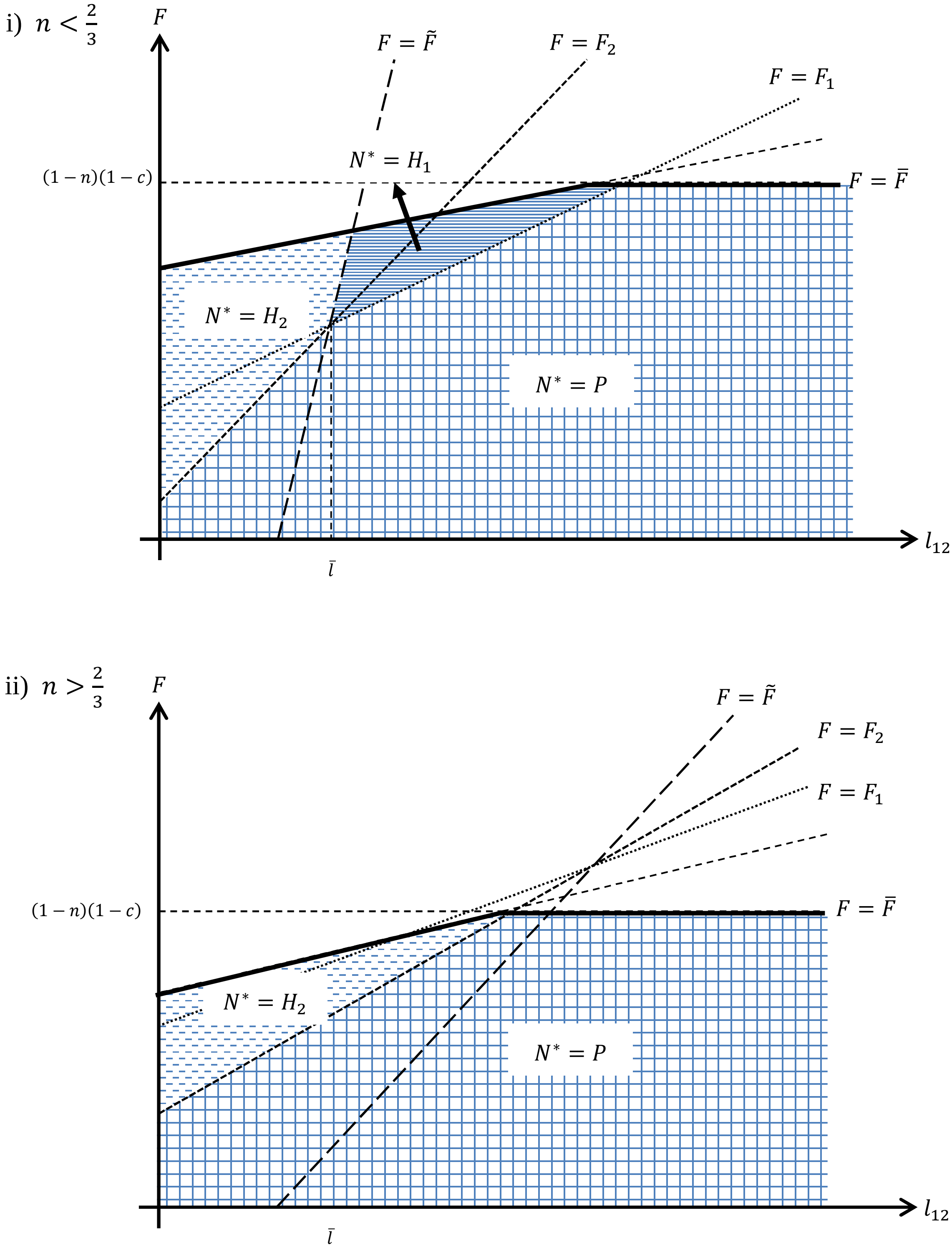

Figure 3: The Equilibrium Network Configuration, N^*

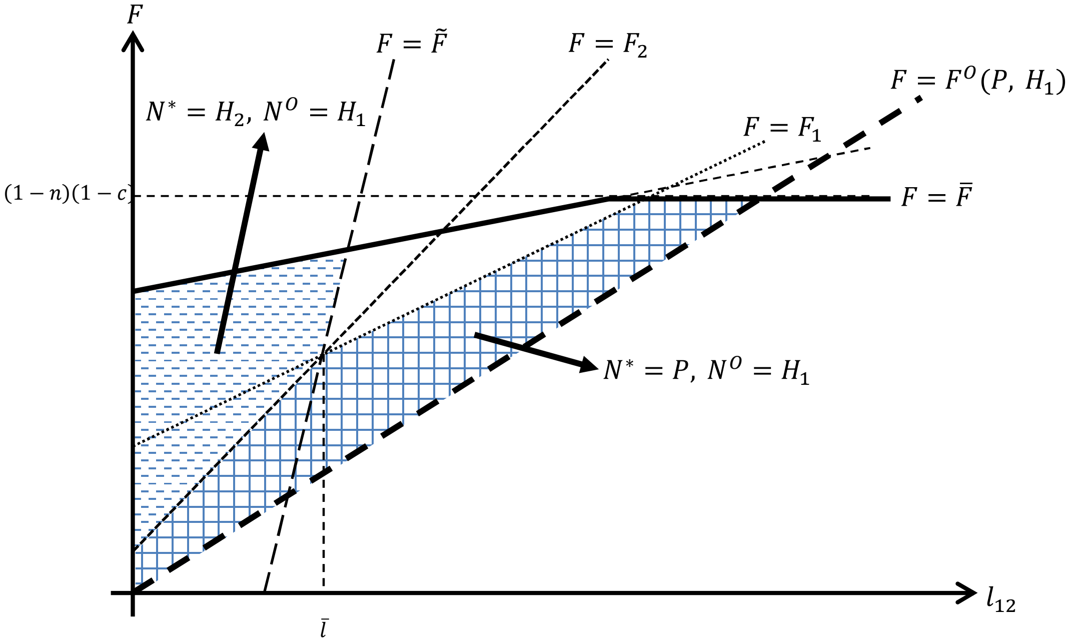

Figure 4: The Equilibrium vs. the Optimum