Economic Analysis of Multiple Airports in a Metropolitan Area

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Abstract:

This paper deals with the allocation of international and domestic flights (allocation of services) into multiple airports in a metropolitan area. We construct an economic model in which two airports are located on one-dimensional space. We investigate two types of allocation of services under different regimes of airport operations: (PP) separate operation by two private firms, (M) integrated operation by a single private firm, (G) integrated operation by the government. Under each regime, we examine two types of allocations: One is the equilibrium allocation as the outcome of the decentralized decision-making by operators. The other is the surplus-maximizing in which the allocation is set to maximize the social surplus. We evaluate the equilibrium allocation by comparing with the surplus-maximizing allocation. It is shown that i) under the separate operation (PP), the equilibrium allocation coincides with the surplus-maximizing allocation: ii) under the integrated operation (M), the equilibrium allocation resembles to the optimal allocation in which the government sets the airport charges and the allocation so as to maximize the social surplus.

1. Introduction

It is observed that some metropolitan areas have multiple airports each of which might have a different role. For example, in Osaka Metropolitan Area, Osaka International Airport provides domestic flights while Kansai International Airport provides both international and domestic flights. This paper deals with allocations of services among multiple airports in a metropolitan area, as described above. The allocation of services among airports might be the result of the regulation by the government or of the decentralized decision-making by airport operators. There exist various alternative ways of airport operations: integrated or separated, public or private. Also note that multiple airports arise as the result of new airport construction to address the shortage of capacity in the existing airports. This paper investigates how the choices regarding the allocation of services are affected by the types of operations, and airport congestion.

Several earlier studies focused on multiple airports in the same region: such as Pels et al. (2000), Van Dender (2005), De Borger and Van Dender (2006), and Basso and Zhang (2007). Pels et al. (2000) modeled the vertical relationship between the users and carriers in multiple airports in the same region. They studied about the effect of the accessibility on the behaviors of the carriers and the airports but focused only on the average cost pricing. De Borger and Van Dender (2006) developed the model of the vertical relationship between the users and the airports including the capacity choices of the airports. As argued in Brueckner (2002) and Pels and Verhoef (2004), the carriers have the market power: therefore, the behavior of the carrier should be included in the model. Basso and Zhang (2007) introduced the behavior of the carriers into the similar model to De Borger and Van Dender (2006). These two articles, De Borger and Van Dender (2006) and Basso and Zhang (2007), studied the pricing and the capacity choices of congested airports under several alternative regimes: such as separate operation by two private firms and integrated operation by a single private firm. All studies mentioned above supposed that a single service existed, so two airports provided an identical service. Van Dender (2005) focused on two types of competitions between facility operators, Cournot and Bertrand types, including the case where each facility provides two services. He studied about the pricing but did not consider the alternative allocations. To the best of our knowledge, none of studies dealt with the allocation of services among airports.

The structure of the problem focused in this paper resembles to the one analyzed in the literature of the local public finance: such as Takahashi (2004) and Akutagawa and Mun (2005). In those two articles, the local government decides whether or not providing the service at its facility. This type of discrete choice by the provider is similar to the analysis of the allocation of the services between airports.

We construct an economic model in which two airports are located on one-dimensional space. The model describes interaction among user's choice, carrier's competition, and policy choice of airport operator. This model also incorporates airport congestion. Using this model, we examine the allocation of services among airports in a metropolitan area with the tradeoff between the accessibility and the frequencies as Pels et al (2001) claimed. The accessibility is better if the service is available at all airports. On the other hand, the frequency is larger if the service is concentrated at a single airport: as a result, this airport becomes more congested. Focusing on this tradeoff, to investigate the relationship between the allocation and the airport operation, we set three alternative regimes: one is the case where each airport is operated by a single private firm (Regime PP); another, a single private firm operates two airports (Regime M); the other, the government operates two airports (Regime G). We also evaluate the equilibrium allocations of services under the former two regimes by comparing with the surplus-maximizing allocations as the outcome of the regulation by the government and the optimal allocation as the outcome under Regime G.

The rest of this paper is organized as follows. Section 2 introduces the model and describes the behaviors of users and carriers. In Section 3, we set the parameters for the simulation and derive the equilibrium allocation under two regimes, PP and M, by means of numerical simulations. Section 4 shows the surplus-maximizing allocations under two regimes and the optimal allocation in which the government sets both the allocation and the airport charges to maximize the social surplus. The surplus-maximizing allocation corresponds to the situation where the airport operators can set the airport charge but cannot determine the services to be provided at their airports because the government sets the allocation to maximize the social surplus. After that, Section 5 compares the two types of allocations, the equilibrium and the surplus-maximizing, among regimes. Finally, Section 6 summarizes the results and states some topics for the future study.

2. The Model

2.1. The Basic Setting

Suppose a linear economy, as illustrated in Figure 1, which consists of two regions, the City and the Hinterland. Each location of this economy is identified by the distance from the center of the City, 0. The segment [–*b*, *b*] represents the City: within this segment, users are uniformly distributed with density ρ_C. The Hinterland is outside the segment [–*b*, *b*]: in this region, users are uniformly distributed with density $\rho_H < \rho_C$.

The City has two airports, named as airports 1 and 2 respectively. Their locations are exogenously given and denoted by x_1 and x_2. Without loss of generality, we assume that $x_1<x_2$ and that airport 2 locates at the fringe of the city: that is, $x_2=b$. In addition, the congestion may occur in airport 1 but not in airport 2: only carriers incur the congestion costs but users do not. These airports can provide two types of services, international and domestic flights. Hereafter, they are denoted by I and D respectively.

<<Figure 1: About here>>

Let us denote by a_j the service provided at airport *j* (j=1, 2). The allocation of services is represented by the sets of services provided at two airports, (a_1, a_2). Table 1 summarizes the possible 16 allocation of services.

<<Table 1: About here>>

In Table 1, $a_j = ID$ implies that airport *j* (*j*=1, 2) provides services I and D: $a_j = N$ implies that airport *j* provides no services[1].

2.2. Users

The trip demand for service *S* (*S*=*I*, *D*) is inelastic. Individuals make trips by using service *S* d^S times per a given period unless the trip cost exceeds the reservation price, $\bar{C}^S$. All users have the same value of the reservation price in consuming service *S*, $\bar{C}^S$ (*S*=*I*, *D*). In addition, we set two assumptions: the trip demand for service D, d^D, is larger than that for I, d^I; the reservation price for service I, $\bar{C}^I$, is higher than that for D, $\bar{C}^D$.

The trip cost of using service *S* at airport *j* for a user located at *x*, $C_j^S(x)$, is defined as:

$$C_j^S(x) = t\left|x - x_j\right| + \frac{vh}{4F_j^S} + P_j^S, \quad \text{for } j=1, 2 \text{ and } S=I, D, \tag{1}$$

where *t*, *v*, *h*, F_j^S, and P_j^S respectively represent the access cost per a unit distance, the value of waiting time, the operating hours of airports, and the frequency and the fare of service *S* at airport *j*. In Eq. (1), the first term is the access cost for using airport *j*. The second term is the average waiting time cost for service *S* at airport *j*: the value of waiting time, *v*, is multiplied by the average waiting

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[1] We do not eliminate the possibility of emerging the allocations such as (N, N), (S, N), and (N, S), in which at most a single service *S* (*S*=*I*, *D*) is available at an airport. In such case, we assume that users of the services not available at both airports choose other modes such as vehicles or railways.

time for service *S* at airport $j, 1/4F_j^S$, for a given period of time.

Each user chooses one of two airports so as to minimize the trip cost. Therefore, the demand of users located at *x* for service *S* at airport *j*, $q_j^S(x)$, is derived as:

$$q_j^S\left(x\right)=\begin{cases}\rho_C d^S & \text{if } C_j^S\left(x\right)\le C_i^S\left(x\right) \text{ and } C_j^S\left(x\right)\le \bar{C}^S \text{ for } x\in\left[-b,b\right] \text{ and } i\ne j,\\ \rho_H d^S & \text{if } C_j^S\left(x\right)\le C_i^S\left(x\right) \text{ and } C_j^S\left(x\right)\le \bar{C}^S \text{ for } x\notin\left[-b,b\right] \text{ and } i\ne j,\\ 0 & \text{if } C_j^S\left(x\right)> C_i^S\left(x\right) \text{ or } C_j^S\left(x\right)> \bar{C}^S \text{for } i\ne j.\end{cases} \tag{2}$$

Using Eq. (2), the aggregate demand for service *S* (*S*=*I*, *D*) at airport *j* (*j*=1, 2) is derived as:

$$Q_j^S=\int_{\underline{z}_j^S}^{\bar{z}_j^S} q_j^S\left(x\right)dx, \tag{3}$$

where $\bar{z}_j^S$ and $\underline{z}_j^S$ respectively represents the right-side and left-side of the market boundaries for service *S* at airport *j*. There are three possible cases regarding to market boundaries:

i) Services *S* is only provided at airport *j*. In this case, at the boundaries, the trip cost is equalized to the reservation price: $C_j^S\left(\bar{z}_j^S\right)=C_j^S\left(\underline{z}_j^S\right)=\bar{C}^S$.

ii) Two airports provide service *S* and these markets are adjacent, $\bar{z}_1^S=\underline{z}_2^S$. In this case, At the this boundary, $\bar{z}_1^S=\underline{z}_2^S$, the trip costs for both airports are equalized: $C_1^S\left(\bar{z}_1^S\right)=C_2^S\left(\underline{z}_2^S\right)$. At the boundaries, $\underline{z}_1^S$ and $\bar{z}_2^S$, the trip cost is equalized to the reservation price: that is, $C_1^S\left(\underline{z}_1^S\right)=C_2^S\left(\bar{z}_2^S\right)=\bar{C}^S$.

iii) Two airports provide service *S* and these markets are segregated. In this case, same as i), at all the boundaries, the trip cost is equalized to the reservation price: $C_j^S\left(\bar{z}_j^S\right)=C_j^S\left(\underline{z}_j^S\right)=\bar{C}^S$ (*j*=1, 2).

2.3. Carriers

We assume that there are two carriers in each service market *S* (*S*=*I*, *D*). Let us denote by f_j^{Sk} the number of flights at airport *j* (*j*=1, 2) provided by the carrier *k* (*k*=1, 2) in service *S* (*S*=*I*, *D*) market. We assume the symmetric equilibrium in which two carriers in each market provide the same number of flights with the same schedule at each airport. This situation is realized through the competition in the schedule of flights. Consequently, the frequency of service *S* at airport *j* perceived by users, F_j^S, is equal to f_j^{Sk}.

All flights from each airport are operated with full capacity denoted as σ; therefore, each carrier of service *S* earns $P_j^S\sigma$ per a flight from airport *j*. A carrier incurs the marginal cost m_j^S, and the airport charge r_j^S per a flight of service *S* from airport *j*. Therefore, the profit for the carrier *k* of service *S* from airport *j*, π_j^{Sk}, is,

$$\pi_j^{Sk} = \left(P_j^S\sigma - m_j^S - r_j^S\right) f_j^{Sk}. \tag{4}$$

Since carriers face the congestion when they use airport 1, the marginal cost, m_j^S, varies between airports:

$$m_1^S = \omega^S + c\sum\nolimits_{S,k} f_1^{Sk}$$
$$m_2^S = \omega^S,$$

where ω^S and *c* capture the marginal cost of an operation and congestion.

We assume that the competition between two carriers in market *S* is the Cournot type: each carrier chooses the frequency. Since the inverse demand function for service *S* at airport

j, P_j^S, depends on the frequencies of all carriers and the carriers face the congestion at airport 1, carrier *k*'s profit from airport j, π_j^{Sk}, depends on not only its frequencies but frequencies of other carriers in both markets.

Recall that depending on the allocation of services, (a_1, a_2), carriers may not be allowed to operate the flights in a particular airport. Therefore, we have two types of the profit maximization problem for carrier *k* in the market of service *S*:

i) If carriers in market *S* are allowed to operate at a single airport *j* (*j*=1, 2), the carrier *k* sets the frequency at airport j, f_j^{Sk}, to maximize the profit from airport *j*.

ii) If carriers in market *S* are allowed to operate at two airports, the carrier *k* sets the frequencies at two airports, $\mathbf{f}^{\mathbf{Sk}} = (f_1^{Sk}, f_2^{Sk})$, to maximize the sum of profits from two airports.

The equilibrium frequency of carrier *k* at airport j, f_j^{Sk}, is the best response against the other carriers' frequencies at both airports. Also note that the equilibrium frequency of carrier *k* at airport *j* depends on the airport charges, $\mathbf{r}_\mathrm{j} = (r_j^I, r_j^D)$, and the services to be provided at both airports, a_j (*j*=1, 2): therefore, the equilibrium frequency of carrier *k* at airport *j* is $f_j^{Sk}(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2)$.

2.4. Airports

Operators first determine the service to be provided at their airports, a_j, then the airport charges , $\mathbf{r}_\mathrm{j}$. There are two types of operators, the private firm and the government. The private firm maximizes the revenue: the government maximizes the social surplus.

This paper examines three alternative regimes of airport operation as shown in Table 2.

<<Table 2: About here>>

Regime PP is the case that each airport is operated by a single private firm. Each operator maximizes the revenue from its airport in setting the type of services and the airport charges. Regime M is the monopoly: that is, a single private firm operates two airports. In this case, the operator maximizes the revenue from two airports in determining the types of services and the airport charges at both airports. Finally, Regime G is the situation where the government operates two airports. The government sets the types of services and the airport charges at both airports to maximize the social surplus.

2.5. The Sequence of the Game

Under any regime, at the first period, airport operators determine the services provided at their airports, a_j (j=1, 2). In the second period, given the allocation between two airports, each operator sets the airport charges, $\mathbf{r}_j$. In the third period, carriers determine the number of flights at each airport, f_j^{Sk}, as described in Subsection 2.3. After that, in the final stage, all individuals choose whether or not using service *S*. In addition, users of service *S* determine which airport to use if two airports provide it as explained in Subsection 2.2.

3. The Equilibrium Allocations

3.1. Parameters

We investigate the equilibrium allocations under two regimes by means of numerical simulations. We set the values of parameters so that the outcomes of the model are not far from the real world.

<<Table 3: About here>>

We set the size of the City as the segment of [–50, 50]. Population density of the City ρ_C is chosen so that the population of Osaka Metropolitan Area is accommodated in a one-dimensional space with the size of 100 square kilometers. The population density of the Hinterland ρ_H, on the other hand, is the average population density of Japan[2].

The values of d^I and d^D respectively correspond to the average trip frequencies of international and domestic flights in Japan. To obtain the values of v and h, we assume that the flights at each airport are daily operated with the equal interval: therefore, all users of service S at each airport incur the identical average waiting time cost. We set the value of v respectively 3,000 yen per an hour, which is used in Cost-Benefit Analysis of Kobe Airport (Kobe City, 2004), and the value of h as 5475 hours $(365 \text{ days} \times 15 \text{ hours})$. To calibrate the access cost per a distance, we calculate the access cost to Kansai International Airport by railway for 50 largest cities in Osaka Metropolitan

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[2] To obtain this, we adjusted the area of Japan so that the area of Osaka Metropolitan Area was equal to 100 square kilometers.

Area. According to these values, we use the weighted average of the access costs per a kilometer for 50 cities for the value of t.

We use the average size of the ANA's aircraft for the value of σ. The values of the cost parameters, ω^I, ω^D, and c, are calibrated from the following procedures. Following Pels and Verhoef (2004), we assume that the total delay cost for each carrier is equal to 5 % of its total operating cost. Therefore 95 % of the total operating cost corresponds to the sum of the total operating costs for international and domestic flights. Using the financial data of JAL and ANA for 2004, we calculate the total operating costs for international and domestic flights so that the sum of them is equal to 95 % of the total operating cost. From the calculated total operating cost for each service, we obtain the value of parameter ω^S ($S=I, D$) from dividing it by the total number of flights for each service. To calibrate the parameter of congestion cost, we set 5 % of the total operating costs as the total delay costs for two carriers, JAL and ANA. According to this, we set the value of c so that the total congestion cost based on this model is equal to the sum of 5 % of total operating costs.

The reservation price for each service is obtained through the calibration. Table 4 in below shows the calibrated number of passengers for each service at two airports in Osaka Metropolitan Area[3].

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[3] In Table 4, we assume that airport 1 locates at $x_1=-11$ (the distance between Osaka Station and Osaka International Airport): airport 2, at $x_2=36$ (the distance between Osaka Station and Kansai International Airport). Due to the asymmetry in congestion, the number of passengers for domestic flights at each airport is different from the one in 2004. The total number of passengers for domestic flights, however, is close to the one in 2004.

<<Table 4: About here>>

Based on these parameter values, we derive the equilibrium allocation under each regime. The following subsection shows the equilibrium allocation under Regime PP.

3.2. Regime PP

Under this regime, each airport is operated by a single private firm. The operator of the airport *j* (*j*=1, 2) chooses the services to be provided at airport *j*, a_j, then the airport charges, $\mathbf{r}_j = (r_j^I, r_j^D)$, so as to maximize the revenue. Given the allocation, (a_1, a_2), and the airport charges at the other airport, $\mathbf{r}_i$, the operator *j* sets the airport charge for service *S* (*S*=*I*, *D*) as:

$$\hat{r}_j^S\left(\mathbf{r}_i; a_1, a_2\right) = \arg\max_{\mathbf{r}_j}\left\{\sum_{S,k} r_j^S f_j^{Sk}\left(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2\right) | \text{s.t.} \quad C_j^S\left(x_j\right) \le C_i^S\left(x_j\right) \text{ for } S = I, D\right\}. \tag{5}$$

In (5), the constraint implies that the operator of airport *j* plays the strategy of protecting its market of service *S* from the undercutting by the other airport operator *i*. Eq. (5) represents the best response function of airport *j* for service *S* (*S*=*I*, *D*). Given the allocation, (a_1, a_2), at Nash equilibrium, each operator sets the airport charges so that they become the best responses against the equilibrium airport charges of the other operator. Therefore, the equilibrium airport charge for service *S* at airport *j*, $r_j^{S*}\left(a_1, a_2; PP\right)$, satisfies the following relation:

$$r_j^{S*}\left(a_1, a_2; PP\right) = \hat{r}_j^S\left(\mathbf{r}_i^*; a_1, a_2\right) \quad \text{for } S = I, D,\ j = 1, 2, \text{and } i \ne j, \tag{6}$$

where $\mathbf{r}_i^*$ is the vector of the equilibrium airport charges set by the other operator *i*,

$$\mathbf{r_i^*} = \left(r_i^{I*}\left(a_1, a_2; PP\right), r_i^{D*}\left(a_1, a_2; PP\right)\right).$$

Substituting the equilibrium airport charges, $r_j^S\left(a_1, a_2; PP\right)$, into the objective of (5), we obtain the each operator's payoffs for each of nine allocations:

$$R_j\left(a_j, a_i; PP\right) = \sum_{S,k} r_j^S\left(a_1, a_2; PP\right) f_j^{Sk}\left(a_1, a_2; PP\right) \text{for}\, a_j = ID, I, D,\ j = 1, 2, i \neq j.$$

Given the services provided at the other airport *i*, a_i, each operator chooses the providing services at its airport, a_j, to maximize the payoff, $R_j(a_j, a_i; PP)$. Let us denote by $a_j^*(PP)$ the equilibrium services chosen by the operator of airport *j* (*j*=1, 2) then, this satisfies:

$$R_j\left(a_j^*\left(PP\right), a_i^*\left(PP\right); PP\right) \geq R_j\left(a_j, a_i^*\left(PP\right); PP\right) \text{ for } {}^\forall a_j \neq a_j^*\left(PP\right),$$

where $a_i^*\left(PP\right)$ is the equilibrium service chosen by the other operator.

According to the numerical simulation, it turns out that the dominant strategy for each airport is ID[4] regardless of the location of airport 1,

$$\left(a_1^*\left(PP\right), a_2^*\left(PP\right)\right) = \left(ID, ID\right), \text{for} -50 \leq x_1 \leq 50.$$

Table 5 shows the payoff matrix under the situation where airport 1 locates at the center of the City, x_1=0.

<<Table 5: About here>>

Both airport operators find that providing two services gives an additional revenue compared to

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[4] We can show analytically that ID is the dominant strategy for both operators if two airports are uncongested.

providing a single service *S* (*S*=*I*, *D*) irrelevant from the choice of the other operator. Therefore, the equilibrium allocation under Regime PP is (ID, ID) at all possible locations of airport 1.

3.3. Regime M

Under this regime, a single private firm operates two airports. The operator first determines the services provided at both airports (a_1, a_2), and then it sets the airport charges, ($\mathbf{r_1}$, $\mathbf{r_2}$). Given the equilibrium allocation, the operator maximizes the revenue in setting the airport charge:

$$\max_{\mathbf{r_1},\mathbf{r_2}} \sum\nolimits_{j,S,k} r_j^S f_j^{Sk}\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right). \tag{7}$$

Solving this, (7), we obtain the equilibrium airport charge under each of 16 allocations, (a_1, a_2), as $r_j^{S*}\left(a_1,a_2;M\right)$.

Substituting the equilibrium airport charge, $r_j^{S*}\left(a_1,a_2;M\right)$, into the objective of (7), the payoff for each of 16 allocations, $R(a_1,a_2;M)$, is derived as:

$$R\left(a_1,a_2;M\right)=\sum\nolimits_{j,S,k} r_j^{S*}\left(a_1,a_2;M\right) f_j^{Sk}\left(\mathbf{r_1^*},\mathbf{r_2^*};a_1,a_2\right),$$

where $\mathbf{r_j^*}$ is the vector of the equilibrium airport charges at airport *j* (*j*=1, 2),

$$\mathbf{r_j^*}=\left(r_i^{I*}\left(a_1,a_2;M\right),r_i^{D*}\left(a_1,a_2;M\right)\right).$$

Denote $(a_1^*(M),a_2^*(M))$ as the equilibrium allocation under Regime M, then, the operator chooses this to maximize its payoff, $R(a_1,a_2;M)$: that is,

$$\left(a_1^*(M),a_2^*(M)\right)=\arg\max_{a_1,a_2} R\left(a_1,a_2;M\right)$$

According to the comparison of the operator's payoffs, the equilibrium allocation, $(a_1^*(M),a_2^*(M))$, is obtained and shown in Figure 2.

<<Figure 2: About here>>

As shown in this figure, the operator sets the allocation (ID, ID) if two airports are distant. The number of services provided at airport 1 decreases as the distance between two airports becomes closer. When two airports are sufficiently close, the allocation (N, ID) is chosen.

Figure 3 compares the payoffs of four allocations in Figure 2: such as (ID, ID), (D, ID), (I, ID), and (N, ID)[5]:

<<Figure 3: About here>>

To understand this intuitively, we first compare the revenues under the allocations (ID, ID) and (D, ID):

$$R(ID, ID; M) - R(D, ID; M) = \Delta R_1^I + \Delta R_2^I + \Delta R_1^D + \Delta R_2^D, \tag{8}$$

where

$$\begin{aligned}
\Delta R_1^I &\equiv r_1^I(ID, ID; M)\, f_1^I(ID, ID; M), \\
\Delta R_2^I &\equiv \left[r_2^I(ID, ID; M)\, f_2^I(ID, ID; M) - r_2^I(D, ID; M)\, f_2^I(D, ID; M) \right], \\
\Delta R_1^D &\equiv \left[r_1^D(ID, ID; M)\, f_1^D(ID, ID; M) - r_1^D(D, ID; M)\, f_1^D(D, ID; M) \right], \\
\Delta R_2^D &\equiv \left[r_2^D(ID, ID; M)\, f_2^D(ID, ID; M) - r_2^D(D, ID; M)\, f_2^D(D, ID; M) \right].
\end{aligned}$$

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[5] Revenues under the allocations (ID, ID) and (D, ID) are not continuous at location, $x_1 = -30$. At this location, the market boundaries of service D are changed: at $x_1 = -30$, the left-side boundary of airport 1 moves to the inside of the City.

The first term of the RHS in (8), ΔR_1^I , can be interpreted as the opportunity cost of not providing service I at airport 1 if the operator changes the allocation from (ID, ID) to (D, ID). The second term, ΔR_2^I , is the effect on the revenue of the concentration of service I at airport 2 since under the allocation (D, ID), only airport 2 provides service I. The third term, ΔR_1^D , represents the effect on the revenue of the reduction in congestion. Since providing a single service (D) at airport 1 imposes smaller congestion cost on the carriers of service D operating at airport 1 compared to the allocation (ID, ID), they change the number of flights: therefore, the revenue from service D at airport 1 changes. This change in service D at airport 1 affects service D at airport 2 if the markets of two airports are adjacent: therefore, it indirectly affects the revenue from the service D at airport 2. This is captured by the last term of the RHS in (8), ΔR_2^D .

According to the equilibrium allocation summarized in Figure 2, when two airports are sufficiently distant, the operator chooses the allocation (ID, ID) since the opportunity cost captured in the first term in (8) dominates the other effects. When two airports become closer, however, we cannot tell which effect makes the operator change the allocation. To see this, Table 6 shows the values of four terms in (8) for five locations of airport 1.

<<Table 6: About here>>

As shown in Table 6, as two airports become closer, the concentration effect, ΔR_2^I, and the opportunity cost, ΔR_1^I, increase: on the contrary, the congestion and indirect effects (ΔR_1^D and ΔR_2^D) are constant and quite small[6]. Also note that the concentration effect increases more rapidly than the opportunity cost as two airports become closer. According to this, we can conclude that when the distance between two airports is intermediate, reducing the congestion improves the revenue since the concentration effect becomes as large as the opportunity cost[7]: therefore, the operator changes the allocations from (ID, ID) to (D, ID).

According to Figures 2 and 3, as the distance between two airports becomes smaller, the operator changes the equilibrium allocation from (D, ID) to (I, ID). At these locations of airport 1, the operator faces the problem, which service, I or D, to be concentrated in airport 2 and which to be provided at airport 1. The change in the allocation from (D, ID) to (I, ID) implies that the concentration of service D and the provision of service I at airport 1 improves the revenue.

As shown in Figures 2 and 3, when two airports are sufficiently close (for example at $x_1 = 50$), the equilibrium allocation changes from (I, ID) to (N, ID). In this case, the operator faces the problem, whether or not concentrating service I in airport 2. The change in the allocation from (I, ID) to (N, ID) implies that the operator finds that concentrating service D improves the revenue.

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[6] In Table 6, when two airports are distant (for example x_1=50 or x_1=25), the indirect effect, ΔR_2^D, is zero because the markets of service D are segregated.

[7] At x_1=20, the concentration effect is smaller than the opportunity cost. The sum of the concentration and congestion effects, however, dominates the opportunity cost. Therefore, the operator considers the congestion effect on its revenue as significant as long as the concentration effect is sufficiently large.

4. The Surplus-Maximizing Allocations

This section shows the surplus-maximizing allocations in which the allocation of services is set so as to maximize the social surplus. We evaluate the equilibrium allocations of two regimes derived in Section 3 by comparing with the surplus-maximizing allocations. The surplus-maximizing allocation may be attained as a result of the regulation by the government. We can interpret that the difference between the outcomes under the equilibrium and the surplus-maximizing allocations as the effect of the regulation.

In this section, we modify the sequence of the game. First the government chooses the allocation to maximize the social surplus, and then the operators under each regime set the airport charge. This section is organized as follows: we first show the surplus-maximizing allocations under Regimes PP and M. After showing the allocations under these two regimes, we derive the optimal allocation, in which the government chooses both the airport charges and the allocation (Regime G).

4.1. Regime PP

Given the allocation (a_1, a_2), the private firms set the airport charges to maximize the revenue as described in Subsection 3.1. Taking the airport charge characterized by (6) into account, the government sets the allocation to maximize the social surplus:

$$\max_{a_1,a_2} \sum_{S,j} \int q_j^S(x)\left[\bar{C}^S - C_j^S(x)\right]dx + \sum_{S,k} \pi^{Sk} + \sum_{S,j} R_j^S,$$

where the first term is the consumer surplus: the second term, the profits of carriers: the third term, the revenues of airport operators. Denote the allocation chosen by the government as

$(a_1^O(PP), a_2^O(PP))$, then the surplus-maximizing allocation is numerically obtained as:

$$\left(a_1^O\left(PP\right), a_2^O\left(PP\right)\right) = \left(ID, ID\right), \text{for} -50 \le x_1 \le 50. \tag{9}$$

At all locations of airport 1, the government sets the allocation (ID, ID) to maximize the social surplus.

To understand this, we decompose the social surplus of service *S* (*S=I*, *D*) into four parts:

$$SW^S\left(a_1, a_2; PP\right) = \left(\sigma\bar{C}^S - \omega^S\right)\sum_{j,k} f_j^{Sk}\left(a_1, a_2; PP\right) - t\sum_j \int q_j^S\left(x\right)\left|x_j - x\right| dx$$
$$-\frac{v\sigma}{4}\lambda^S\left(a_1, a_2; PP\right) - c\left[\sum_{S,k} f_1^{Sk}\left(a_1, a_2; PP\right)\right]\sum_k f_1^{Sk}\left(a_1, a_2; PP\right),$$
$$\text{for } S=I, D, \tag{10}$$

where $\lambda^S(a_1, a_2; PP)$ is the number of airports providing service S[8]. As shown above the surplus-maximizing allocation is (ID, ID): therefore, under Regime PP, $\lambda^S(ID, ID; PP) = 2$ since the government allocates two services to each airport. In Eq. (10), the first term is the benefit of providing service *S*: we call this the social benefit. The second term represents the total access cost for using service *S*. The third term is the total scheduling cost for using service *S*. The last term is the total congestion cost for service *S*.

Under this regime, the competition between two airports results in the lower airport charges: because of this, the frequencies of two services at both airports increase. According to (10), the increase in the frequencies results in the increase in the social benefit, the first term of (10), as well

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[8] Under Regime *Z* (*Z=PP*, *M*, *G*), when two airports provide service *S* (*S=I*, *D*) or two services, *ID*, then, $\lambda^S(a_1, a_2; Z) = 2$: if one of two airports provide service *S* or two services, *ID*, while the other provide the other service $T (T \ne S)$ or none of services, *N*, then, $\lambda^S(a_1, a_2; Z) = 1$: if two airports provide only the other service *T* or none of services, *N*, then, $\lambda^S(a_1, a_2; Z) = 0$.

as the increase in the social cost, the last three terms of (10) including the access cost[9]. Eq. (9) implies that the competition generates the larger social benefit than the social cost. Also note that the allocation shown in Eq. (9) coincides with the equilibrium allocation. This means that under this regime, each operator chooses the type of services to be provided at its airport efficiently.

4.2. Regime M

A single private operator sets airport charges for services and both airports given the allocation (a_1, a_2). For each of 16 allocations, the airport charge is obtained as described in Subsection 3.3. Taking this into account, the government determines the allocation to maximize the social surplus. Denote by $(a_1^O(M), a_2^O(M))$ the surplus-maximizing allocation under Regime M. Figure 4 shows the surplus-maximizing allocation for various locations of airport 1:

<<Figure 4: About here>>

As shown in Figure 4, when two airports are sufficiently distant, the surplus-maximizing allocation under this regime becomes (ID, ID). As two airports become closer, the number of services at airport 1 decreases. If two airports are sufficiently close, the government sets the allocation (N, ID) to maximize the social surplus.

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[9] Since the reduction in the airport charge due to the competition expands the market area of each airport, the access cost increases if the increase in the access cost due to this expansion dominates the reduction of the access cost due to providing service S (S=I, D) at two airports.

Table 7 shows the values of four terms of social surplus as explained in (10) under four allocations, such as (ID, ID), (D, ID), (I, ID), and (N, ID), at each of four locations of airport 1.

<<Table 7: About here>>

According to Table 7, we can interpret the surplus-maximizing allocation under Regime M, shown in Figure 4, as follows. When two airports are sufficiently distant, the reduction in the total access cost dominates the increase in the total scheduling and congestion costs: therefore, the allocation (ID, ID) maximizes the social surplus.

When the distance between two airports is intermediate (for example, $x_1=0$), the government chooses the allocation (D, ID). Under the allocation (D, ID), service I is available only at airport 2 while service D is provided at both airports: the access cost for service I users increases. On the contrary, since airport 1 provides a single service, D, the congestion at airport 1 decreases. The reduction in the congestion has two effects on the social surplus: one is the reduction in the congestion cost; the other, the increase in the social benefit. The latter effect is caused by the following mechanism. Since the congestion at airport 1 is reduced, the service D carriers increase the number of flights at airport 1. Obviously, according to Eq. (10), the increase in the number of flights results in the increase in the social benefit for service D. Table We can conclude that the government changes the allocation from (ID, ID) to (D, ID) because reduction in the congestion by not providing service I at airport 1 improves the social surplus more than the reduction in the access cost by providing service I at airport 1. As shown in Table 7, when airport 1 locates at 25 (x_1=25), the social surplus of the allocation (I, ID) gives the largest social surplus. Since the number of flights of service I is smaller than that of service D, the congestion at airport 1 is smaller if airport 1 provides only service I: therefore, in this case, the reduction in the congestion cost plays the significant role. If two airports are sufficiently close (for example, x_1=40), the reduction in the total scheduling and congestion costs is larger than the increase in the total access cost: therefore, the allocation (N, ID) maximizes the social surplus.

Figure 5 in below compares the equilibrium and the surplus maximizing allocations:

<<Figure 5: About here>>

According to Figure 5, under the decentralized equilibrium, the private firm overuse airport 1 especially when the distance between two airports is intermediate; for example, airport 1 locates at the center of the City, x_1=0. If two airports are close, the equilibrium allocation becomes relatively close to the one that maximizes the social surplus.

When, for example, airport 1 locates at the center of the City, x_1=0, to improve the social surplus, the government decides to reduce the congestion cost for the service D carriers since the reduction in the congestion cost and its effect on the social benefit is more significant than the increase in the access cost for the service I users. The private operator, on the other hand, keeps the allocation (ID, ID) because providing the service I at airport 1 gives the larger revenue than concentrating it at airport 2: that is, the private operator has no incentives to reduce the congestion. Therefore, under the decentralized equilibrium, the operator tends to overuse airport 1 without the regulation.

Also note that the difference in the social surplus between the equilibrium and the surplus-maximizing allocation is quite small. For example, when airport 1 locates at the center of the City (x_1=0), under the equilibrium allocation, (ID, ID), the access cost is smaller than the surplus-maximizing allocation, (D, ID) while the social benefit is smaller and the rest of two terms in the social cost are larger. In other words, the difference in the social surplus between two allocations is quite small because the increase in the access cost offsets the change in other three terms, the increase in the social benefit and the reduction in the congestion and the scheduling costs.

4.3. Regime G

Under this regime, the government operates two airports. The government first determines the allocation of services between two airports, (a_1, a_2), and then it sets the airport charges of services at both airports, $(\mathbf{r}_1, \mathbf{r}_2)$. Hereafter, we call the allocation under this regime the optimal allocation. Given the optimal allocation, the government sets the airport charge to maximize the social surplus:

$$\max_{\mathbf{r}_1,\mathbf{r}_2} \sum_{S,j} \int q_j^S(x)\left[\bar{C}^S - C_j^S(x)\right]dx + \sum_{S,k} \pi^{Sk} + \sum_{S,j} R_j^S. \tag{11}$$

Solving (11), we obtain the airport charge for each of 16 allocations, (a_1, a_2), as $r_j^S(a_1, a_2; G)$. Substituting this into the social surplus in (11), we obtain the social surplus under each of 16 allocations $,(a_1, a_2)$, as $SW(a_1, a_2; G)$:

$$SW\left(a_1, a_2; G\right) \max_{\mathbf{r}_1, \mathbf{r}_2} \sum_{S,j} \int q_j^S\left(x\right)\left[\bar{C}^S - C_j^S\left(x\right)\right] dx + \sum_{S,k} \pi^{Sk} + \sum_{S,j} R_j^S .$$

Denote the optimal allocation as $(a_1^O(G), a_2^O(G)),$ then it satisfies:

$$\left(a_1^O(G), a_2^O(G)\right) = \arg\max_{a_1, a_2} SW\left(a_1, a_2; G\right).$$

Figure 6 shows the optimal allocation $,(a_1^O(G), a_2^O(G))$.

<<Figure 6: About here>>

According to this figure, when two airports are sufficiently distant, the government chooses the allocation (ID, ID): both airports provide two services. As two airports become closer, the government stops providing service I at airport 1 and chooses the allocation (D, ID). If two airports are sufficiently close, it decides not utilizing airport 1 and concentrates two services in airport 2: the allocation (N, ID) is chosen.

To understand this intuitively, Table 8 shows the values of four terms of the social surplus under three allocations, (ID, ID), (D, ID), and (N, ID) at four locations of airport 1.

<<Table 8: About here>>

As shown in Table 8, providing service *S* (*S*=*I*, *D*) at two airports minimizes the total access cost while it increases the total scheduling and the congestion costs compared to providing only at airport 2. When two airports are sufficiently distant (for example, airport 1 locates at the left-side of the fringe, $x1=-50$), the reduction in the access cost dominates the increase in the congestion and scheduling costs. Therefore, the government chooses the allocation (ID, ID) to maximize the social surplus.

When the distance between two airports is intermediate (for example, airport 1 locates at the center of the City, the government changes the allocation from (ID, ID) to (D, ID). As shown in Table 8, in this case, the government changes the allocation because reduction in the congestion by not providing service I at airport 1 improves the social surplus more than the reduction in the access cost by providing service I at airport 1. When two airports are sufficiently close (for example, airport 1 locates at 25), the government changes the allocation from (D, ID) to (N, ID) because of the similar reason to the change from (ID, ID) to (D, ID).

5. Comparisons

This section compares the equilibrium and the surplus-maximizing allocations among three regimes[10]. We start with showing Figure 7 which compares the equilibrium allocations under three regimes.

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[10] Note that, under Regime G, the equilibrium and the surplus-maximizing allocations coincide with the optimal allocation: that is,

$$\left(a_1^*(G), a_2^*(G)\right) = \left(a_1^O(G), a_2^O(G)\right) \text{ for } -50 \le x_1 \le 50.$$

<<Figure 7: About here>>

Under Regime PP, the allocation (ID, ID) is always observed. This is because the dominant strategy for each operator is providing two services, ID, since it generates the additional revenue compared to providing one of two services, *S* (*S*=*I*, *D*). On the contrary, under Regime M, the operator takes the effects on the other airport into account: therefore, the equilibrium allocations vary with the distance between two airports and the observed allocations is relatively similar to the optimal allocation. Even though they are quite similar, the allocation (ID, ID) is more observed under Regime M because the trade-off faced by the private operator differs from the one faced by the government. The private operator ceases providing service I at airport 1 if it feels indifferent between concentrating service I at airport 2 and providing service I at both airports. The government, on the other hand, ceases if the reduction in the congestion cost for service D carriers and its effect on the social benefit for service D are larger than the reduction in the access cost for service I users.

According to Figure 7, the allocation under Regime M resembles Regime G more than the one under Regime PP: therefore, we can conclude that, only focusing on the allocation, the integration of the operation has positive effect. From the aspect of the social surplus, the effect of the integrated operation is ambiguous: therefore, to check this, define $\gamma^*(Z)$ and $\delta^*(Z)$ as:

$$\gamma^*(Z) \equiv \frac{SW^*(Z)}{SW^O(G)}, \tag{12-1}$$

$$\delta^*(Z) \equiv SW^O(G) - SW^*(Z), \text{ for } Z = PP, M. \tag{12-2}$$

where $SW^*(Z)$ and $SW^O(G)$ are the social surpluses of the equilibrium allocation under Regime Z (*Z*=*PP*, *M*) and of the optimal allocation respectively. Eq. (12-1), $\gamma^*(Z)$, indicates the relative welfare gain of the equilibrium allocation under Regime Z. Eq. (12-2), $\delta^*(Z)$, is the difference in the social surplus between the optimal allocation and the equilibrium under Regime Z. Table 9 shows $\gamma^*(Z)$ and $\delta^*(Z)$ (*Z*=*PP*, *M*) at five locations of airport 1.

<<Table 9: About here>>

According to this table, Regime PP gives the larger social surplus than Regime M. This implies that, although the operator under Regime M allocates the services between two airports relatively efficiently, lack of competition between two airports results in the lower social surplus. Alternatively, the losses due to lack of competition worsen the social surplus more severely than those due to the allocation of services. Also note that, under Regime PP, $\gamma^*(PP)$ increases as two airports become closer because the competition between two operators become more severe.

Figure 8 shows the comparison of the surplus-maximizing allocations under three regimes.

<<Figure 8: About here>>

From the comparison of Figures 7 and 8, the allocation is changed only under Regime M. The surplus-maximizing allocation of Regime M is more similar to the optimal allocation than the equilibrium. On the contrary, under Regime PP the equilibrium allocation coincides with the surplus-maximizing allocation but it completely differs from the optimal allocation. We compare the airport charges and social surpluses among Regimes at $x_1=0$ in Table 10.

<<Table 10: About here>>

As shown in Table 10, the airport charges for service under Regime PP are close to those under Regime M while the airport charges for service I under Regime PP are much lower than Regime M[11]. According to this, the difference in the social surplus between Regimes PP and M is attributed to the difference in the airport charges for service I. In other words, when airport 1 locates at the center of the City, due to the competition in service I market, Regime PP assures the larger social surplus than Regime M. Also note that, from the comparison of the equilibrium and the surplus-maximizing allocations under Regime M, the government cannot reduce the losses due to lack of competition between two airports even if it regulates the allocation to maximize the social

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[11] Under these regimes, even though airport 1 locates at the center of the City, the markets for service D are segregated.

surplus.

6. Conclusion

This paper focused on the allocations of the services between two airports in the same metropolitan area. Under each of two regimes, PP and M, we examined the equilibrium allocations as the solutions under the decentralized decision-making and evaluated such allocation by comparing with the surplus-maximizing allocations as the solutions under the regulation by the central government. Furthermore, we compared those allocations with the optimal allocation in which the government set both the airport charges and the allocation to maximize the social surplus. The main results are summarized as follows:

i) Under the separated operation by private firms (Regime PP), the surplus-maximizing allocation coincides with the equilibrium allocation: each airport provides two services. Moreover, the social surplus approaches to the optimal one as two airports become closer since the competition between two operators become more severe.

ii) Under the integrated operation by a private firm (Regime M), the congested airport is overused in the equilibrium allocation because the effect of the congestion on the revenue is much smaller than that on the social surplus. In addition, the regulation on the allocation improves the social surplus little.

iii) The integrated operation by a private firm gives the lower social surplus than separated operation even though the integration has a positive effect on the allocation. This is because the losses due to the lack of competition are more significant than those due to the allocation.

Finally, we pose two topics for the future research. One is the mixed duopoly case, in which one of two airports is operated by the government and the other, by a private firm. In some metropolitan areas, public and private airports coexist: therefore, studying the mixed duopoly case might give some insights. The other is the regulations. In this paper, to derive the surplus-maximizing allocations, we implicitly assume that the regulation by the government is always feasible. In reality, however, the operators of the airports might outstand against the regulation: therefore, we should take the feasibility of the regulation into account. Also note that, as explained above, the regulation on the allocation gives little improvement on the social surplus under Regime M: therefore, we also take the regulation on the airport charges into account.

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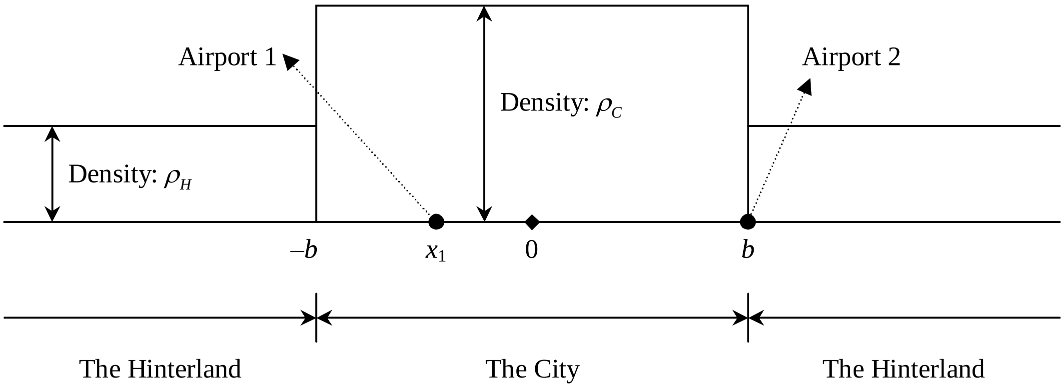

Figure 1: The Economy and the Locations of Airports

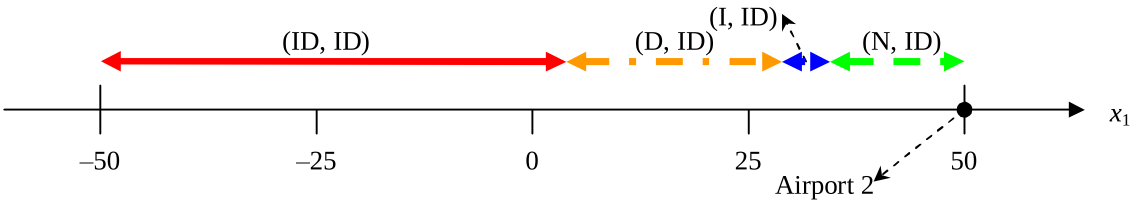

Figure 2: The Equilibrium Allocation $(a_1^*(M), a_2^*(M))$

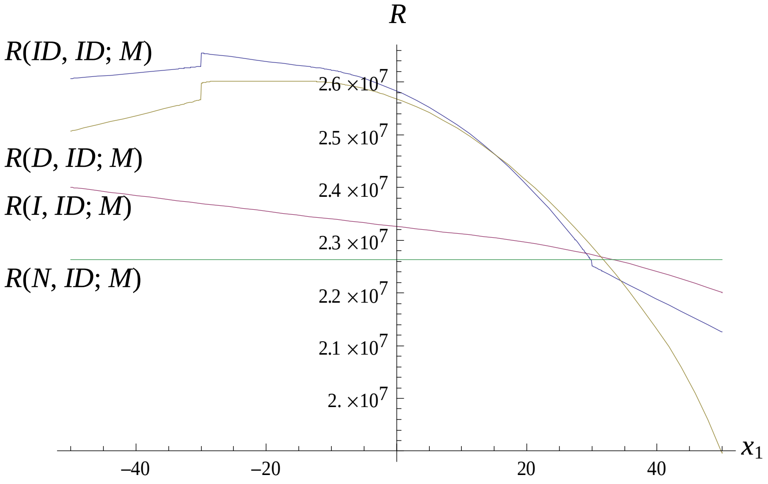

Figure 3: The Comparison of Payoffs $R(a_1, a_2; M)$ (unit: billion yen)

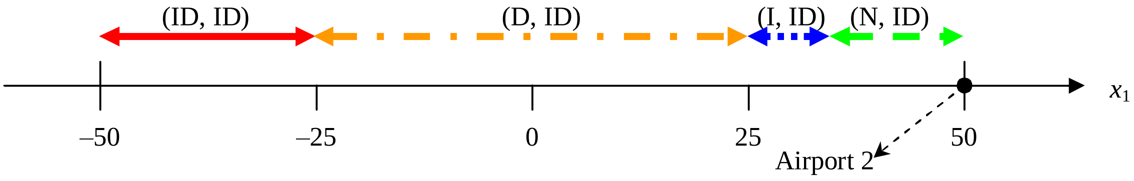

Figure 4: The Surplus-Maximizing Allocation $(a_1^o(M), a_2^o(M))$

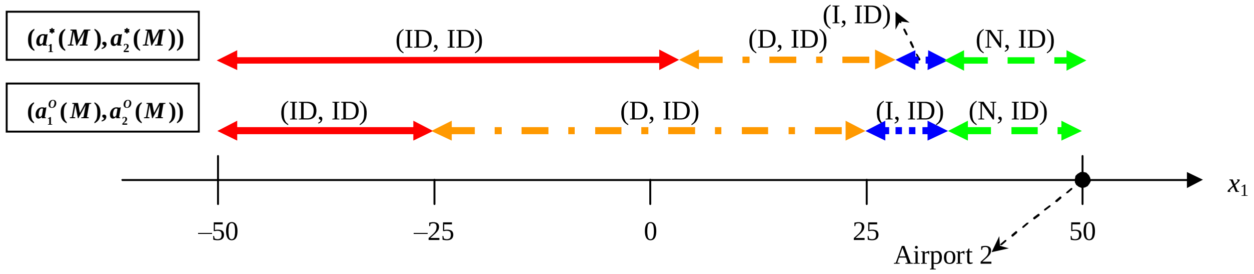

Figure 5: Comparison of $(a_1^*(M),a_2^*(M))$ and $(a_1^o(M),a_2^o(M))$

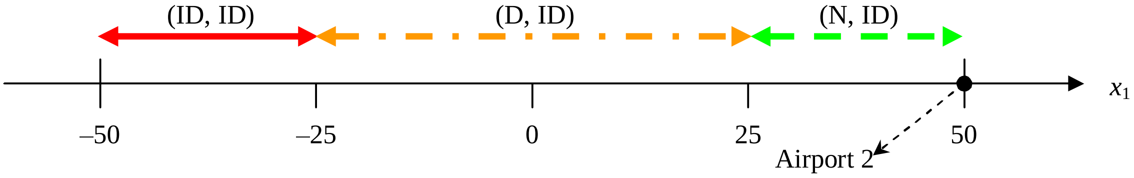

Figure 6: The Optimal Allocation $(a_1^o(G),a_2^o(G))$

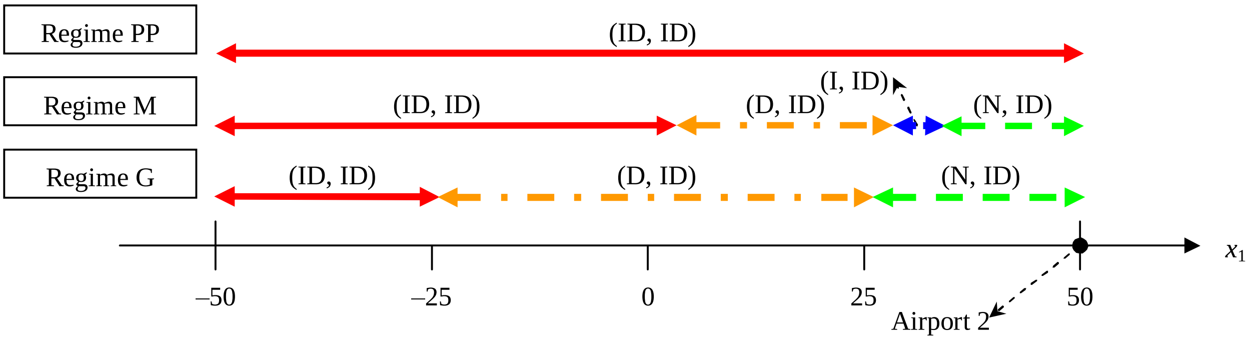

Figure 7: Comparison of the Equilibrium Allocations under Three Regimes

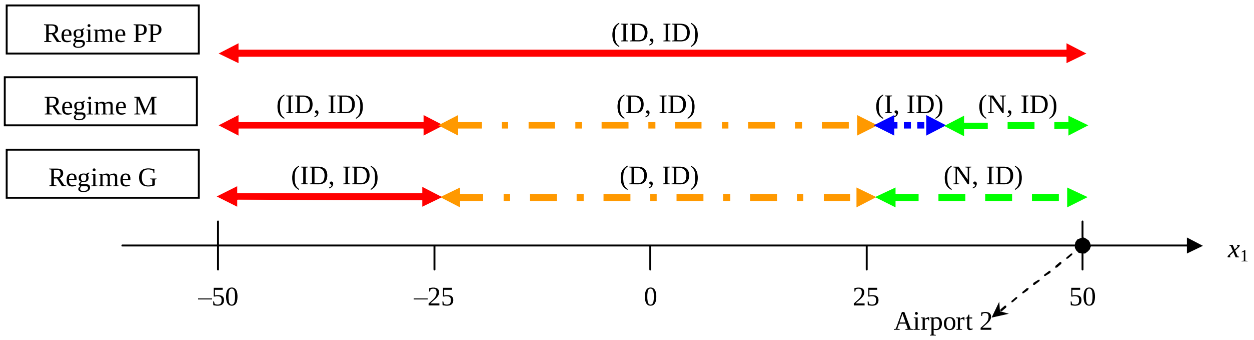

Figure 8: Comparison of the Surplus-Maximizing Allocations under Three Regimes

Table 1: Notations for the Allocations of Services between Two Airports

a_2 a_1	ID	I	D	N
ID	(ID, ID)	(ID, I)	(ID, I)	(ID, N)
I	(I, ID)	(I, I)	(I, D)	(I, N)
D	(D, ID)	(D, I)	(D, D)	(D, N)
N	(N, ID)	(N, I)	(N, D)	(N, N)

Table 2: Three Regimes and the Operators of the Airports

Regimes	Operators	
	Airport 1 (Congested)	Airport 2 (Uncongested)
Regime PP	Private firm	Private firm
Regime M	Private firm	
Regime G	Government	

Table 3: Parameter Values

b	The boundary of the City	50	(kilometers)
ρ_C	Population density of the City	164	(thousand people)
ρ_H	Population density of the Hinterland	26	(thousand people)
d^I	Frequency for service I usage	0.17	(times per a year)
d^D	Frequency for service D usage	0.73	(times per a year)
v	Value of waiting time	3	(thousand yen per an hour)
h	Operating hours of airports		(hours per a year)
t	Access cost per a unit distance	0.1	(thousand yen per a kilometer)
σ	Size of the aircraft	272	(seats)
ω^I	Marginal operation cost for service I	12188	(thousand yen per a flight)
ω^D	Marginal operation cost for service D	1740	(thousand yen per a flight)
c	Marginal congestion cost for flights	0.027	(thousand yen per a square of flight)
$\bar{C}^I$	Reservation price for service I	148	(thousand yen)
$\bar{C}^D$	Reservation price for service D	19	(thousand yen)

Table 4: The Results of the Calibration (Unit: thousand people)

	International		Domestic	
	Airport 1 (Osaka)	Airport 2 (Kansai)	Airport 1 (Osaka)	Airport 2 (Kansai)
Calibration	-	5583	6445	5204
The Passengers in 2004	-	5596	9742	2089

Table 5: The Payoff Matrix at x_1=0 (Unit: billion yen)

a_2 A_1	ID	I	D
ID	9.2, 9.9	9.2, 6.3	20.9, 3.7
I	6.6, 9.6	6.6, 6.3	18.5, 3.7
D	3.4, 22.6	3.4, 19.0	3.4, 3.7

Table 6: The Values of Four Terms in (8) at Five Locations of Airport 1 (Unit: billion yen)

Locations of airport 1	Distance b/w two airports	ΔR_1^I the opportunity cost	ΔR_2^I the concentration effect	ΔR_1^D the congestion effect	ΔR_2^D the indirect effect	Total
$x_1 = -50$	100	89.4	-77.6	-1.9	0.0	9.9
$x_1 = -25$	75	91.9	-84.3	-2.2	0.0	5.4
$x_1 = 0$	50	95.3	-92.5	-3.0	0.6	0.4
$x_1 = 10$	40	100.3	-97.6	-3.3	1.1	0.5
$x_1 = 20$	30	112.3	-111.0	-3.9	1.8	-0.8

Table 7: The Comparison of Social Surpluses among Allocations at Four Locations of Airport 1 under M (unit: billion yen)

Location of Airport 1	Allocation	Social Surplus	Social Benefit	Access	Scheduling	Congestion
$x_1 = -50$	$\boxed{\textbf{\textit{(ID, ID)}}}$	386.0	427.0	27.7	4.5	8.8
	(D, ID)	381.2	426.1	36.0	3.4	5.5
	(I, ID)	357.4	385.0	23.4	3.4	0.8
	(N, ID)	342.2	375.0	30.6	2.2	0.0
$x_1 = -25$	***(ID, ID)***	393.9	440.3	27.5	4.5	14.4
	$\boxed{\text{(D, ID)}}$	394.4	445.0	36.7	3.4	10.5
	(I, ID)	355.2	381.9	22.5	3.4	0.8
	(N, ID)	342.2	375.0	30.6	2.2	0.0
$x_1 = 0$	***(ID, ID)***	373.3	411.8	22.4	4.5	11.6
	$\boxed{\text{(D, ID)}}$	375.1	415.5	29.4	3.4	7.6
	(I, ID)	351.0	378.9	23.7	3.4	0.9
	(N, ID)	342.2	375.0	30.6	2.2	0.0
$x_1 = 25$	(ID, ID)	330.0	358.4	16.4	4.5	7.5
	(D, ID)	335.8	364.2	21.4	3.4	3.6
	$\boxed{\text{(I, ID)}}$	345.0	375.7	26.1	3.4	1.2
	(N, ID)	342.2	375.0	30.6	2.2	0.0

Note: the allocation $\boldsymbol{(a_1, a_2)}$ corresponds to the equilibrium; the allocation $\boxed{(a_1, a_2)}$ corresponds to the surplus-maximizing.

Table 8: The Comparison of Social Surpluses among Allocations at Four Locations of Airport 1 under G (unit: billion yen)

Location of Airport 1	Allocation	Social Surplus	Social Benefit	Access	Scheduling	Congestion
$x_1 = -50$	$\boxed{\text{(ID, ID)}}$	675.9	1149.2	447.2	4.5	21.6
	(D, ID)	667.6	1138.3	457.4	3.4	9.9
	(N, ID)	640.6	1123.3	480.5	2.2	0.0
$x_1 = -25$	(ID, ID)	665.8	1131.3	435.2	4.5	25.8
	$\boxed{\text{(D, ID)}}$	667.3	1123.6	440.4	3.4	12.5
	(N, ID)	640.6	1123.3	480.5	2.2	0.0
$x_1 = 0$	(ID, ID)	641.5	1108.2	422.8	4.5	39.4
	$\boxed{\text{(D, ID)}}$	656.6	1094.1	418.7	3.4	15.4
	(N, ID)	640.6	1123.3	480.5	2.2	0.0
$x_1 = 25$	(ID, ID)	594.3	1080.6	416.4	4.5	65.4
	(D, ID)	631.3	1046.5	382.9	3.4	28.9
	$\boxed{\text{(N, ID)}}$	640.6	1123.3	480.5	2.2	0.0

Note: the allocation $\boxed{(a_1, a_2)}$ corresponds to the optimal.

Table 9: The Comparison of $\gamma^*(Z)$ and $\delta^*(Z)$ ($Z=PP, M$) at Five Locations of Airport 1

		$x_1 = -50$	$x_1 = -25$	$x_1 = 0$	$x_1 = 25$	$x_1 = 50$
PP	$\gamma^*(PP)$	0.68	0.79	0.77	0.82	0.83
	$\delta^*(PP)$	215.6	142.9	154.1	112.2	110.4
M	$\gamma^*(M)$	0.57	0.59	0.57	0.52	0.53
	$\delta^*(M)$	289.9	273.4	283.3	304.8	298.4

(Note: The unit for $\delta^*(Z)$ is a billion yen.)

Table 10: The Comparison of the Social Surplus and Airport Charges at x_1=0

Regime	Allocation		Airport Charges (unit: thousand yen)				Social Surplus (unit: billion yen)
			International		Domestic		
			Airport 1	Airport 2	Airport 1	Airport 2	
PP	$(a_1^*(PP), a_2^*(PP))$ $(a_1^O(PP), a_2^O(PP))$	(ID, ID)	7492	7187	1714	2181	502.5
M	$(a_1^*(M), a_2^*(M))$	(ID, ID)	18230	17736	1941	2106	355.9
	$(a_1^O(M), a_2^O(M))$	(D, ID)	-	17643	1975	2164	361.3
G	$(a_1^O(G), a_2^O(G))$	(D, ID)	-	-17643	-4925	-5416	656.6