Allocation of Services to 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. Through the privatization of airports, there are various types of airport operation. Consequently, we set three alternative airport operations: (PP) separate operation by two private firms; (M) integrated operation by a single private firm; (G) integrated operation by the government. Moreover, airport operators face the several types of regulations such as on airport charges, allocation of services, or both: therefore, we examine three types of allocation such as the decentralized decision-making by airport operators on the provision of service, the airport charges, and both. By comparing these three allocations within and among regimes, this paper investigates two issues: i) the relationship between the allocation and the location of airports; ii) the relationship between the allocation and the types of airport operations.

Keywords: Allocation of services, airport operation, regulation, location of airports

1. Introduction

It is observed that some metropolitan areas have multiple airports each of which 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 multiple airports might be the result of the regulation by the government or of the decentralized decision-making by airport operators. Also note that the airport privatization results in various types of airport operation such as public and private. This paper investigates the allocation of services among airports and the relationship between the allocation and the airport operation. Moreover, multiple airports in a metropolitan area arise as a result of new airport construction to address the shortage of capacity in the existing airports. Consequently, we also need to focus on the 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). De Borger and Van Dender (2006) developed the model of the vertical relationship between users and airports including the capacity choice of airports. As argued in Brueckner (2002), carriers are not atomistic in the congested airport: therefore, the behavior of carriers should be included in the model. From this viewpoint, Basso and Zhang (2007) introduced the behavior of carriers into the similar model to De Borger and Van Dender (2006). These two articles studied the pricing and the capacity choices of congested airports under several alternative regimes, such as separate operation by private firms and integrated operation by a single private firm. Pels et al. (2000) studied about the effect of the accessibility on the airfares and airport charges incorporating the vertical relationships among users, carriers, and airports: however, they focused on the case where airports are constrained by the average cost pricing. When airports are not congested, the allocation of services between airports is the problem to determine the number of airports providing a particular service (e. g. domestic or international flights)[1]. On the other hand, if the airport congestion exists, the congestion generates the interaction between different services provided at an airport. Consequently, we need to focus on the combination of multiple services. Van Dender (2005) focused on the competition between facility operators, including the case where two services are provided in each facility. However, he did not consider the allocation of services between facilities.

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. Our model describes the tradeoff between the accessibility, the frequencies, and the airport congestion. The accessibility is better if the service is provided at both airports. On the other hand, the frequency is larger if the service is concentrated at a single airport: as a result, however, this airport becomes more congested.

Using this model, we examine the allocation of services among airports in a metropolitan area

[1] This problem resembles to the one studied by Takahashi (2004) and Akutagawa and Mun (2005). In those two articles, providers of public service decide whether or not providing the service at its facility.

under three alternative airport operations: (1) each airport is operated by a single private firm (Regime PP); (2) a single private firm operates two airports (Regime M); (3) the government operates two airports (Regime G). Operators under each regime can set airport charges and services to be provided at their airports.

In reality, however, there exists the regulation on airport charges and services provided at airports. In consideration of the regulations, we investigate three types of allocations under each of three regimes, PP, M and G. First, we consider the case where airport operators set the services to be provided at their airports while airport charges are exogenously given. The second type is the allocation without regulation on the airport charges in which airport operators set both airport charges and the services to be provided at their airports. The third type is the surplus-maximizing allocation in which airport operators set airport charges while the government determines the allocation of services in order to maximize the social surplus. This type of allocation can be interpreted as the regulation on the allocation of services[2]. We also compare these three types of allocation within each regime and among three regimes.

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. In addition, by means of numerical simulations, this section shows the allocations under three regimes, PP, M and G, with exogenously fixed airport charges. Section 4 focuses on the case where airport operators

[2] Several studies focused on the regulation of airports due to a growing number of privatized airports. Most of these studies, however, focused on the regulation on pricing (e. g. Oum et al. (2003) and Czerny (2006)).

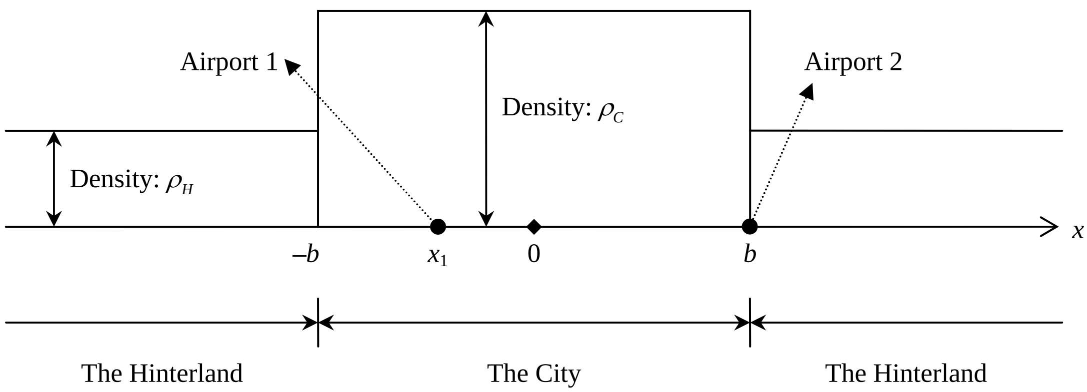
under each of three regimes, PP, M, and G, set both the services and airport charges at their airports. Section 5 focuses on the case where airport operators set the airport charges while the government determines the allocation in order to maximize the social surplus. Section 6 compares three types of allocations derived in proceeding three sections. Finally, Section 7 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 is consisted from the City and the Hinterland:

Figure 1: The Economy and the Locations of Airports



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 the 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. Their locations are exogenously given and denoted by x_1 and x_2. Without loss of generality, we assume that $x_1<x_2$. Moreover, we assume that airport 2 locates at the fringe of the City: that is, $x_2=b$. Airport 1 is congested while airport 2 is free from congestion[3]. Carriers incur the congestion cost when they utilize airport 1 while users do not.

These two airports can provide two types of services, international and domestic flights. Hereafter, they are denoted by I and D respectively. Let us denote by a_j the service provided at airport j (j=1, 2), then we have four types of services: that is, $a_j=I, D, ID, N$. Note that $a_j = ID$ implies that airport j (j=1, 2) provides services I and D: $a_j = N$ implies that airport j provides no services[4]. The allocation of services is represented by the set of services provided at two airports, (a_1, a_2). Table 1 summarizes the possible 16 allocation of services.

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

a_1 \ a_2	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)

2.2. Users

[3] This situation can be interpreted as the case where airport 2 is newly constructed to address the shortage of the capacity of airport 1. This is observed in some metropolitan areas, such as Tokyo, Osaka, and Montreal. Moreover, in these cases, the newly constructed airport locates at the fringe of the city while the existing airport locates closer to the center.

[4] We do not exclude the possibility of the allocations such as (N, N), (S, N) and (N, S), in which some services are not provided in this region. In such case, we assume that users of the services not available at both airports choose other modes such as autos or railways.

The trip demand for service S ($S=I$, D) by an individual is inelastic. Individuals make trips by service S d^S times per a given period unless the trip cost exceeds the reservation price, $\bar{C}^S$ ($S=I$, D). All users have the same value of the reservation price in consuming service S, $\bar{C}^S$. In addition, we set two assumptions: the trip demand for service D, d^D, is larger than that for service 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 service S at airport j for a user located at x, $C_j^S(x)$, is defined as:

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

The first term of the RHS in Eq. (1) represents the access cost to airport j in which t is the access cost per a distance. The second term of the RHS is the average waiting time cost at airport j in which F_j^S is the frequency of service S at airport j. The average waiting time cost is expressed the value of waiting time, v, multiplied by the average waiting time for service S at airport j, $h/4F_j^S$, for a given operating hours of airport j, h. The last term of the RHS is the fare for service S at airport j.

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

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

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 $\overline{z}_j^S$ and $\underline{z}_j^S$ respectively represents the right-side and left-side of the market boundaries for service S at airport j. Solving Eq. (3) for the fare of service S at airport j, P_j^S, we obtain the inverse demand function for service S at airport j[5].

On the relationship between boundaries, we have two cases:

i) When service S is only provided at airport j, or when two airports provide service S and these markets are segregated, the trip cost is equalized to the reservation price at the boundaries: $C_j^S\left(\overline{z}_j^S\right)=C_j^S\left(\underline{z}_j^S\right)=\overline{C}^S$.

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

2.3. Carriers

We assume that there are two carriers in each market S (S=I, D). Let us denote by f_j^{Sk} the number of flights at airport j (j=1, 2) operated by carrier k (k=1, 2) in market S. We assume that 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[6]. Consequently, the frequency of service S at airport j perceived by users, F_j^S, is equal to f_j^{Sk}.

[5] Details are shown in Appendix A.
[6] This result is based on the minimum product differentiation by Hotelling (1929).

All flights from each airport are served with full capacity, σ. In addition carrier k providing service S at airport j faces the inverse demand $p_j^S(\mathbf{f^{Sk}} \mid \mathbf{f^{Sl}})$ in which $\mathbf{f^{Sk}} = (f_1^{Sk}, f_2^{Sk})$ and $\mathbf{f^{Sl}} = (f_1^{Sl}, f_2^{Sl})$ respectively represent the vectors of frequencies provided by carriers k and l in market S. As a result, each carrier providing service S earns $p_j^S(\mathbf{f^{Sk}} \mid \mathbf{f^{Sl}})\sigma$ per a flight from airport j. A flight of service S from airport j generates the marginal cost m_j^S and the airport charge r_j^S. Therefore, the profit for carrier k providing service S from airport j, π_j^{Sk}, is,

$$\pi_j^{Sk}\left(\mathbf{f^{Sk}} \mid \mathbf{f^{Sl}}\right) = \left[\, p_j^S\left(\mathbf{f^{Sk}} \mid \mathbf{f^{Sl}}\right)\sigma - m_j^S - r_j^S \,\right] f_j^{Sk}. \tag{4}$$

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. In addition, we assume that the competition between two carriers in market S is the Cournot type: each carrier chooses the frequency.

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 profit maximization problem for carrier k providing service S[7]:

i) If carriers providing service S are allowed to operate at a single airport j (j=1, 2), we have

[7] If carrier k providing service S operates only at airport 1, or if carrier k providing service S operates at both airports, the profit might depend on the frequencies of carriers providing the other service $T \neq S$ as well as the frequencies of the rival, l, due to the congestion at airport 1.

$f_i^{Sk} = f_i^{Sl} = 0\,(i \neq j)$. Consequently, carrier k sets only the frequency at airport j, f_j^{Sk}, to maximize the profit $\pi_j^{Sk}(\mathbf{f^{Sk}} \mid \mathbf{f^{Sl}})$.

ii) If carriers providing service S are allowed to operate at two airports, carrier k sets the frequencies at two airports, f_1^{Sk} and f_2^{Sk}, to maximize the sum of profits in two airports $\sum_j \pi_j^{Sk}(\mathbf{f^{Sk}} \mid \mathbf{f^{Sl}})$.

We consider the behavior of carriers providing service S in case of i) as an example. Let us denote by $\mathbf{f^{Sk*}}$ carrier k's Nash Equilibrium frequency at airport j, then, it satisfies:

$$\pi_j^{Sk}\left(\mathbf{f^{Sk*}} \mid \mathbf{f^{Sl*}}\right) = \max_{f_j^{sk}} \pi_j^{Sk}\left(\mathbf{f^{Sk}} \mid \mathbf{f^{Sl*}}\right), \quad \text{for } S=I, D \text{ and } k=1, 2,$$

where $\mathbf{f^{Sk*}} = (f_j^{Sk*}, 0)$ and $\mathbf{f^{Sl*}} = (f_j^{Sl}, 0)$. Moreover, since the equilibrium frequency of carrier k at airport j depends on the airport charges, $\mathbf{r_j} = (r_j^I, r_j^D)$, and the services to be provided at both airports, a_j (j=1, 2), the equilibrium frequency of carrier k providing service S at airport j is expressed as $f_j^{Sk*}(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2)$. In case of ii), carriers set the frequencies at two airports in order to maximize the sum of the profits from two airports. Following the same procedure described above, we obtain the equilibrium frequency of carrier k at each airport.

2.4. Airports

There are two types of operators, the private firm and the government. The private firm maximizes the airport charge revenue by setting the services provided at its airport, the airport charges, or both, while the government maximizes the social surplus.

This paper examines three alternative regimes of the airport operation as summarized below:

i) Regime PP: in this regime, each airport is operated by a single private firm.

ii) Regime M: in this regime, a single private firm operates two airports.

iii) Regime G: in this regime, the government operates two airports.

2.5. The Sequence of the Game

In following three sections, Sections 3, 4, and 5, we assume that, in the first stage, services to be provided, a_j (j=1, 2), at each airport is chosen. In the second stage, the airport charge, r_j^S, at each airport is determined. In the third stage, carriers determine the number of flights at each airport, f_j^{Sk}, as described in Subsection 2.3. After that, as explained in Subsection 2.2, in the final stage, all users choose whether or not using service *S*. In addition, users who use service *S* determine which airport to use if service *S* is provided at both airports.

The difference among following three sections is attributed to who chooses services to be provided, a_j (j=1, 2) and the the airport charge, r_j^S:

i) In Section 3, the second stage is omitted since airport charges are exogenously fixed. In the first stage, airport operators set services to be provided at their airports;

ii) In Section 4, in the first stage, airport operators set services at their airports. In the second stage, airport operators determine airport charges;

iii) In Section 5, in the first stage, the government sets the services provided at two airports in order to maximize the social surplus. In the second stage, airport operators set airport charges at their airports.

In the following three sections, by means of numerical simulations, we derive the solutions.

3. Choices by Operators with Parametric Airport Charges

3.1. Parameters

We set the values of parameters so that the solutions of the model are not far from the observed value in the real world. First, we consider the case where airport charges for service S, r_j^S, are set as:

$$r_1^I = r_2^I = 1537.39 \text{ (thousand yen)},$$

$$r_1^D = r_2^D = 718.08 \text{ (thousand yen)}.$$

These values are the airport charges for services I and D at Kansai International Airport. Other parameter values are summarized in Table 2 below:

Table 2: 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 a year)
h	Operating hours of airport	5475	(hours per a year)
t	Access cost per a unit distance	0.01	(thousand yen per a kilometer)
σ	Size of the aircraft	272	(seats)
ω^I	Marginal operation cost for service I	13522	(thousand yen per a flight)
ω^D	Marginal operation cost for service D	2015	(thousand yen per a flight)
c	Marginal congestion cost for flights	0.01	(thousand yen per a square of flight)
$\bar{C}^I$	Reservation price for service I	142	(thousand yen)
$\bar{C}^D$	Reservation price for service D	29	(thousand yen)

We set the size of the City as the segment of [–50, 50]. Population density of the City ρ_C is calibrated so that the population of the City with the size of 100 square kilometers is equal to that of the Osaka Metropolitan Area. The population density of the Hinterland ρ_H, on the other hand, is the average population density of Japan[8].

To calibrate the access cost per a distance, *t*, we calculate the access cost to Kansai International Airport by railway for 50 largest cities in Osaka Metropolitan Area. According to these values, we use the weighted average of the access costs per a kilometer for 50 cities as 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. As Pels and Verhoef (2004) explained, 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 costs for providing international and domestic flights. Using the financial data of JAL and ANA for 2004, we calculate the costs for providing each service *S* (*S*=*I*, *D*) according to the share of each service[9] so that the sum of them is equal to 95 % of the total operating cost. Using the calculated total cost for providing each service, *S*, we set the average cost per a flight for each service, *S*, as the value of parameter ω^S (*S*=*I*, *D*). To calibrate the value of parameter *c*, we set 5 % of the total operating costs as the total delay costs. We set the value of *c* so that the total congestion cost based on this model is equal to the sum of total delay costs.

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

9 The share of each service is equal to that of revenue passenger kilometers.

Based on these parameter values[10], we derive the allocations in the following three subsections.

3.2. Regime PP

Under this regime, each airport is operated by a single private firm. Given the airport charges r_j^S, the operator of airport j (j=1, 2) chooses the services to be provided at airport j, a_j, so as to maximize the revenue, $\tilde{R}_j(a_1, a_2; PP)$:

$$\tilde{R}_j\left(a_1, a_2; PP\right) = \sum_{S,k} r_j^S f_j^{Sk}\left(\mathbf{r_1}, \mathbf{r_2}; a_1, a_2\right).$$

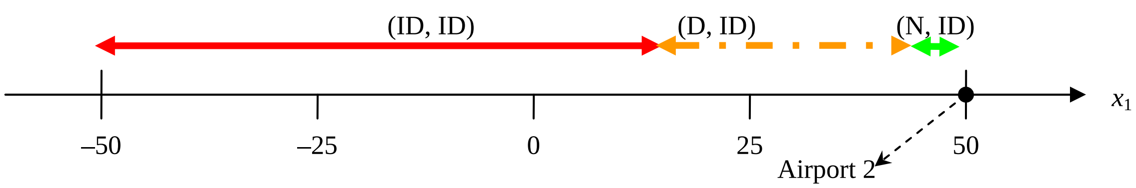
The operator of airport j sets the services to be provided at airport j, a_j, so as to maximize the revenue from its airport, $\tilde{R}_j(a_1, a_2; PP)$. Let us denote by $\tilde{a}_j(PP)$ services chosen by the operator of airport j (j=1, 2) then, given a_i, this satisfies:

$$\tilde{R}_j\left(\tilde{a}_j\left(PP\right), \tilde{a}_i\left(PP\right); PP\right) \geq \tilde{R}_j\left(a_j, \tilde{a}_i\left(PP\right); PP\right) \text{ for } {}^\forall a_j \neq \tilde{a}_j\left(PP\right),$$

where $\tilde{a}_i\left(PP\right)$ is the service to be provided at the other airport i.

The allocations under Regime PP in various locations of airport 1 are summarized in the following figure:

Figure 2: The Allocation under Regime PP with Parametric Airport Charges $(\tilde{a}_1(PP), \tilde{a}_2(PP))$



As shown in Figure 2, the allocation changes from (ID, ID) to (N, ID) through (D, ID) as two airports become closer.

[10] Explanation of the rest of parameter values and the result of the calibration are summarized in Appendix B.

When two airports are distant, the dominant strategy for each airport operator is ID as shown in Table 4:

Table 3: The Payoff Matrix at x_1=0 (Unit: billion yen)

a_1 \ a_2	ID	I	D
ID	3.51, 2.86	4.51, 1.57	4.92, 1.34
I	1.79, 4.47	1.79, 1.51	3.22, 2.96
D	1.81, 4.52	2.81, 3.25	1.39, 1.27

Hence, the allocation becomes (ID, ID).

When the distance between two airports is moderate, the allocation becomes (D, ID). To explain this, we compare the user costs of two airports for service I at x_1:

$$C_1^I(x_1) - C_2^I(x_1) = \left(P_1^I - P_2^I\right) + \left(\frac{vh}{4F_1^I} - \frac{vh}{4F_2^I}\right) - t\left|x_1 - b\right|.$$

The first bracket terms represent the difference in fares between two airports. The second bracket and the last terms respectively represent the differences in the waiting time costs and in the access costs. Table 4 below compares these three terms at three locations of airport 1:

Table 4: Difference in Trip Cost for Service I at Three Locations of Airport 1 (Unit: thousand yen)

x_1	$P_1^I - P_2^I$	$\frac{vh}{4F_1^I} - \frac{vh}{4F_2^I}$	$-t\left\|x_1 - b\right\|$	Total
15	3.19	-0.11	-3.5	-0.42
20	3.32	-0.13	-3	0.19
25	3.45	-0.15	-2.5	0.8

According to Table 4, in absolute value, the differences in fares increases while the difference in sum of average waiting time and access costs decrease. Consequently, when x_1 is larger than 20, service I at airport 1 loses its service I market because of the increase in the difference in fares.

To explain the reason why the difference in fares is generated, we decompose the fare of service I at each airport j as[11]:

$$P_j^I = \frac{m_j^I + r_j^I}{\sigma} \times \eta_j^I,$$

where η_j^I represents the markup at airport j. Following table compares the marginal cost and the markup at each airport:

Table 5: Comparison of Marginal Costs and Markups between Two Airports (Unit: thousand yen)

x_1	P_1^I			P_2^I		
	Fare	Marginal cost	Markup	Fare	Marginal cost	Markup
15	94.0	54.8	1.72	90.8	50.6	1.79
20	94.0	54.7	1.72	90.7	50.6	1.79
25	94.0	54.7	1.72	90.5	50.6	1.79

As shown in this table, while the markup is higher at airport 2 than at airport 1, the marginal costs at airport 1 is higher than at airport 2 due to the congestion. According to Table 5, that airport 1 loses its service I market since the congestion increases the fare for service I at airport 1. Due to the similar reason, when two airports are sufficiently close (x_1 is around 50), the allocation becomes (N, ID).

By stopping the provision of service I, the operator of airport 1 can reduce the congestion. Reduction in the congestion increases the revenue from service D at airport 1. However, unless the operator of airport 1 loses its service I market, the operator does not stop providing service I because the increase in the revenue from service D cannot recover the loss of the revenue from

[11] The fare for service I at each airport j can be rewritten as:

$$P_j^I = \frac{m_j^I + r_j^I}{\sigma} \times \eta_j^I,$$

where η_j^I represents the markup at airport j.

service I due to stopping the provision of service I.

3.3. Regime M

Under this regime, a single private firm operates two airports. Given the airport charges, the operator determines the services provided at both airports (a_1, a_2) in order to maximize the sum of revenue in two airports, $\tilde{R}(a_1, a_2; M)$:

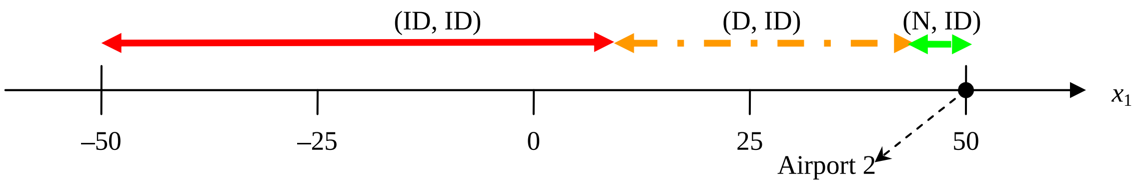
$$\tilde{R}\left(a_1, a_2; M\right) = \sum_{j,S,k} r_j^S f_j^{Sk}\left(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2\right).$$

Denote by $(\tilde{a}_1(M), \tilde{a}_2(M))$ the allocation chosen by the operator, which is characterized as follows:

$$\left(\tilde{a}_1(M), \tilde{a}_2(M)\right) = \arg\max_{a_1, a_2} \tilde{R}\left(a_1, a_2; M\right).$$

The allocations under Regime M $(\tilde{a}_1(M), \tilde{a}_2(M))$ in different locations of airport 1 are shown in Figure 3.

Figure 3: The Allocation under Regime M with Parametric Airport Charges $(\tilde{a}_1(M), \tilde{a}_2(M))$



As shown in this figure, the operator sets the allocation (ID, ID) if two airports are distant. The operator sets the allocation (D, ID) when the distance between two airports is moderate. When two airports are sufficiently close, the allocation (N, ID) is chosen since all individuals use airport 2 when they consume service D.

To understand the reason why the operator changes the allocation from (ID, ID) to (D, ID), we decompose the change in revenue when the operator changes the allocation from (ID, ID) to (D, ID):

$$\tilde{R}(D, ID; M) - \tilde{R}(ID, ID; M) = \Delta R_1^I + \Delta R_2^I + \Delta R_1^D + \Delta R_2^D, \tag{5}$$

where ΔR_j^S represents the change in the revenue from service *S* at airport *j*:

$$\begin{aligned}
\Delta R_1^I &\equiv -R_1^I(ID, ID; M), \\
\Delta R_2^I &\equiv R_2^I(D, ID; M) - R_2^I(ID, ID; M), \\
\Delta R_1^D &\equiv R_1^D(D, ID; M) - R_1^D(ID, ID; M), \\
\Delta R_2^D &\equiv R_2^D(D, ID; M) - R_2^D(ID, ID; M).
\end{aligned}$$

The first term of the RHS in (5), ΔR_1^I, is the loss of revenue due to stopping the provision of service I at airport 1. 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. Because providing a single service (D) at airport 1 imposes smaller congestion cost on the carriers of service D operating at airport 1, they change the number of flights: consequently, the revenue from service D at airport 1 changes. This change in service D at airport 1 affects service D at airport 2: as a result, it indirectly affects the revenue from service D at airport 2. This is captured by the last term of the RHS in (5), ΔR_2^D.

Table 6 shows the values of four terms in (5) for three locations of airport 1.

Table 6: The Values of Four Terms in (5) at Three Locations of Airport 1 (Unit: billion yen)

Locations of airport 1	Distance b/w two airports	ΔR_1^I the loss of reveue	ΔR_2^I the concentration effect	ΔR_1^D the congestion effect	ΔR_2^D the indirect effect	Total
$x_1 = 0$	50	–16.1	15.6	0.5	–0.4	–0.3
$x_1 = 5$	45	–16.2	15.8	0.5	–0.4	–0.2
$x_1 = 10$	40	–16.0	15.7	0.9	–0.3	0.3

Stopping the provision of service I at airport 1 reduces the congestion. As a result, carriers providing service D shift some of flights from airport 2 to airport 1 since airport 1 has an advantage of the location: therefore the revenue from service D at airport 1, ΔR_1^D, increases while the revenue at airport 2, ΔR_2^D, decreases. As a whole, the change in the allocation from (ID, ID) to (D, ID) increases the sum of revenues from service D at two airports. On the contrary, at all three locations of airport 1, the revenue from service I decreases when the operator changes the allocation from (ID, ID) to (D, ID) because stopping the provision of service I at airport 1 downscales the market of service I. As shown in Table 6, the operator changes the allocation from (ID, ID) to (D, ID) if the operator can recover the loss of the revenue from service I, $\Delta R_1^I + \Delta R_2^I$, by the increase in the revenue from service D, $\Delta R_1^D + \Delta R_2^D$.

3.4. Regime G

In this subsection, we consider the case where the government operates both airports. The allocation is set in order to maximize the social surplus, $SW(a_1, a_2; G)$:

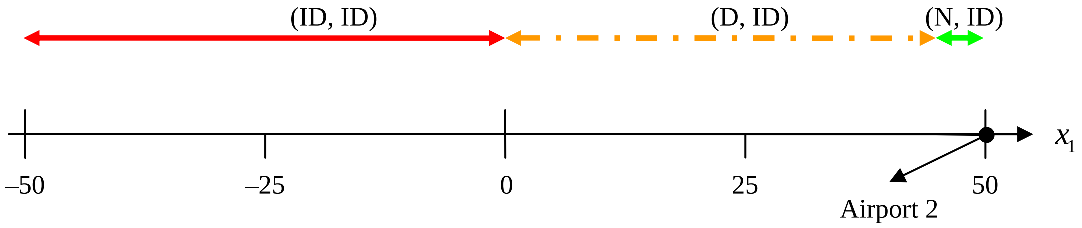
$$SW\left(a_1, a_2; G\right) = \sum_{S,j} \int q_j^S\left(x\right)\left[\bar{C}^S - C_j^S\left(x\right)\right] dx + \sum_{S,k} \pi^{Sk} + \sum_{S,j} R_j^S, \tag{6}$$

where, starting from the left, three terms in the RHS respectively represent the consumer surplus, the sum of carriers' profits, and the airport charge revenue. Denote by $(\tilde{a}_1(G), \tilde{a}_2(G))$ the allocation set by the government which is characterized as follows:

$$\left(\tilde{a}_1(G), \tilde{a}_2(G)\right) = \arg\max_{a_1, a_2} SW\left(a_1, a_2; G\right).$$

The allocations under Regime G, $(\tilde{a}_1(G), \tilde{a}_2(G))$, in different locations of airport 1, x_1, are shown in the following figure:

Figure 4: The Allocation under Regime G with Parametric Airport Charges $(\tilde{a}_1(G), \tilde{a}_2(G))$



According to Eqs (1) and (4), we can rewrite Eq. (6) as follows:

$$SW\left(a_1, a_2; G\right) = \sum_{S,j,k}\left(\sigma\bar{C}^S - \omega^S\right) f_j^{Sk}\left(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2\right) - \sum_{S,j} t \int_{\underline{z}_j^S}^{\bar{z}_j^S} q_j^S\left(x\right)\left|x - x_j\right| dx$$

$$-\frac{vh\sigma}{2}\sum_S \delta^S\left(a_1, a_2\right) - c\left(\sum_{s,k} f_1^{Sk}\left(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2\right)\right)^2. \tag{7}$$

where $\delta^S\left(a_1, a_2\right)$ is the number of airports providing service S[12]. In Eq. (7), the first term of the RHS is the total benefit of the allocation (a_1, a_2): we call this the social benefit. The second term represents the total access cost under the allocation (a_1, a_2). The third term is the total scheduling cost. The last term is the total congestion cost under the allocation (a_1, a_2).

The allocation (ID, ID) minimizes the total access cost while it maximizes the total scheduling cost. As a result, when the allocation changes from (ID, ID) to (D, ID), the government faces the

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[12] When two airports provide service S (S=I, D) or two services, ID, then, $\delta^S\left(a_1, a_2\right) = 2$: if one of two airports provide service S or two services, ID, while the other provide service $T\,(T \neq S)$ or none of services, N, then, $\delta^S\left(a_1, a_2\right) = 1$: if two airports provide only the other service T or none of services, N, then, $\delta^S\left(a_1, a_2\right) = 0$.

increase in the total access cost and the decrease in the total scheduling cost. In addition, under the allocation (D, ID), the congestion at airport 1 is smaller than under (ID, ID). The reduction in the congestion at airport 1 affects two components of the social surplus, the total congestion cost and the social benefit. Since under the allocation (D, ID), the number of services at airport 1 is reduced, the total congestion cost is smaller than under (ID, ID). In addition to this, the reduction in the congestion at airport 1 makes carriers providing service D shift some of flights from airport 2 to airport 1 because of the advantage of the location of airport 1. As a result, the social benefit of service D increases under the allocation (D, ID). On the other hand, the social benefit of service I decreases under the allocation (D, ID) because service I loses the market of airport 1.

Table 7 below shows the differences in four components of social surplus between under the allocations (ID, ID) and (D, ID):

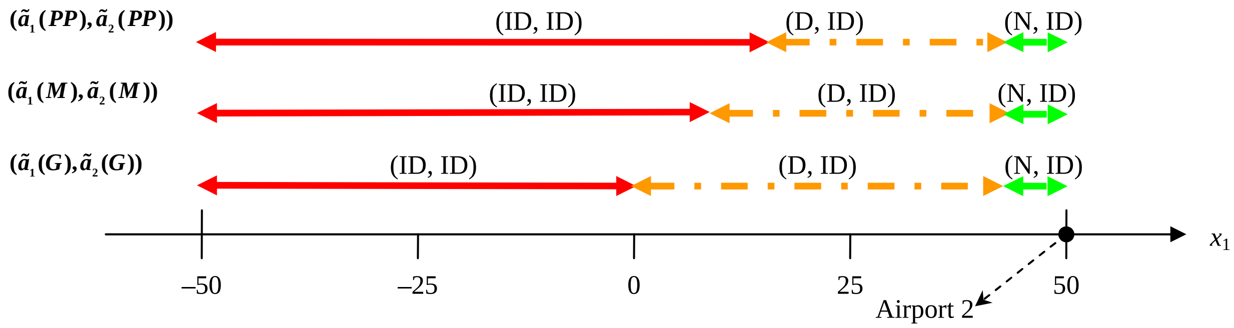
<<Table 7 about here>>

As shown in Table 7, although the sum of the differences in social benefit and congestion cost is positive at all locations of airport 1, the allocation changes from (ID, ID) to (D, ID) at $x_1 = 5$. This is because the loss of social benefit for service I and the increase in the total access cost is recovered by the reduction in the congestion and scheduling costs.

3.5. Comparison

Figure 5 shows the comparison of the allocations among three regimes described in proceeding three subsections.

Figure 5: Comparison of the Allocations with Parametric Airport Charges



The results under three regimes are qualitatively similar. As the distance between two airports becomes closer, the allocation changes from (ID, ID) to (N, ID) through (D, ID). However, the domain of (ID, ID) is the largest under Regime PP while it is the smallest under Regime G. Under Regime PP, the operator of airport 1 does not stop providing service I unless it loses the market of service I because the loss of the revenue from service I dominates the increase in the revenue from service D due to the reduction in the congestion. On the contrary, under Regime M, the operator recovers the loss of the revenue from service I at airport 1 by the increase in the revenue at airport 2. As a result, the operator stops providing service I at airport 1 before airport 1 loses the market of service I.

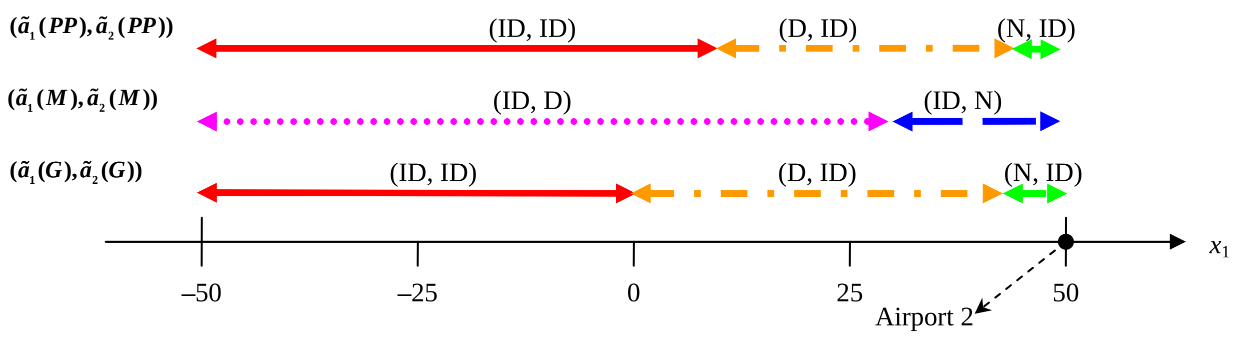
The domain of (ID, ID) under Regime M is still larger than the one under Regime G. Under Regime M, since the airport charges are exogenously given, the monopolistic operator maximizes the sum of revenues by maximizing the total number of flights provided at both airports. Consequently, the monopolistic operator only cares about the effect of the congestion on the number of flights. Also note that, as shown Eq. (7), the maximization of the total number of flights results in the maximization of the social benefit. Therefore, under Regime M, the operator considers the effect of the congestion on the social benefit while the government takes into account the congestion costs incurred by carriers, the access cost, and the scheduling cost as well as the effect of the congestion on the social benefit.

In basic case as described above, we have assumed that airport charges at both airports are equalized. In the rest of this subsection, we consider the case where airport charges differ between airports. More precisely, we set airport charges as follows:

$$r_1^I = 1984.24 \text{ (thousand yen)},$$
$$r_2^I = 1537.39 \text{ (thousand yen)},$$
$$r_1^D = 897.60 \text{ (thousand yen)},$$
$$r_2^D = 718.08 \text{ (thousand yen)}.$$

In this case, airport charges at airport 1 are 1.25 times as high as those at airport 2. Following figure shows the allocations under three regimes:

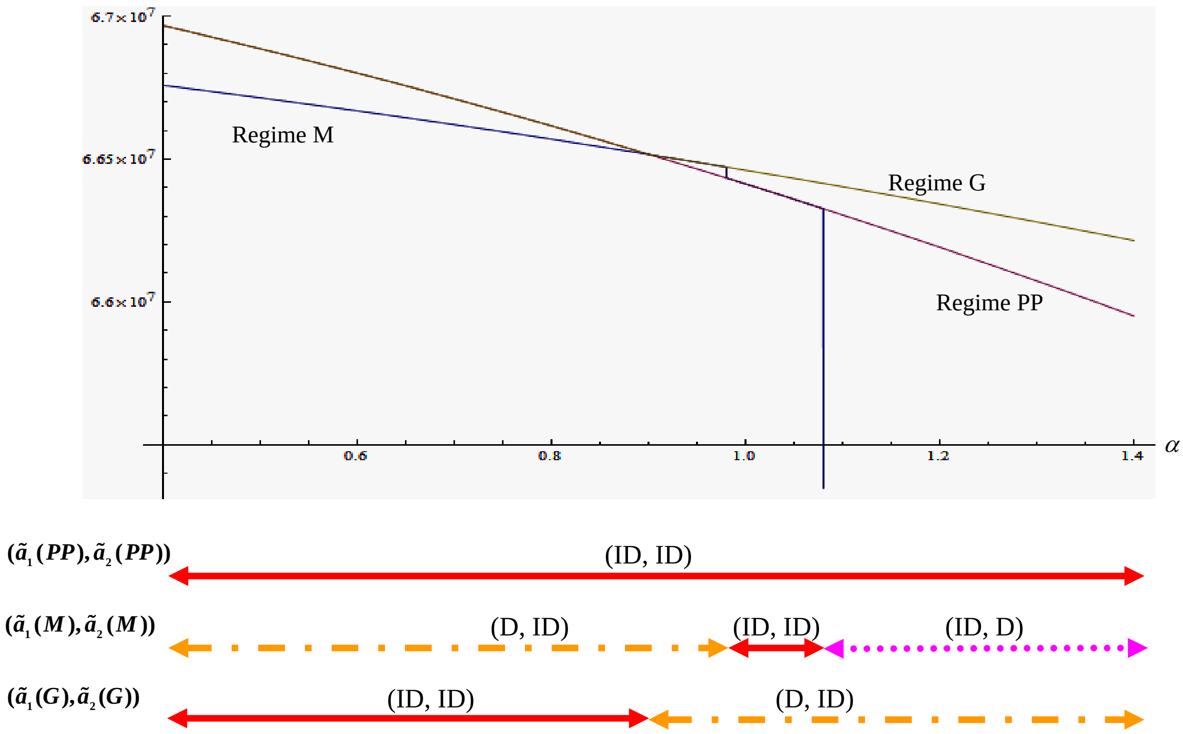
Figure 6: Comparison of the Allocations with Parametric Airport Charges



By comparing with Figure 5, the allocation under Regime M changes drastically. In Figure 5, the allocation under Regime M changes from (ID, ID) to (N, ID) through (D, ID) while, in Figure 6, the allocation changes from (ID, D) to (ID, N). In Figure 6, the monopolistic private operator always allocates two services, ID, to airport 1 because the airport charges at airport 1 is sufficiently high so that the operator can recover the loss of the revenue due to the congestion.

In addition to this, according to Figures 5 and 6, as the differences in airport charges between two airports become larger, we can expect that the social surplus under Regime M becomes inferior to the one under Regime PP. To confirm this expectation, we plot the change in social surpluses under three regimes as α changes in the following figure:

Figure 7: Change in Social Surpluses under Three Regimes at x_1=0.



According to Figure 7, the allocation under Regime M is at least as efficient as the one under Regime PP when α is around 1.0. However, as the difference in airport charges becomes larger, the allocation under Regime M is inferior to the one under Regime PP. This is because the monopolistic operator tends to allocate two services to the airport where higher airport charges are set.

4. Allocations without Regulations on Airport Charges

In this section, we consider the case where each operator under three regimes, PP, M and G, sets both the airport charges and the services provided at their airports.

4.1. Regime PP

Under this regime, each airport is operated by a single private firm. The operator of airport j (j=1, 2) chooses the services to be provided at airport j, a_j, then the airport charges, $\mathbf{r_j}$, so as to maximize the revenue, R_j:

$$R_j\left(\mathbf{r_j},\mathbf{r_i};a_1,a_2\right)=\sum_{S,k} r_j^S f_j^{Sk}\left(\mathbf{r_j},\mathbf{r_i};a_1,a_2\right). \quad (8)$$

Let us denote by $\mathbf{r_j^*}$ the vector of the airport charges set by the operator j at Nash Equilibrium, then it satisfies:

$$R_j\left(\mathbf{r_j^*},\mathbf{r_i^*};a_1,a_2\right)=\max_{\mathbf{r_j}}\left\{R_j\left(\mathbf{r_j},\mathbf{r_i^*};a_1,a_2\right) \mid \text{s.t. } C_j^S\left(x_j\right)\le C_i^S\left(x_j\right) \text{ for } S=I,D\right\}, \quad (9)$$

where $\mathbf{r_i^*}$ is the vector of the Nash Equilibrium airport charges set by the other operator i. In (9), the constraint implies that the operator of airport j plays the strategy of protecting its service S market if it faces the undercutting by its competitor i. Since the equilibrium airport charge depends on the allocation of services, (a_1, a_2), we can express the equilibrium airport charge for service S at airport j under the allocation (a_1, a_2) as $r_j^{S*}\left(a_1,a_2;PP\right)$.

By using Eq. (9), the allocation without regulation, $\left(a_1^*\left(PP\right),a_2^*\left(PP\right)\right)$, satisfies the following relation:

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

where $a_i^*(PP)$ is the service chosen by the other operator under no regulation. According to the numerical simulation, we obtain the allocation under Regime PP without regulations as:

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

As explained in Section 3, the dominant strategy for each airport is providing two services, ID unless operators lose their markets. Moreover, as shown in Eq. (9), each operator can adjust its airport charges in order to preserve its market area from the competitor. As a result, at any location of airport 1, the allocation under Regime PP without regulations becomes (ID, ID).

4.2. Regime M

Under this regime, a single private firm operates two airports. The operator determines the services provided at both airports (a_1, a_2), and then it sets the airport charges, ($\mathbf{r_1}$, $\mathbf{r_2}$). Let us define by $R(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2)$ the sum of revenues from airport charges under the allocation, (a_1, a_2).

Given the allocation, (a_1, a_2), the operator maximizes the revenue in setting the airport charge:

$$\max_{\mathbf{r_1},\mathbf{r_2}} R\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right). \tag{10}$$

Solving (10), we obtain the airport charges under each of 16 allocations, (a_1, a_2), without regulations as $r_j^{S*}\left(a_1,a_2;M\right)$.

Denote by $(a_1^*(M),a_2^*(M))$ the allocation under Regime M without regulation, then, this satisfies the following:

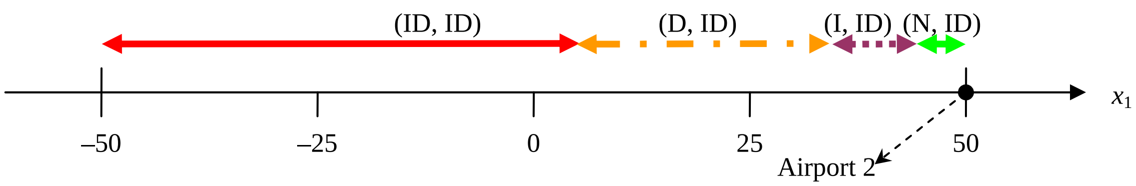
$$\left(a_1^*(M), a_2^*(M)\right) = \arg\max_{a_1, a_2} R\left(\mathbf{r}_1^*, \mathbf{r}_2^*; a_1, a_2\right),$$

where $\mathbf{r}_\mathbf{j}^*$ is:

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

According to the comparison of the operator's payoffs, the allocation under Regime M without regulation $(a_1^*(M), a_2^*(M))$ is shown in Figure 8.

Figure 8: The Allocation under Regime M without Regulations $(a_1^*(M), a_2^*(M))$



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. As explained in Section 3, when the distance between two airports is smaller than 50, the operator stops providing service I at airport 1 because the loss of the revenue from service I at airport 1 is recovered by the increase in the revenue from service D. Moreover, when airport 1 locates around 40, the operator allocates service I instead of service D to airport 1. This is because due to the higher airport charges for service I, the operator can recover the revenue from service D through the decrease in number of flights by providing service I at two airports. If two airports are sufficiently close to each other, the allocation (N, ID) is chosen.

4.3. Regime G

Under this regime, the government operates both airports. The government first determines the allocation of services (a_1, a_2), and then it sets the airport charges, ($\mathbf{r_1}$, $\mathbf{r_2}$). Let us denote by $SW(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2)$ the social surplus under the allocation (a_1, a_2).

Given the allocation, this operator sets the airport charge, ($\mathbf{r_1}$, $\mathbf{r_2}$), to maximize the social surplus $SW(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2)$. By solving this maximization problem, we obtain the surplus-maximizing airport charge for each of 16 allocations, (a_1, a_2), as $r_j^{S*}(a_1, a_2; G)$.

Denote by $(a_1^*(G), a_2^*(G))$, the allocation chosen by the government, then it satisfies:

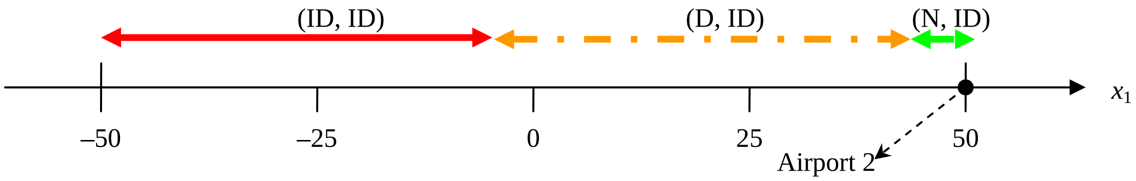
$$\left(a_1^*(G), a_2^*(G)\right) = \arg\max_{a_1, a_2} SW\left(\mathbf{r}_1^*, \mathbf{r}_2^*; a_1, a_2\right),$$

where $\mathbf{r}_\mathbf{j}^*$ is:

$$\mathbf{r}_\mathbf{j}^* = \left(r_j^{I*}\left(a_1, a_2; G\right), r_j^{D*}\left(a_1, a_2; G\right)\right).$$

Figure 9 shows the allocation under Regime G without regulations, $(a_1^*(G), a_2^*(G))$.

Figure 9: The Allocation under Regime G without Regulations $(a_1^*(G), a_2^*(G))$

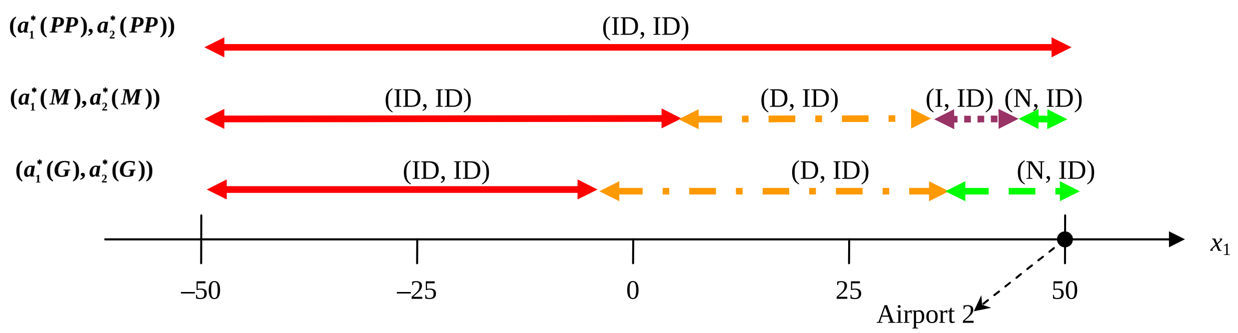


According to this figure, as long as two airports are relatively distant, the government chooses the allocation (ID, ID): two airports provide two services. As two airports become closer, the government stops providing service I at airport 1 and chooses the allocation (D, ID) since as explained in Section 3, by stopping the provision of service I at airport 1, the government can reduce the congestion costs incurred by carriers and scheduling costs incurred by users. If two airports are sufficiently close, the government decides not utilizing airport 1 and concentrates two services in airport 2: the allocation (N, ID) is chosen.

4.4. Comparison

We show Figure 10 which compares the allocations under three regimes without regulations.

Figure 10: Comparison of the Allocations without Regulations



Under Regime PP, the allocation (ID, ID) is always realized. On the contrary, under Regimes M and G, allocations vary with the distance between two airports because each operator under these two regimes takes the congestion at airport 1 into account when they set the allocation.

As the distance between two airports becomes smaller, the congestion at airport 1 worsens since the more individuals located in the City use airport 1. In such case, each operator under Regimes M and G has an incentive to reduce the congestion at airport 1 by stopping the provision of one of two services at airport 1. The difference between the allocations under two regimes, M and G, is attributed to how much the operator values the effect of the congestion. Under Regime M, the operator considers only the effect of the congestion on the number of flights. On the other hand, the government cares about the congestion costs incurred by carriers as well as the effect of the congestion on the number of flights.

Following table compares the social surpluses under three regimes without regulations:

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

	$x_1 = -50$	$x_1 = -25$	$x_1 = 0$	$x_1 = 25$
Regime PP	675.6	690.7	622.8	598.7
Regime M	487.2	504.1	427.4	415.6
Regime G	758.5	748.3	728.7	705.5

According to this table, Regime PP gives the larger social surplus than Regime M. As shown below, the difference in the social surpluses between Regimes PP and M is due to the difference in the airport charges.

<<Table 9 about here>>

This implies that, although the operator under Regime M cares about the congestion when the operator allocates the services between two airports, no competition in airport charges between two airports results in the lower social surplus.

5. The Surplus-Maximizing Allocations

In this section, we consider the case where each operator under three regimes, PP, M, and G sets the airport charges while the government sets the allocation in order to maximize the social surplus.

5.1. Regime PP

Given the allocation, (a_1, a_2), the private firms set the airport charges to maximize the revenue as described in Subsection 4.1. In consideration of the airport charges set by the private firms, the government sets the allocation so as to maximize the social surplus. Denote by $(a_1^O(PP), a_2^O(PP))$

the allocation chosen by the government, then it is numerically obtained as:

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

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

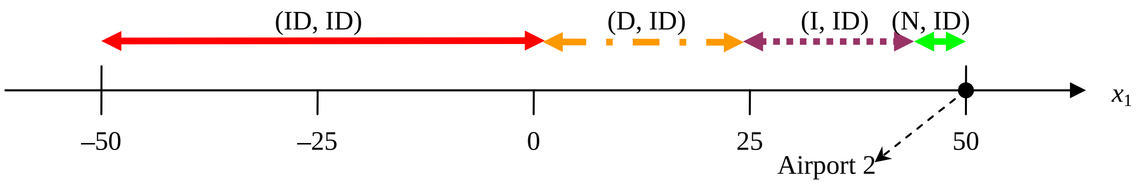
Under the allocation (ID, ID), the competition between two airports reduces the airport charges for both services: consequently, the frequencies of both services at two airports increases. The increase in the frequencies leads to the increase in the social benefits as well as the increase in the social costs, such as the congestion and the access costs[13]. However, the government sets the allocation (ID, ID) since the increase in the social benefits dominates the increase in the social costs.

5.2. Regime M

A single private operator sets airport charges at both airports given the allocation (a_1, a_2). For each of 16 allocations, the airport charge is obtained as described in Subsection 4.2. Taking this into account, the government determines the allocation, (a_1, a_2), to maximize the social surplus. Denote by $(a_1^O(M), a_2^O(M))$ the surplus-maximizing allocation under Regime M, then it becomes as shown in Figure 11:

[13] Since the reduction in the airport charge due to the competition expands the market area of each airport, 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: therefore, the access cost increases.

Figure 11: The Surplus-Maximizing Allocation under Regime M $(a_1^o(M), a_2^o(M))$



As shown in Figure 11, when two airports are sufficiently distant, the surplus-maximizing allocation under this regime becomes (ID, ID). As two airports become closer, the government reduces the services provided at airport 1. As explained in proceeding sections, as the distance between two airports becomes smaller, the congestion at airport 1 worsens. Consequently, the government stops providing one of two services in order to reduce the congestion at airport 1. In addition, the government allocates service I instead of service D to airport 1 if the distance between two airports is below 25 kilometers. Since the number of service I flights is smaller than the one for service D, the government can reduce the congestion cost by changing the service provided at airport 1 from D to I. Moreover, in our setting, the social benefit per a flight for service I, $\sigma\bar{C}^I - \omega^I$, is larger than the one for service D, $\sigma\bar{C}^D - \omega^D$. As a result, by changing the allocation from (D, ID) to (I, ID), the government can recover the loss of the social benefit through the decrease in service D flights through the reduction in the congestion cost and the increase in social benefit from service I. If two airports are sufficiently close, the government stops utilizing airport 1: as a result, the allocation becomes (N, ID).

5.3. Regime G

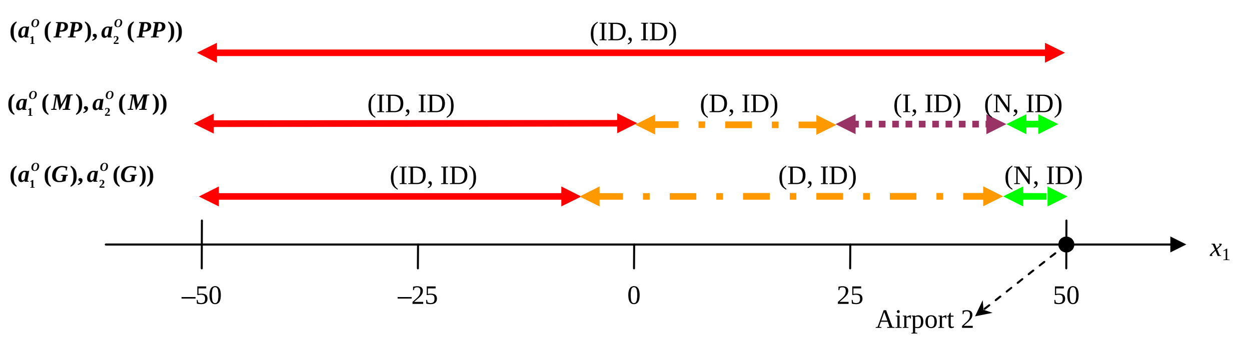
Under this regime, the regulation on the allocation implies that the government sets both airport charges and the allocation in order to maximize the social surplus. Therefore, the surplus-maximizing allocation coincides with the one without regulation shown in Subsection 4.3: that is,

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

5.4. Comparison

Figure 12 shows the comparison of the surplus-maximizing allocations under three regimes:

Figure 12: Comparison of the Allocations with Regulation on the Allocation



Under Regime PP, the allocation (ID, ID) is always observed. On the contrary, under Regimes M and G, allocations vary with the distance between two airports. However, the domain of (ID, ID) under Regime M is larger than the one under Regime G.

To explain this, we show the differences in four components of social surpluses between under (ID, ID) and (D, ID) as in the following table:

<<Table 10 about here>>

Since the government sets lower airport charges than the monopolistic operator does, the frequencies and the size of the market under Regime G becomes larger than under Regime M. As a result, under Regime G, stopping the provision of service I at airport 1 reduces the congestion and the access costs. When airport 1 locates around –5, since the reduction in the congestion, scheduling, and access costs dominates the loss of the social benefit, the allocation changes from (ID, ID) to (D, ID) under Regime G.

Under Regime M, since the operator sets high airport charges, the market size of each service is relatively small. Consequently, the allocation (ID, ID) assures the lower access cost than (D, ID). On the other hand, by stopping the provision of service I at airport 1, the government can reduce the congestion at airport 1. Reduction in the congestion has two positive effects on the social surplus, the increase in the social benefit and the reduction in the congestion cost incurred by carriers. However, when airport 1 locates around –5, the increase in the total access cost dominates the increase in the social benefit and the reduction in the congestion and scheduling costs: therefore, under Regime M, the government keeps the allocation (ID, ID).

Following table compares the social surpluses among three regimes when the allocations are regulated.

Table 11: The Comparison of Social Surpluses at Four Locations of Airport 1 (The unit: billion yen)

	$x_1 = -50$	$x_1 = -25$	$x_1 = 0$	$x_1 = 25$
Regime PP	675.6	690.7	622.8	598.7
Regime M	487.2	504.1	437.5	415.6
Regime G	758.5	748.3	728.7	705.5

According to this table, even if the government sets the allocation in order to maximize the social surplus, Regime PP gives the larger social surplus than Regime M because of the competition in airport charges between two airports. This implies that the regulation on the allocation is less effective in improving the social surplus than the competition between two airports.

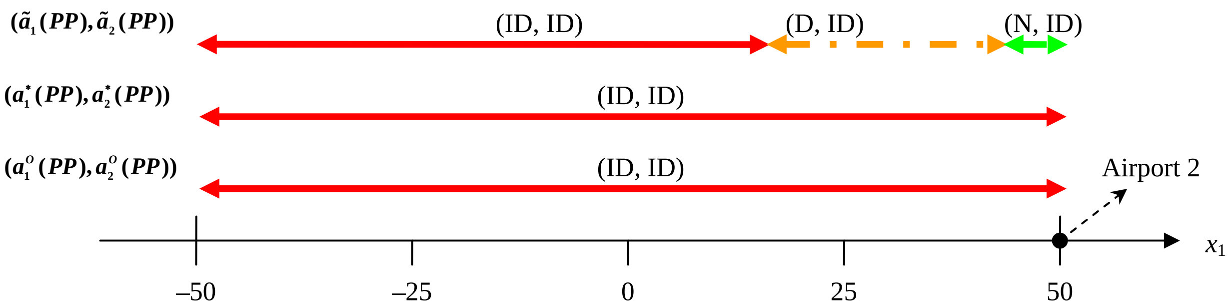
6. Comparison

By means of numerical simulations, we examined three types of allocations under three regimes, PP, M, and G. As described in Section 3, if the airport charges are exogenously fixed, the allocation under Regime M is at least as efficient as the one under Regime PP when the difference in the airport charges between airports is sufficiently small. This is because, in this case, the operator under Regime M cares about the congestion at airport 1 in order to maximize the revenue while the operator of airport 1 under Regime PP does not. On the other hand, as the difference in the airport charges between airports becomes larger, the allocation under Regime M becomes inferior to the one under Regime PP since the monopolistic operator excessively allocates two services to the airport where the higher airport charges are set.

In Section 4, we considered the case where each operator sets both airport charges and the services provided at each airport. In this case, even though the monopolistic operator takes the congestion into account, the allocation under Regime M gives lower social surplus than the one under Regime PP because of the lack of the competition in airport charges between two airports. Moreover as shown in Section 5, even if the government sets the allocation in order to maximize the social surplus under Regime M, the allocation under Regime M is inferior to the allocation without regulation under Regime PP.

In the rest of this section, we compare three types of allocations under each regime. As shown in the following figure, the allocation with the parametric airport charges, $(\tilde{a}_1(PP), \tilde{a}_2(PP))$, varies with the distance between two airports while the others are (ID, ID) at all locations of airport 1.

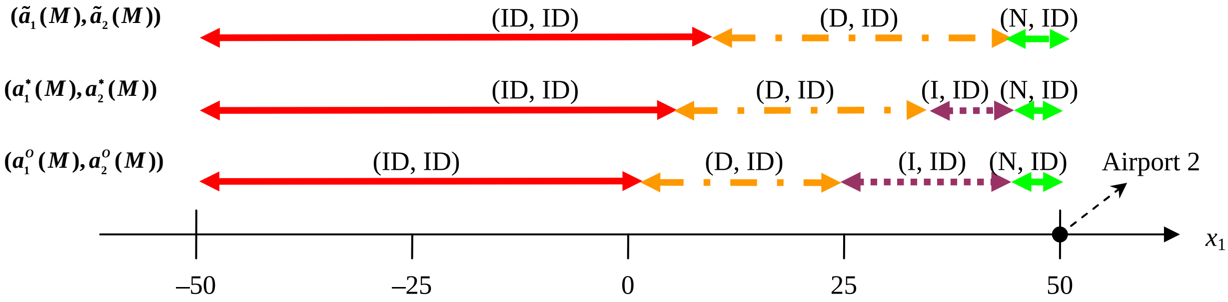
Figure 13: Comparison of the Allocations under Regime PP



This is because in the latter two allocations, airport 1 can adjust airport charges in order to preserve the markets of services I and D while airport 1 loses the markets when airport charges are exogenously given. Also note that the allocation without regulation perfectly coincides with the surplus-maximizing. As explained in Section 5, the competition in airport charges increases the social surplus through the increase in the total number of flights.

Figure 14 below compares three types of the allocations under Regime M:

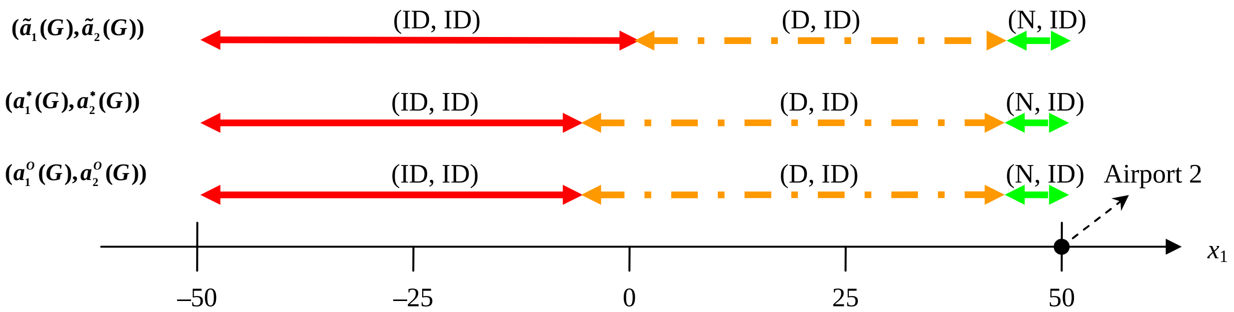
Figure 14: Comparison of the Allocations under Regime M



The difference among three types of allocations is that, in $(a_1^*(M), a_2^*(M))$ and $(a_1^o(M), a_2^o(M))$, the allocation (I, ID) is observed while, in $(\tilde{a}_1(M), \tilde{a}_2(M))$, (I, ID) is not observed. Moreover, the domain of (I, ID) is larger under $(a_1^o(M), a_2^o(M))$ than under $(a_1^*(M), a_2^*(M))$ since the government cares about the congestion cost incurred by carriers as well as the change in the total number of flights through the change in the congestion while the monopolistic operator considers only the latter effect.

Figure 15 compares three types of the allocations under Regime G:

Figure 15: Comparison of the Allocations under Regime G



Under Regime G, three types of the allocations are qualitatively similar. However, the domain of (ID, ID) is larger under the allocation with parametric airport charges $(\tilde{a}_1(G), \tilde{a}_2(G))$. This is due to the difference in the airport charges. As explained in Section 4, the government sets the negative airport charges under the surplus-maximizing allocation, $(a_1^o(G), a_2^o(G))$ while under $(\tilde{a}_1(G), \tilde{a}_2(G))$, the airport charges are positive. As a result, under the surplus-maximizing allocation, the congestion and the access costs become larger than those under the allocation with parametric airport charges.

7. Conclusion

This paper focused on the allocation of services to two airports in a metropolitan area with the tradeoff between the accessibility, the frequency, and the airport congestion. Under three types of airport operation, Regimes PP, M, and G, we considered three types of allocations such as (1) the allocation with parametric airport charges, (2) the allocation without the regulation on airport charges, and (3) the surplus-maximizing allocations.

Our results are summarized as follows:

i) In case of the allocation with parametric airport charges, if the difference in the airport charges between two airports is relatively small, the integrated operation (Regime M) allocates the services to two airports at least as efficient as the separate operation (Regime PP).

ii) On the other hand, if the difference in the airport charges between two airports is relatively large, the integrated operation allocates the services to two airports inefficiently.

iii) If each operator can set the airport charges at its airport, the separate operation is more efficient than the integrated operation due to the competition in airport charges under the integrated operation.

iv) Under the separated operation, the allocation without regulation coincides with the surplus-maximizing allocation while, under the integrated operation, the operator tends to excessively allocate multiple services to the congested airport;

v) The separate operation without regulations generates higher social surplus than the integrated operation even if the government regulates the allocation in order to maximize the social surplus.

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 need to consider the regulation on the airport charges.

Appendix A: The Inverse Demand Functions

As we explained in Subsection 2.2, we have two cases on the relationship between boundaries, we have two cases:

i) When service S is only provided at airport j, or when two airports provide service S and these markets are segregated, the trip cost is equalized to the reservation price at the boundaries: $C_j^S\left(\overline{z}_j^S\right) = C_j^S\left(\underline{z}_j^S\right) = \overline{C}^S$.

ii) Two airports provide service S and these markets are adjacent: that is, $\overline{z}_1^S = \underline{z}_2^S$. In this case, at the boundary, $\overline{z}_1^S = \underline{z}_2^S$, the trip costs for both airports are equalized: $C_1^S\left(\overline{z}_1^S\right) = C_2^S\left(\underline{z}_2^S\right)$.

At the boundaries, $\underline{z}_1^S$ and $\overline{z}_2^S$, the trip cost is equalized to the reservation price: $C_1^S\left(\underline{z}_1^S\right)$ $= C_2^S\left(\overline{z}_2^S\right) = \overline{C}^S$.

In case i), the inverse demand function $p_j^S(f_j^{Sk} \,|\, \mathbf{f}^-)$ is derived as follows:

$$p_j^S(f_j^{Sk} \,|\, \mathbf{f}^-) = \begin{cases} \overline{C}^S + \dfrac{bt(\rho_C - \rho_H)}{\rho_H} - \dfrac{vh}{4f_j^{Sk}} - \dfrac{\sigma t\left(f_j^{S1} + f_j^{S2}\right)}{d^S \rho_H}, \text{ if } \underline{z}_j^S < -b, b < \overline{z}_j^S, \\ \overline{C}^S + \dfrac{bt(\rho_C - \rho_H)(b + x_1)}{(\rho_C + \rho_H)} - \dfrac{vh}{4f_j^{Sk}} - \dfrac{\sigma t\left(f_j^{S1} + f_j^{S2}\right)}{d^S(\rho_C + \rho_H)}, \text{ if } \underline{z}_j^S < -b, \overline{z}_j^S \le b, \\ \overline{C}^S + \dfrac{bt(\rho_C - \rho_H)(b - x_1)}{(\rho_C + \rho_H)} - \dfrac{vh}{4f_j^{Sk}} - \dfrac{\sigma t\left(f_j^{S1} + f_j^{S2}\right)}{d^S(\rho_C + \rho_H)}, \text{ if } -b \le \underline{z}_j^S, b < \overline{z}_j^S, \\ \overline{C}^S - \dfrac{vh}{4f_j^{Sk}} - \dfrac{\sigma t\left(f_j^{S1} + f_j^{S2}\right)}{d^S \rho_C}, \text{ if } -b \le \underline{z}_j^S, \overline{z}_j^S \le b. \end{cases}$$

In case ii), the inverse demand function $p_j^S(f_j^{Sk} \,|\, \mathbf{f}^-)$ is derived as follows:

$$p_1^S(f_1^{Sk} \,|\, \mathbf{f}^-) = \begin{cases} \overline{C}^S + \dfrac{bt(\rho_C - \rho_H)}{\rho_H} + \dfrac{t(\rho_C b - \rho_H x_1)}{\rho_C + \rho_H} - \dfrac{vh}{4f_1^{Sk}} - \dfrac{\sigma t\left[(\rho_C + 2\rho_H)\sum_k f_1^{Sk} + \rho_C \sum_k f_2^{Sk}\right]}{2d^S(\rho_C + \rho_H)}, \text{ if } \underline{z}_1^S < -b, \\ \overline{C}^S + \dfrac{bt(\rho_C - \rho_H)}{\rho_C + 3\rho_H} + \dfrac{t\left[2\rho_H b - (\rho_C + \rho_H)x_1\right]}{\rho_C + 3\rho_H} - \dfrac{vh}{4f_1^{Sk}} - \dfrac{\sigma t\left[(\rho_C + 2\rho_H)\sum_k f_1^{Sk} + \rho_C \sum_k f_2^{Sk}\right]}{d^S(\rho_C + 3\rho_H)}, \\ \qquad \text{if } \underline{z}_1^S \ge -b, \end{cases}$$

$$p_2^S(f_2^{Sk} \,|\, \mathbf{f}^-) = \begin{cases} \overline{C}^S + \dfrac{bt(\rho_C - \rho_H)}{\rho_H} + \dfrac{t(\rho_H b - \rho_C x_1)}{\rho_C + \rho_H} - \dfrac{vh}{4f_2^{Sk}} - \dfrac{\sigma t\left[(\rho_C + 2\rho_H)\sum_k f_2^{Sk} + \rho_C \sum_k f_1^{Sk}\right]}{2d^S(\rho_C + \rho_H)}, \text{ if } \underline{z}_1^S < -b, \\ \overline{C}^S + \dfrac{3bt(\rho_C - \rho_H)}{\rho_C + 3\rho_H} - \dfrac{t\left[(\rho_C - 3\rho_H)b + 2\rho_C x_1\right]}{\rho_C + 3\rho_H} - \dfrac{vh}{4f_2^{Sk}} - \dfrac{\sigma t\left(3\sum_k f_2^{Sk} + \sum_k f_1^{Sk}\right)}{d^S(\rho_C + 3\rho_H)}, \text{ if } \underline{z}_1^S \ge -b, \end{cases}$$

Appendix B: Parameters

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 equal interval: therefore, all users of service S at each airport incur the identical average waiting time cost. We set 3,000 yen per an hour as the values of v, which is used in Cost and Benefit Analysis of Kobe Airport (Kobe City, 2004). We set 5,475 hours $(365 \text{ days} \times 15 \text{ hours})$ as the value of h.

The reservation price for each service is obtained through the calibration. The following table shows the calibrated number of passengers for each service at two airports in Osaka Metropolitan Area. In the following table, 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 A1: 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

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Table 7: the Difference in Four Components of Social Surplus between the allocations (ID, ID) and (D, ID) (Unit: billion yen)

x_1	Social Benefit $\sum_{S,j,k}\left(\sigma\bar{C}^S-\omega^S\right)f_j^{Sk}(D,ID)-\sum_{S,j,k}\left(\sigma\bar{C}^S-\omega^S\right)f_j^{Sk}(ID,ID)$		Total Congestion Cost $c\left(\sum_{S,k} f_1^{Sk}(ID,ID)\right)^2-c\left(\sum_{k} f_1^{Dk}(D,ID)\right)^2.$	Total Access Cost	Total Scheduling Cost	Allocation
	Service I	Service D				
-10	-10.54	0.94	5.98	-1.76	2.23	(ID, ID)
-5	-9.33	0.95	6.13	-1.35	2.23	(ID, ID)
0	-8.12	0.95	6.27	-0.86	2.23	(ID, ID)
5	-6.91	0.96	6.42	-0.31	2.23	(D, ID)

Table 9: The Comparison of Airport Charges at Four Locations of Airport 1 (The unit: thousand yen)

	$x_1=-50$				$x_1=-25$				$x_1=0$				$x_1=25$			
	r_1^I	r_2^I	r_1^D	r_2^D	r_1^I	r_2^I	r_1^D	r_2^D	r_1^I	r_2^I	r_1^D	r_2^D	r_1^I	r_2^I	r_1^D	r_2^D
PP	6634	6773	2937	2937	6729	6561	3183	2937	6838	6384	2602	2508	5413	5575	2432	2167
M	16814	16814	3637	3637	16767	16521	3767	4370	16721	16721	3644	3644	-	16134	3203	3396
G	-16046	-16814	-6503	-7200	-15932	-16521	-6401	-6906	-	-16134	-6557	-6613	-	-16134	-6529	-6219

Table 10: The Difference in Four Components of Social Surplus between (ID, ID) and (D, ID) at Four Locations of Airport 1 (The unit: billion yen)

x_1	Regime M					Regime G				
	Social Benefit	Access	Congestion	Scheduling	Allocation	Social Benefit	Access	Congestion	Scheduling	Allocation
-15	-0.6	9.2	-2.9	-2.2	(ID, ID)	20.5	-6.4	-9.7	-2.2	(ID, ID)
-10	-2.8	9.3	-2.2	-2.2	(ID, ID)	23.2	-10.8	-10.0	-2.2	(ID, ID)
-5	-3.5	9.0	-1.9	-2.2	(ID, ID)	26.5	-15.8	-10.2	-2.2	(D, ID)