The Organization of Multiple Airports in a Metropolitan Area

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Abstract

This study deals with the allocation of international and domestic flights (allocation of services) among multiple airports in a metropolitan area. We examine three types of airport operation: separate operation by two private firms (*PP*); integrated operations by a single private firm (*M*); and by the government (*G*). By means of numerical simulations, we obtain the following results: i) the allocation of services varies with the location of airports and types of operation; ii) the welfare gain of the service choice regulation is quantitatively small compared with the airport charge regulation.
Keywords: multiple airports, allocation of services, airport pricing, private operation, regulation

1.0 Introduction

It is observed that some metropolitan areas have multiple airports, each of which has a different role. For example, in the Osaka Metropolitan Area, Japan, Osaka Airport specializes in serving domestic flights while Kansai International Airport serves both international and domestic flights. This division of roles among multiple airports is called the *allocation of services* in this paper. The allocation of services might be the result of governmental regulation or decentralized decision-making by airport operators. Recently, newly constructed airports have been under the private operation, and existing public airports have been privatized. Furthermore, private operations may take different forms in multiple airport settings. In some metropolitan areas, each airport is operated independently (separate operation), while in others a single firm operates all airports (integrated operation).[1] These various types of operations would lead to different results concerning the allocation of services among airports. In addition, the locations of airports might affect the allocation of services among them. For example, in NYC, Seoul, and Osaka, airports closer to the city center provide only domestic (or short-distance) flights, while the other serves both domestic and international (or both short-distance and long-distance) flights.[2] Our study attempts to address these questions: how the locations of airports and the different types of operation affect the allocation of services and the economic welfare; how effective the regulation of the allocation of services is.

[1] In London, two of the three major airports, Heathrow and Stansted, are operated by a single private operator, BAA, while the other airport, Gatwick, is operated by a different private operator. On the other hand, in Paris, all three airports, Charles de Gaulle, Orly, and Beauvais, are operated by a single private firm, ADP.

[2] There are other types of allocation: in Amsterdam and Melbourne, airports closer to the city center provide both domestic and international flights while other airports provides only domestic.

In many real cases, the construction of new airports in a metropolitan area arises from the need to address the shortage of capacity in existing airports. Therefore, the airport congestion is an indispensable factor in the discussion of multiple airports. There is substantial literature on airport congestion (Brueckner 2002; Pels and Verhoef 2004; Zhang and Zhang 2006). Most papers address the congestion pricing at a single airport, but few deal with the multiple airport setting. Pels et al.[3] (2000) first developed a model to describe the competition between multiple airports by incorporating behaviors of airport users and carriers. Their model, however, assumes that airport operators set charges by average cost pricing, and it does not consider the situation where airport operators choose decision variables for their interest. With airports and seaports in mind, De Borger and Van Dender (2006) introduce pricing and capacity choice in the model of competition between congestible facilities. They consider two types of private operation: separate operation by private firms and integrated operation by a single private firm. Basso and Zhang (2007) extended the model of De Borger and Van Dender (2006) by introducing the vertical relationship among users, carriers, and airport operators.[4] These earlier works, however, suppose a single type of service, and the allocation of services is not a consideration.[5]

In this study, we construct a model in which two airports may provide services for two types of air

[3] They (Pels et al. 2001) also conducted the empirical analysis with the multiple airport setting, but they mainly analyzed the user’s choices about airports and airlines.

[4] Dunkerley et al. (2009) study about the multiple airports in the same region, but their focus is different from ours in that they mainly deal with the problem of the congestion at the access from the users’ location (the city) to airports.

[5] Van Dender (2005) incorporates two different types of services in a model of competition between two facility operators. However, he focuses on the case that each facility provides all types of services, and so does not examine alternative allocations.

transportation (international and domestic),[6] and the allocation of services is a policy variable. The model describes interaction among choices of users, carriers, and airport operators. Using this model, we examine the allocation of services among airports in a metropolitan area under three alternative forms of 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*).

In each regime of the airport operation, the airport operator chooses the type of service and the level of airport charge. Consequently, the inefficiency of the private operation (Regimes *PP* and *M*) is generated from both the service choice and airport charges. By comparing with the public operation (Regime *G*), we investigate the distortion caused by private operations. In order to correct this distortion, the government regulates the private operators on airport charges and service choices. The regulation of airports is a relatively new issue, which reflects the current tendency of growing number of privatized airports. Several studies deal with the regulation of airports, but most of them focus on the regulation on pricing (Oum et al. 2004; Czerny 2006) while no one deals with the service choice regulation. In this paper, we compare the effectiveness of two types of regulations, service choice and airport charges.

[6] The presence of airport congestion is an important factor for modeling how many services should be provided at airports. If present, airport congestion generates an interaction between different types of services (domestic or international flights) provided at an airport. Consequently, we should solve the problem to obtain the combination of services provided at two airports.

In contrast, if airport congestion is absent, the interaction between services diminishes. Therefore, the problem for each service is solved independently to determine the number of airports providing a particular service. This problem resembles the one studied by Takahashi (2004) and Akutagawa and Mun (2005). In those two articles, providers of public service decide whether to provide the service at its facility.

The rest of the paper is organized as follows. Section 2 presents the model and describes the behavior of users and carriers. Section 3 formulates the problem of airport operators under alternative regimes, and shows the simulation results. Section 4 proposes the measures to evaluate the welfare gains from regulations on the service choice and the airport charge. In addition, this section discusses the effectiveness of these two regulations. Section 5 concludes the paper. In the Appendices, we summarize the setting of parameter values and the details of the numerical simulation results.

2.0 The Model

2.1 The Basic Setting

Suppose a metropolitan area developed along the linear space, as illustrated in Figure 1, which consists of the City and the Hinterland. Each location is identified by the coordinate value of x, where the origin of coordinates ($x = 0$) is at the center of the City. The City is represented by the segment $x \in [-b, b]$, and the Hinterland is outside this segment. Individuals are uniformly distributed with density ρ_C within the City, and ρ_H within the Hinterland. Naturally, we assume $\rho_H < \rho_C$.

<<Figure 1: About here>>

The City has two airports, Airports 1 and 2, whose locations are exogenously given and denoted by x_1 and x_2 respectively. Without loss of generality, we assume that $x_1 < x_2$. Moreover, we assume that Airport 2 is located at the fringe of the City ($x_2 = b$). Airport 1 is congestible while Airport 2 is free from congestion.[7] The congestion costs, including extra labor, fuel costs due to delay, and the like, are incurred by carriers (airline companies).

These two airports can provide two types of service, international and domestic flights, which are hereafter denoted by I and D respectively. Let us denote by a_j the type of services provided at airport j, where $a_j = I$ (D) means that the airport is specialized in international (domestic) flights; $a_j = ID$ indicates that the airport provides both international and domestic flights; $a_j = N$ indicates that the airport is closed. The allocation of services is represented by the combination of services provided at two airports, (a_1, a_2). So, there are 16 possible allocations.[8]

This economy has three types of agents: airport users (travelers), carriers, and airport operators. The sequence of decisions is as follows: first, the airport operator(s) determine their decision variables, the service choice and airport charges. Second, carriers choose the number of flights at each airport. Finally, users make their decisions about air trips, such as whether or not to make trips and which airport to utilize if they make trips. Following subsections describe the behavior of each type of agents by tracking back this sequence of decisions.

2.2 Users

The trip demand for service S (S=I, D) is inelastic at the individual level, but the aggregate demand is elastic. Each individual makes type S trips d^S times per given period unless the trip cost

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[7] This situation supposes that Airport 2 is newly constructed to address the shortage of capacity in Airport 1. Examples are Montreal, Tokyo, and Osaka. In these cases, the newly constructed airport is located at the fringe of the city, and suffers from the shortage of demand compared to its capacity.

[8] 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 a case, we assume that travelers choose other modes, such as autos or railways.

exceeds the reservation price, $\bar{C}^S$ (S=I, D). All individuals have the same value of the reservation price for trip type S, $\bar{C}^S$. In addition, we introduce two assumptions, $d^D > d^I$ and $\bar{C}^I > \bar{C}^D$: the frequency of domestic trips is greater than that for international, and the reservation price for international trips is higher than that for domestic.

Let us denote by $C_j^S(x)$ the trip cost for an individual located at x using airport j for trip of type S, which is defined as:

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

The first term on the RHS of Eq. (1) represents the access cost to airport j that is proportional to the distance between the locations of the user (x) and the airport (x_j), in which t is the access cost per distance. The second term 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 as the value of waiting time, v, multiplied by the average waiting time for service S at airport j, $h/4F_j^S$, for the given operating hours of airport j, h.[9] The last term, P_j^S, is the airfare for service S at airport j.

When an individual located at x decides to make a trip of type S, she chooses the airport where the trip cost is lower.[10] In addition, if she makes a trip of type S, the trip cost should not exceed the reservation price $\bar{C}^S$: that is, $\bar{C}^S \geq \min_j\{C_j^S(x)\}$ should hold. Therefore, the trip demand generated from x for service S at airport j, $q_j^S(x)$, is calculated by:

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[9] This expression of the average waiting time is based on the assumption that trip demand is uniformly distributed across the time of day.

[10] Note that, in our model, the service is not necessarily provided at all airports. In such case, $C_j^S(x) = \infty$ since $F_j^S = 0$ if service S is not available at airport j.

$$q_j^S(x) = \begin{cases} \rho_C d^S & \text{if } C_j^S(x) \le C_i^S(x) \text{ for } -b \le x \le b \text{ and } i \ne j, \\ \rho_H d^S & \text{if } C_j^S(x) \le C_i^S(x) \text{ for } x < -b, b < x, \text{ and } i \ne j. \end{cases} \tag{2}$$

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

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

where $\overline{z}_j^S$ and $\underline{z}_j^S$ respectively represent the locations of the right and left ends of the catchment area for service S at airport j. By solving Eq. (3) for airfare, P_j^S, we have the inverse demand function for service S at airport j, $p_j^S(\mathbf{Q^S}, \mathbf{F^S})$, where $\mathbf{Q^S} = (Q_1^S, Q_2^S)$ and $\mathbf{F^S} = (F_1^S, F_2^S)$.

To determine the boundaries, $\overline{z}_j^S$ and $\underline{z}_j^S$, we should distinguish two cases:

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

ii) Two airports provide service S and these catchment areas share the boundary: that is, $\overline{z}_1^S = \underline{z}_2^S$. At this location, the trip costs for both airports are equalized: $C_1^S(\overline{z}_1^S) = C_2^S(\underline{z}_2^S) < \overline{C}^S$. At the outer boundaries, $\underline{z}_1^S$ and $\overline{z}_2^S$, the trip cost is equalized to the reservation price: $C_1^S(\underline{z}_1^S) = C_2^S(\overline{z}_2^S) = \overline{C}^S$.

2.3 Carriers

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) that is operated by carrier k (k=1, 2) in market S. We assume 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 competition in the schedule of flights.[11] Consequently, the frequency of service S at airport j perceived by users, F_j^S, is equal to f_j^{Sk} ($F_j^S = f_j^{Sk}$).

All flights from each airport are served with full capacity, σ. Therefore, at the equilibrium, the following relation must hold:

$$Q_j^S = \sigma \sum_{k=1,2} f_j^{Sk}, \quad \text{for } S=I, D \text{ and } j=1, 2. \tag{4}$$

By using the relation $F_j^S = f_j^{Sk}$ and Eq. (4), the inverse demand function, $p_j^S(\mathbf{Q^S}, \mathbf{F^S})$, is expressed as $p_j^S(\mathbf{f^{Sk}}, \mathbf{f^{Sl}})$,[12] in which $\mathbf{f^{Si}} = (f_1^{Si}, f_2^{Si})$ represents the vector of frequencies provided by carrier i ($i=k, l$) in market S. The detailed expression of $p_j^S(\mathbf{f^{Sk}}, \mathbf{f^{Sl}})$ is given in Appendix A. The revenue per flight from airport j for each service S carrier is expressed as $p_j^S(\mathbf{f^{Sk}}, \mathbf{f^{Sl}})\sigma$. A service S carrier incurs the marginal cost m_j^S and the airport charge r_j^S for each flight from airport j. Since carriers encounter congestion when they use Airport 1, the marginal cost, m_j^S, varies between airports:

$$m_1^S = \omega^S + c\left(\sum_k f_1^{Sk} + \sum_k f_1^{Tk}\right),$$

$$m_2^S = \omega^S,$$

where ω^S and c capture the marginal cost of an operation and congestion. Therefore, the profit of carrier k providing service S from airport j, π_j^{Sk}, is,

$$\pi_j^{Sk}\left(\mathbf{f^{Sk}}, \mathbf{f^{-}}\right) = \left[p_j^S\left(\mathbf{f^{Sk}}, \mathbf{f^{Sl}}\right)\sigma - m_j^S - r_j^S\right] f_j^{Sk}, \tag{5}$$

where $\mathbf{f^{-}} = (f_1^{Sl}, f_2^{Sl}, f_1^{T1}, f_1^{T2})$. The vector, $\mathbf{f^{-}}$, is composed of two types of elements: the frequency

[11] This result is based on the minimum product differentiation by Hotelling (1929).

[12] By using these relations,

$$p_j^S(\mathbf{Q^S}, \mathbf{F^S}) = p_j^S(\sigma(\mathbf{f^{Sk}} + \mathbf{f^{Sl}}), \mathbf{f^{Sk}}) = p_j^S(\mathbf{f^{Sk}}, \mathbf{f^{Sl}}).$$

provided by the other carrier l in the same service market S, f_j^{Sl}, and that provided by carriers in the other service market T at Airport 1, f_1^{Tk}.[13]

We assume the quantity (Cournot) competition: that is, each carrier chooses the frequency, $\mathbf{f}^{\mathbf{Sk}}=(f_1^{Sk}, f_2^{Sk})$, to maximize the sum of the profits from two airports, $\sum_j \pi_j^{Sk}(\mathbf{f}^{\mathbf{Sk}}, \mathbf{f}^{-})$. Let us denote by $\mathbf{f}^{\mathbf{Sk*}}$ carrier k's Nash Equilibrium frequencies at two airports; then, it satisfies

$$\mathbf{f}^{\mathbf{Sk*}} = \arg\max_{\mathbf{f}^{\mathbf{sk}}} \sum_j \pi_j^{Sk}\left(\mathbf{f}^{\mathbf{Sk}}, \mathbf{f}^{-*}\right), \text{ for } S = I, D \text{ and } k = 1, 2,$$

where $\mathbf{f}^{-*}$ is the vector of the Nash Equilibrium frequencies set by the other carriers.[14] Since the equilibrium frequency depends on the airport charges, $\mathbf{r_j}=(r_j^I, r_j^D)$, and the services provided at both airports, a_j (j = 1, 2), the equilibrium frequencies of carrier k providing service S are expressed as $\mathbf{f}^{\mathbf{Sk*}}=(f_1^{Sk*}(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2), f_2^{Sk*}(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2))$. Plugging the equilibrium frequencies of carriers, $\mathbf{f}^{\mathbf{Sk*}}$, into Eq. (5), the profit of carrier k providing service S is given by $\Pi^{Sk}\left(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2\right)=\sum_j \pi_j^{Sk}\left(\mathbf{f}^{\mathbf{Sk*}}, \mathbf{f}^{-*}\right)$.

2.4 Airports

The airport operator determines the levels of charges and the service choice at their airports. Two types of operators are considered, a private firm and the government. The private firm maximizes the airport charge revenue while the government maximizes the social surplus. This paper examines the following three alternative regimes of the airport operation:

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[13] (f_1^{T1}, f_1^{T2}) are included because flights of the other service type, T, affect the profit of carrier k providing service S through the congestion at Airport 1.

[14] Note that carriers may not choose to use one of two airports even if both airports are open for use. This case corresponds to the corner solution: $f_i^{Sk} = f_i^{Sl} = 0$ is obtained as an optimal solution for a carrier. In other cases, the airport operator does not allow the use of flights for a particular service, S. In this situation, carriers providing service S should solve the problem with the constraint of $f_i^{Sk} = f_i^{Sl} = 0$.

Regime *PP*: each airport is operated by a single private firm. Each operator chooses their decision variables simultaneously in order to maximize the revenue from their airport. Hence, the solution is characterized by the Nash Equilibrium.

Regime *M*: a single private firm operates two airports. The integrated operator chooses decision variables to maximize the sum of the revenues from two airports.

Regime *G*: the government operates two airports. The integrated operator maximizes the social surplus by choosing decision variables. Also note that we treat this regime as the benchmark case to measure the inefficiency of the private operations (PP and M).

3.0 Variable Airport Charges and Service Choices

This section postulates that airport operators are free to choose both airport charges and the services provided at their airports. In each regime, the operator first determines the services provided at their airports, and then airport charges.

3.1 Decisions of Airport Operators under Alternative Regimes

3.11 Regime PP

The game between two operators is solved backward. Given the allocation, (a_1, a_2), each operator simultaneously sets the airport charges, r_j^S, so as to maximize the revenue, $R_j(\mathbf{r_j},\mathbf{r_i};a_j,a_i)$:

$$R_j\left(\mathbf{r_j},\mathbf{r_i};a_j,a_i\right)=\sum_{S=I,D}\sum_{k=1,2}r_j^S f_j^{Sk*}\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right). \tag{6}$$

Let us denote by $\mathbf{r}_j^*(a_1,a_2;PP)$ the vector of the airport charges set by airport j at the Nash

Equilibrium, and it satisfies[15]:

$$\mathbf{r}_\mathbf{j}^*\left(a_1,a_2;PP\right)=\arg\max_{\mathbf{r}_\mathbf{j}} R_j\left(\mathbf{r}_\mathbf{j},\mathbf{r}_\mathbf{i}^*\left(a_1,a_2;PP\right);a_j,a_i\right). \tag{7}$$

Plugging Eq. (7) into Eq. (6), we have:

$$R_j\left(a_j,a_i\right)=R_j\left(\mathbf{r}_\mathbf{j}^*\left(a_1,a_2;PP\right),\mathbf{r}_\mathbf{i}^*\left(a_1,a_2;PP\right);a_j,a_i\right). \tag{8}$$

Given the competitor's service choice, a_i, each airport operator j chooses a_j to maximize Eq. (8). Let us denote by $a_j^*(PP)$ the equilibrium service choice of airport j; then it is the best response against the equilibrium choice of the other airport i, $a_i^*(PP)$:

$$R_j\left(a_j^*\left(PP\right),a_i^*\left(PP\right)\right)\geq R_j\left(a_j,a_i^*\left(PP\right)\right) \quad \text{for } \forall a_j\neq a_j^*\left(PP\right),\ j=1,2, i\neq j.$$

In other words, the allocation of services under Regime PP, $(a_1^*(PP),a_2^*(PP))$, is derived as the Nash Equilibrium of the service choice game.

3.12 Regime M

The monopolistic operator chooses the allocation, (a_1, a_2), and airport charges, r_j^S, so as to maximize the sum of revenues, $R(\mathbf{r_1},\mathbf{r_2};a_1,a_2)$:

$$R\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right)=\sum_{j=1,2}R_j\left(\mathbf{r_j},\mathbf{r_i};a_j,a_i\right). \tag{9}$$

Given the allocation, (a_1, a_2), the charges set by the monopolistic operator, $\mathbf{r}_\mathbf{j}^*(a_1,a_2;M)$, are derived as follows:

$$\left(\mathbf{r}_\mathbf{1}^*\left(a_1,a_2;M\right),\mathbf{r}_\mathbf{2}^*\left(a_1,a_2;M\right)\right)=\arg\max_{\mathbf{r_1},\mathbf{r_2}} R\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right). \tag{10}$$

By substituting (10) into (9), we define $R(a_1,a_2)$ as:

[15] In some locations of Airport 1, x_1, we assume that each operator, j, plays the strategy that prevents undercutting by its competitor i. Alternatively, we solve problem (7) with the constraint $C_j^S(x_j)=C_i^S(x_j)$.

$$R(a_1,a_2)=R\left(\mathbf{r_1^*}(a_1,a_2;M),\mathbf{r_2^*}(a_1,a_2;M);a_1,a_2\right).$$

The allocation under Regime *M*, $(a_1^*(M),a_2^*(M))$, is chosen as:

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

3.13 Regime G

Given the allocation, (a_1, a_2), the government determines the airport charges so as to maximize the social surplus $SW(\mathbf{r_1},\mathbf{r_2};a_1,a_2)$:

$$SW(\mathbf{r_1},\mathbf{r_2};a_1,a_2)=\sum_{S=I,D}\sum_{j=1,2}\int_{\underline{z}_j^S}^{\overline{z}_j^S} q_j^S(x)\left[\overline{C}^S-C_j^S(x)\right]dx$$
$$+\sum_{S=I,D}\sum_{k=1,2}\Pi^{Sk}(\mathbf{r_1},\mathbf{r_2};a_1,a_2)+R(\mathbf{r_1},\mathbf{r_2};a_1,a_2), \qquad (11)$$

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.

Under the allocation (a_1, a_2), the charges set by the government, $\mathbf{r_j^*}(a_1,a_2;G)$, satisfy:

$$\left(\mathbf{r_1^*}(a_1,a_2;G),\mathbf{r_2^*}(a_1,a_2;G)\right)=\arg\max_{\mathbf{r_1},\mathbf{r_2}} SW(\mathbf{r_1},\mathbf{r_2};a_1,a_2). \qquad (12)$$

By substituting Eq. (12) into Eq. (11), we define $SW(a_1,a_2)$ as:

$$SW(a_1,a_2)=SW\left(\mathbf{r_1^*}(a_1,a_2;G),\mathbf{r_2^*}(a_1,a_2;G);a_1,a_2\right).$$

The allocation under Regime *G*, $(a_1^*(G),a_2^*(G))$, satisfies:

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

3.2 Comparison of Alternative Regimes

Allocations under the three alternative regimes are obtained by means of numerical simulation. The size of the City is set as the segment of [–50, 50] according to the data of the Osaka

Metropolitan Area. We choose the values of parameters so that the solutions of the model fit the observed value in the real world. The explanation for the rest of parameters is summarized in Appendix B, and Table B1 of the Appendix shows the calibration results. Parameter values are summarized in Table 1.

<<Table 1: About here>>

Figure 2 shows the allocations under three alternative regimes for various locations of Airport 1. Figure 2 illustrates that three allocations, (*ID*, *ID*), (*D*, *ID*), and (*N*, *ID*), are realized out of 16 patterns. These allocations shown in Figure 2 indicate that the service choice is different between regimes. At Airport 2, the operator always chooses to provide two services: that is, a_2=*ID*. In contrast, the service choice at Airport 1 is dependent on both the location and the airport operation. Under Regime *PP*, the operator of Airport 1 always provides two types of services, *ID*, while the integrated operators (*M* and *G*) change their service choice as the location of Airport 1 changes: they choose a_1=*ID* if x_1 is small (locations of two airports are sufficiently distant from each other). As the distance between two airports becomes shorter, the operators change their service choice at Airport 1 from *ID* to *D*, and then to *N*. Figure 2 also shows that the domain of a_1=*ID* under Regime *M* is larger than that under Regime *G*. These results imply that private operations lead to excessive entry of services into the congested airport (too many services are provided at Airport 1).

<<Figure 2: About here>>

We explain the mechanism behind the difference in the service choice among regimes. Further details of the numerical simulation results are given in the Appendix C. Under Regime *PP*, independent from the location of Airport 1, the allocation (*ID*, *ID*) is realized. As summarized in Table C1 of the Appendix, this is because the dominant strategy for each operator is always to provide two services, $a_j^*(PP) = ID$ (for j=1, 2). That is, from the viewpoint of a single airport, the revenue from providing two services always exceeds the one from a single service.

In contrast, under the integrated operations (*M* and *G*), the operator considers the effects of the service choice at a single airport on the system of two airports as a whole. Increasing the service provided at an airport has both benefits and costs. Taking into account these benefits and costs, the integrated operators always choose to provide two services at Airport 2 (a_2=*ID*) while, at Airport 1, they alter their service choice as the location of Airport 1 changes. This difference in the service choice between two airports originates from that in the congestibility at two airports. In this model, Airport 2 is free from the congestion; increasing the service at Airport 2 generates no costs. Therefore, as long as it is beneficial, the integrated operator has an incentive to provide two services at Airport 2.[16]

On the other hand, increasing the service at Airport 1 escalates the congestion, and the degree of the congestion depends on the location of Airport 1. As a result, the integrated operators determine the service choice at Airport 1 according to its location. In Figure 2, y^Z (Z=*M*, *G*) is the boundary between domains of (*ID*, *ID*) and (*D*, *ID*) under Regime *Z*. For $y^G \le x_1 \le y^M$, the allocation (*ID*, *ID*)

[16] If two airports locate distant each other (for small value of x_1), providing two services at Airport 2 leads to the expansion of the catchment area. In contrast, when the distance between two airports is relatively small (for large value of x_1), concentrating the service provision to Airport 2 reduces the congestion at Airport 1.

emerges under Regime M while (D, ID) emerges under Regime G. This means that, within this range of x_1, changing from a_1=ID to D decreases the sum of revenue from two airports while it increases the social surplus. To see this, we decompose the difference in the sum of revenues from two airports:

$$R(D, ID) - R(ID, ID) = \Delta R_1^I + \Delta R_1^D + \Delta R_2^I + \Delta R_2^D, \tag{13}$$

where ΔR_j^S is the difference between (D, ID) and (ID, ID) in the revenue from S (S = I, D) at airport j (j=1, 2). For $y^G \le x_1 \le y^M$ in Figure 2, the RHS of (13) is negative, thus the monopolistic operator chooses (ID, ID) instead of (D, ID).

In (13), ΔR_1^I is negative since under (D, ID), revenue from service I at the airport is zero while ΔR_2^I is positive since service I is concentrated at Airport 2. ΔR_1^D is positive since congestion at Airport 1 is relaxed while ΔR_2^D is negative due to the reduction in the congestion at Airport 1.[17] At both airports, the change in the revenue from service I dominates that in the revenue from service D: that is, $|\Delta R_j^I| > |\Delta R_j^D|$ (j=1, 2). Therefore, when it changes the service choice at Airport 1, the monopolistic operator incurs the loss at Airport 1 ($\Delta R_1 = \Delta R_1^I + \Delta R_1^D < 0$), and receives the gain at Airport 2 ($\Delta R_2 = \Delta R_2^I + \Delta R_2^D > 0$).[18] As x_1 increases, changes in revenues at both airports, ΔR_1 and ΔR_2, increase as shown in Table C3 of the Appendix. For $x_1 \le y^M$, a_1=ID always generate the larger revenue compared to a_1=D, vice versa.

[17] When changing the allocation from (ID, ID) to (D, ID), the congestion at Airport 1 is reduced. This reduction in the congestion expands the catchment area of Airport 1 while this induces the shrinkage of the catchment area of Airport 2.

[18] Regime PP, this gain at Airport 2, ΔR_2, is not considered when the operator of Airport 1 sets its service choice. Therefore, under Regime PP, Airport 1 always provides two services, which can be confirmed from Table C2 of the Appendix.

The government considers the welfares of users and carriers as well as the sum of revenues. The difference in the social surplus between the allocations (*ID*, *ID*) and (*D*, *ID*) is decomposed into three parts:

$$SW(D, ID) - SW(ID, ID) = \sum_{S=I,D} \Delta CS^S + \sum_{S=I,D} \Delta \Pi^S + \sum_{j=1,2} \Delta R_j, \tag{14}$$

where, from the left, the three terms in the RHS respectively represent the changes in consumer surplus, profits of carriers, and airport charge revenue. For $y^G \le x_1$ in Figure 2, the RHS of (14) is positive; therefore, the public operator chooses (*D*, *ID*) instead of (*ID*, *ID*). In contrast, recall that the last term of the RHS in Eq. (14) is negative; therefore, the allocation (*ID*, *ID*) is realized under Regime *M*.

In Eq. (14), as shown in Table C4 of the Appendix, users and carriers of service *D* receive the gain ($\Delta CS^D > 0$ and $\Delta \Pi^D > 0$) since the congestion at Airport 1 is relaxed. In contrast, this change in the allocation induces the shrinkage of catchment area for service *I*, and imposes the losses on service *I* carriers and users ($\Delta CS^I < 0$ and $\Delta \Pi^I < 0$) as summarized in Table C4.[19] When two airports are distant each other, the decline in the catchment area is relatively large, and the loss of service *I* users and carriers becomes significant. As the distance between two airports decreases, the degree of the decline in the catchment area becomes smaller, and the losses of service *I* users and carriers are decreased. In contrast, the gains of service *D* users and carriers are relatively constant. As a result, for $y^G \le x_1$, the government can improve the social surplus by changing the service choice

[19] For service *I* carriers, the shrinkage leads to the reduction in the revenues. For service *I* users, it generates the loss in the sense that some of users should give up type *I* trips.

at Airport 1 from *ID* to *D*.

Table 2 compares the social surplus, the airport charges, and the allocation of services under three regimes. In Table 2, the government (Regime *G*) always sets negative airport charges. Our model has two sources of inefficiency, the carrier's market power and the congestion at Airport 1. In order to remedy the former distortion, the government should reduce the airfare through the subsidy to carriers while the government should raise the airport charge in order to correct the latter distortion. The negative value of airport charges under Regime *G* implies that the magnitude of the inefficiency due to the carriers' market power is much larger than the one due to the congestion. In addition, the airport charges under Regime *M* are always the highest among three regimes because the integrated operator has larger market power in determining the airport charges than the separate operator (*PP*). Note that for all values of x_1 in Table 2, the allocation of services under Regime *M* coincides with that under Regime *G*, which is different from that of Regime *PP*. Namely, the service choice under Regime *M* is more efficient than under Regime *PP*.[20] Nevertheless, the social surplus under Regime *M* is lower than Regime *PP*. This implies that inefficiency in the determination of airport charges is dominant.

<<Table 2: About here>>

4.0 Regulation of Service Choice vs. Airport Charges

[20] This implies that when airport charges are fixed (by regulations), Regime *M* assures the larger social surplus compared to Regime *PP*.

In reality, airport operators face the regulations on airport charges and service choice. The airport charge regulation typically takes the form of the price cap regulation (for example, airports in London). Moreover, in some metropolitan areas, the service choices are regulated. For example, in cities such as Osaka, Seoul, and Shanghai, airports closer to the city center are allowed to provide only the service for domestic flights. In addition, the perimeter rule implemented in NYC and Washington D.C can be another type of service choice regulation because it restricts airports closer to the city center to serving flights operating within a certain range of distance. In this section, we evaluate the welfare effect of two types of the regulation on airport charges and service choices.

We describe a method to measure the welfare effect of the regulations as follows. First, to evaluate the effect of the difference in the service choice among regimes, we fix the level of airport charge at ($\mathbf{r_1}$, $\mathbf{r_2}$). The welfare effect of the service choices regulation, $\tilde{\Delta}\left(Z;\mathbf{r_1},\mathbf{r_2}\right)$, is calculated as:

$$\tilde{\Delta}\left(Z;\mathbf{r_1},\mathbf{r_2}\right) = SW\left(\mathbf{r_1},\mathbf{r_2};\tilde{a}_1\left(G\right),\tilde{a}_1\left(G\right)\right) - SW\left(\mathbf{r_1},\mathbf{r_2};\tilde{a}_1\left(Z\right),\tilde{a}_2\left(Z\right)\right). \tag{15}$$

In Eq. (15), $\tilde{a}_j(G)$ and $\tilde{a}_j(Z)$, respectively, represent the service choices of airport *j* under Regimes *G* and *Z* (*Z*=*PP*, *M*) when the airport charges are exogenously given by ($\mathbf{r_1}$, $\mathbf{r_2}$).[21] Given the exogenously fixed airport charges, ($\mathbf{r_1}$, $\mathbf{r_2}$), $\tilde{\Delta}\left(Z;\mathbf{r_1},\mathbf{r_2}\right)$ computes the difference between the levels of social surplus for Regime *G* and the private operations (PP and M). Recall that under Regime *G*,

[21] Since airport charges are exogenously fixed, the sequence of decisions on airport charges and service choices are reversed. That is, given the airport charges ($\mathbf{r_1}$, $\mathbf{r_2}$), each type of the operator determine their service choice. The service choices under three regimes are described below. Under Regime *PP*, given the competitor's choice, the operator of airport *j* chooses the service to be provided at their airport in order to maximize Eq. (6). Namely, the service choice of airport *j*, $\tilde{a}_j(PP)$, is the best response to the choice of the other airport *i*, $\tilde{a}_i(PP)$:

$$R_j(\mathbf{r_j},\mathbf{r_i};\tilde{a}_j(PP),\tilde{a}_i(PP)) \geq R_j(\mathbf{r_j},\mathbf{r_i};a_j,\tilde{a}_i(PP)) \text{ for } {}^{\forall}a_j \neq \tilde{a}_j(PP),\ j=1,2, i \neq j.$$

Under Regimes *M* and *G*, the service choices, $\tilde{a}_j(M)$ and $\tilde{a}_j(G)$, are respectively determined to maximize equations (9) and (11).

the allocation of services, $(\tilde{a}_1(G), \tilde{a}_2(G))$, is chosen to maximize the social surplus. So the social surplus under Regime *G* is considered to be the target of the service choice regulation. In this sense, $\tilde{\Delta}(Z;\mathbf{r_1},\mathbf{r_2})$ measures the welfare gain of the service choice regulation.

The welfare effect of the airport charge regulation, $\Delta^*(Z;a_1,a_2)$, is computed by:

$$\Delta^*(Z;a_1,a_2) = SW(\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2;a_1,a_2) - SW\left(\mathbf{r}_1^*(a_1,a_2;Z),\mathbf{r}_2^*(a_1,a_2;Z);a_1,a_2\right), \tag{16}$$

where $\bar{\mathbf{r}}_\mathrm{j}$ denotes the regulated airport charges, and $\mathbf{r}_\mathrm{j}^*(a_1,a_2;Z)$ is the level of airport charges set by the private operator under Regime *Z* (*Z*=*PP*, *M*). Assuming that the allocation (a_1, a_2) is given, $\Delta^*(Z;a_1,a_2)$ compare the social surplus for the regulated airport charges, $\bar{\mathbf{r}}_\mathrm{j}$, with for charges under Regime *Z* (*Z*=*PP*, *M*), $\mathbf{r}_\mathrm{j}^*(a_1,a_2;Z)$.

In computing $\Delta^*(Z;a_1,a_2)$, we examine two cases of setting the regulated airport charges, $\bar{\mathbf{r}}_\mathrm{j}$: optimal and actual charges. The optimal charges are obtained by (12), the solutions for Regime *G* in variable airport charge.[22] Recall the results in Table 2 showing that the airport charges under Regime *G* are negative and large in absolute value. Under the private operation, however, it is impractical to set the regulated airport charges at negative value. So we consider the case of optimal charges as the reference point indicating the maximal gain achievable by airport charge regulation. The latter case, the actual charges, is considered to be more realistic. In many real cases, the private operator is required to recover the cost for infrastructure (airport capacity).[23]

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[22] In the discussion of price regulation, we fix the allocation of services, and compute the social surplus for the optimal charge. This is a difference from the optimal solution presented in Section 3.

[23] In fact, the actual airport charge in Kansai International Airport used in this simulation is set so that the revenue cover the loan repayment.

<<Table 3: About Here>>

Table 3 shows the welfare effects of regulations, $\tilde{\Delta}(Z;\mathbf{r_1},\mathbf{r_2})$ and $\Delta^*(Z;a_1,a_2)$, at various locations of Airport 1. In computing the welfare effects of the service choice regulation, we use actual airport charges for $(\mathbf{r}_1,\mathbf{r}_2)$ in $\tilde{\Delta}(Z;\mathbf{r_1},\mathbf{r_2})$.[24] It is seen from Table 3 that the welfare gain from optimal regulation of airport charge (column "optimal" in Table 3) is much larger than that in the case of actual charges (column "actual"). Even when $\bar{\mathbf{r}}_\mathrm{j}$ is equal to the actual charge, the welfare gain of the airport charge regulation, $\Delta^*(Z;a_1,a_2)$ is much larger than that of service choice, $\tilde{\Delta}(Z;\mathbf{r_1},\mathbf{r_2})$. The gain of the airport charges regulation, $\Delta^*(Z;a_1,a_2)$, reaches *at least* 41.5 billion yen while that of the service choice regulation, $\tilde{\Delta}(Z;\mathbf{r_1},\mathbf{r_2})$, reaches *at most* 17.2 billion yen. Also note that $\tilde{\Delta}(Z;\mathbf{r_1},\mathbf{r_2})$ has positive value only at x_1=10 and 30. In other words, the service choice regulation has no effect in broad range of x_1. In summary, although the service choice regulation may be effective in some cases, its welfare gain is quantitatively small relative to the gain of the airport charge regulation.

5.0 Conclusion

This paper focuses on the allocation of services between two airports in a metropolitan area. Three types of airport operation, Regimes *PP*, *M*, and *G*, are considered. It is shown that the allocation of services varies depending on the locations of the airports and the types of airport operation. When two airports are distant from each other, both airports provide two types of service, and the number

[24] The result shown in Table 3 is robust against the changes in the level of airport charges.

of services provided at the airport closer to the city center decreases as the distance between two airports decreases. The private operations (Regimes *PP* and *M*) lead to the excess entry of services in the congested airport. Numerical simulations based on realistic parameter values provide quantitative insights on the welfare loss from private operations. Section 3 shows that there are significant differences in the levels of social welfare among Regimes *PP*, *M*, and *G*, even if the allocation of services is the same. This result stems from the difference in the choice of airport charges among three regimes. The results in Section 4 suggest that the service choice regulation is effective in limited situations, and its welfare gain is quantitatively small. In contrast, the airport charge regulation is effective regardless of the locations, and its gain is quantitatively large.

Finally, we suggest topics for future research. First, it would be useful to look at different types of airport operation, which are observed in several metropolitan areas, such as mixes of public and private operations and separate operation by different public authorities. In case of separate operation by different public authorities, we can consider two types of the operation: i) each airport is operated by an independent local authority; and ii) the central government operates one airport while the other is under the local government operation. Capacity choice is also an important issue. Moreover, this is relevant to practical policy because several metropolitan airports are undertaking the expansion of their capacity. In this regard, it is necessary to consider the interaction of capacity choice and allocation of services between multiple airports.

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Appendix A: The Inverse Demand Functions

The inverse demand function for service S at airport j, $p_j^S(\mathbf{Q^S},\mathbf{F^S})$, is derived from equation (3), and it is rearranged as $p_j^S(\mathbf{f^{Sk}},\mathbf{f^{Sl}})$ by using (4). As in Subsection 2.2, we have two cases of the relationship between boundaries. In case i), the inverse demand function $p_j^S(\mathbf{f^{Sk}},\mathbf{f^{Sl}})$ is:

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

In case ii), the inverse demand function $p_j^S(\mathbf{f^{Sk}},\mathbf{f^{Sl}})$ is:

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

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

Appendix B: Parameters

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.

To calibrate the access cost per a distance, *t*, we calculate the access cost to Kansai International Airport by railway for 50 locations in the Osaka Metropolitan Area. According to these values, we use the weighted average of the access costs per kilometer for 50 cities as the value of *t*.

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 intervals; 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 the 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*. We set the number of routes for services *I* and *D* as three and six, respectively, in order to adjust the scheduling cost for users close to realistic values.

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 per revenue passenger kilometer 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 flight for each service 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 total delay cost.

The reservation price for each service, $\bar{C}^s$, is obtained through the calibration. The following table shows the calibrated number of passengers for each service at the two airports in the Osaka Metropolitan Area. In the following table, we assume that Airport 1 locates at $x_1 = -11$ (the distance between Osaka Station and Osaka Airport) and 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 that in 2004. The total number of passengers for domestic flights, however, is close to that in 2004.

<<Table B1: About here>>

Appendix C: Details of Numerical Simulation Results

Table C1 shows the payoff matrix under Regime *PP*. In the table, the value at the left represents the revenue of Airport 1, and the one at the right is the revenue of Airport 2. As shown in Table C1, the dominant strategy for the operator is providing two services, *ID*. Tables C2, C3, and C4 respectively compare the values of components of operator's payoffs at two types of the allocation (*D*, *ID*) and (*ID*, *ID*) under Regimes *PP*, *M*, and *G*. In each table, Δ indicates the difference in each component between (*D*, *ID*) and (*ID*, *ID*).

<<Table C1: About Here>>

<<Table C2: About Here>>

<<Table C3: About Here>>

<<Table C4: About Here>>

Figure 1: The Metropolitan Area and the Locations of Airports

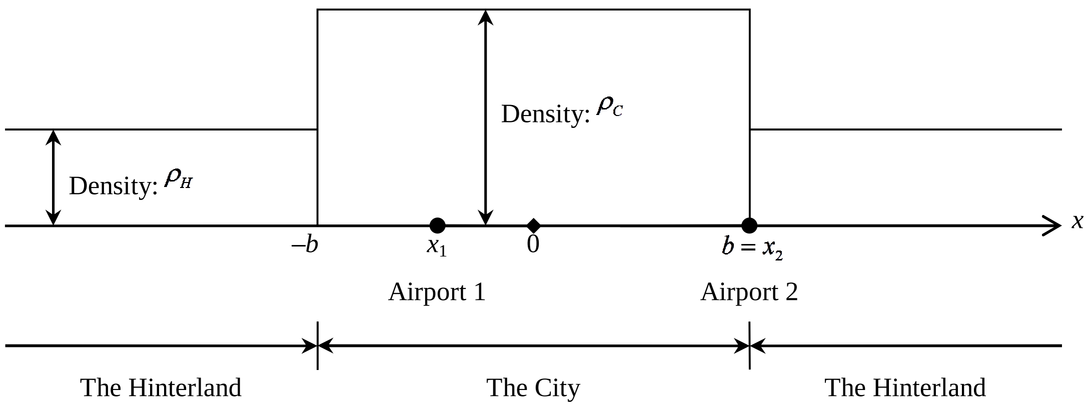

Figure 2: Allocations under Variable Airport Charges

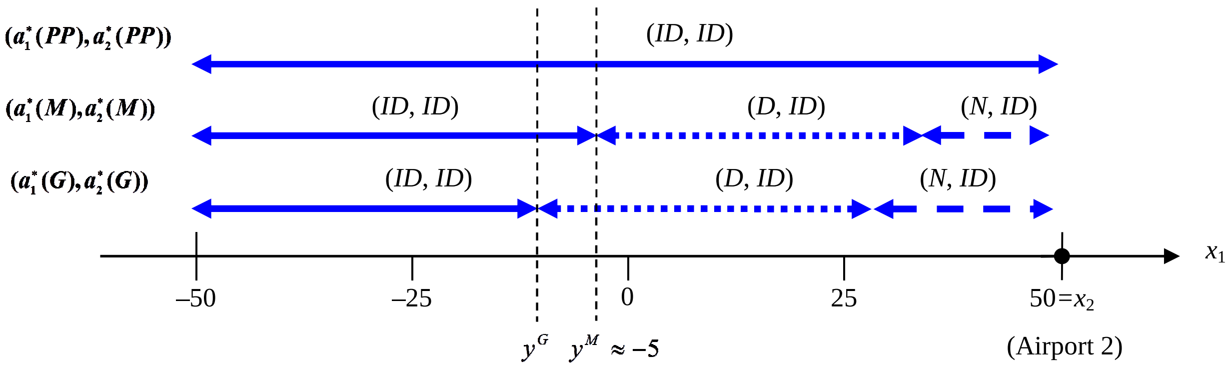

Table 1: Parameter Values

Parameter		Value	Unit
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	0.1	(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*	153	(thousand yen)
$\bar{C}^D$	Reservation price for service *D*	41	(thousand yen)

Table 2: Comparison of Allocation, Airport Charges, and Social Surplus

	Regime PP						Regime M						Regime G					
	(a_1, a_2)	r_1^I	r_2^I	r_1^D	r_2^D	SW	(a_1, a_2)	r_1^I	r_2^I	r_1^D	r_2^D	SW	(a_1, a_2)	r_1^I	r_2^I	r_1^D	r_2^D	SW
x_1		thousand yen				bn yen		thousand yen				bn yen		thousand yen				bn yen
-50	(ID, ID)	7238	7412	3567	3775	808.9	(ID, ID)	18301	18301	6899	6899	692.2	(ID, ID)	-17392	-18310	-8013	-8832	1098.5
-25	(ID, ID)	7328	7186	3656	3547	804.2	(ID, ID)	18263	18017	5754	6617	732.1	(ID, ID)	-17277	-18017	-7911	-8538	1081.0
0	(ID, ID)	7418	6959	3746	3320	797.1	(D, ID)	-	17630	5102	5488	730.8	(D, ID)	-	-17630	-8085	-8245	1058.0
25	(ID, ID)	5995	6182	2216	2508	806.6	(D, ID)	-	17630	4835	5028	703.8	(D, ID)	-	-17630	-8181	-7729	1028.3

Table 3: Welfare Effects of Regulations at Various Locations of Airport 1 (Unit: billion yen)

x_1	Welfare effect of the service choice regulation		Welfare effect of the airport charge regulation							
	Regime PP	Regime M	Regime PP				Regime M			
	$\tilde{\Delta}(PP;\mathbf{r}_1,\mathbf{r}_2)$	$\tilde{\Delta}(M;\mathbf{r}_1,\mathbf{r}_2)$	$\Delta^*(PP;ID,ID)$		$\Delta^*(PP;D,ID)$		$\Delta^*(M;ID,ID)$		$\Delta^*(M;D,ID)$	
			Optimal*)	Actual**)	Optimal	Actual	Optimal	Actual	Optimal	Actual
−50	0.0	0.0	289.6	115.7	437.0	263.4	406.3	232.4	523.4	349.8
−30	0.0	0.0	277.8	109.0	422.8	252.9	403.2	234.4	517.0	347.1
−10	0.0	0.0	261.1	98.7	402.5	235.6	406.4	244.0	408.9	242.0
10	7.2	7.2	239.0	85.7	399.6	124.0	479.4	326.1	430.8	155.2
30	17.2	0.0	200.2	41.5	386.7	59.2	329.8	171.1	493.9	166.4

Note: *) indicates that the regulated airport charges, $\bar{\mathbf{r}}_j$ (j= 1, 2), are equal to that maximizes the social surplus. **) indicates that the regulated airport charges, $\bar{\mathbf{r}}_j$, are equal to values in Kansai International Airport; specifically, $\bar{r}_1^I = \bar{r}_2^I = 1537.39$ (thousand yen), and $\bar{r}_1^D = \bar{r}_2^D = 718.08$ (thousand yen).

Table B1: The Results of the Calibration (Unit: thousand people)

	International		Domestic	
	Airport 1 (Osaka)	Airport 2 (Kansai)	Airport 1 (Osaka)	Airport 2 (Kansai)
Calibration	-	5583	9742	2072
The Passengers in 2004	-	5596	9742	2089

Table C1: the Payoff Matrix at Various Locations of Airport 1 (Unit: Billion yen)

$x_1 = -25$

a_2 \ a_1	*ID*	*I*	*D*
ID	147.7, 146.1	63.6, 320.7	84.3, 270.8
I	300.8, 65.1	63.6, 65.1	242.9, 189.3
D	420.1, 81.5	187.6, 259.5	84.3, 81.5

$x_1 = 25$

a_2 \ a_1	*ID*	*I*	*D*
ID	130.9, 88.3	64.0, 306.0	92.9, 252.1
I	306.9, 53.1	64.0, 53.1	242.9, 189.3
D	351.3, 62.8	187.6, 259.5	92.9, 62.8

Table C2: Revenues at Various Location of Airport 1 under Regime PP (Unit: Billion Yen)

x_1		Revenue						
		Airport 1			Airport 2			Total
		R_1^I	R_1^D	$R_1^I + R_1^D$	R_2^I	R_2^D	$R_2^I + R_2^D$	
	(ID, ID)	65.5	83.3	148.8	64.3	78.9	143.2	292.0
-20	(D,ID)	0.0	85.2	85.2	189.9	78.4	268.3	353.5
	Δ	-65.5	1.9	-63.6	125.6	-0.5	125.1	61.5
	(ID, ID)	66.2	84.9	151.1	64.5	73.0	137.5	288.6
-10	(D,ID)	0.0	86.8	86.8	189.9	74.3	264.2	351.0
	Δ	-66.2	1.9	-64.3	125.4	1.3	126.7	62.4
	(ID, ID)	66.8	86.6	153.4	62.9	69.1	132.0	285.4
0	(D,ID)	0.0	88.5	88.5	189.9	70.3	260.2	348.7
	Δ	-66.8	1.9	-64.9	127.0	1.2	128.2	63.3

Table C3: Revenues and Social Surplus at Various Location of Airport 1 under Regime M (Unit: Billion Yen)

x_1		Revenue						Consumer Surplus		Carriers' Profit		Social Surplus
		Airport 1			Airport 2			Service I	Service D	Service I	Service D	
		R_1^I	R_1^D	$R_1^I + R_1^D$	R_2^I	R_2^D	$R_2^I + R_2^D$	CS^I	CS^D	Π^I	Π^D	SW
	(ID, ID)	95.6	234.0	329.6	101.3	85.4	186.7	42.1	37.7	70.2	55.4	721.7
-20	(D,ID)	0.0	177.8	177.8	189.9	126.1	315.4	34.1	35.1	56.4	44.1	662.9
	Δ	-95.6	-56.2	-151.8	88.0	40.7	128.7	-8.0	-2.6	-13.8	-11.3	-58.8
	(ID, ID)	97.8	228.2	326.0	97.9	65.5	163.4	24.8	36.9	68.2	37.1	656.4
-10	(D,ID)	0.0	222.2	222.2	189.9	73.2	262.5	34.1	35.2	56.4	34.7	645.1
	Δ	-97.8	-6.0	-103.8	91.4	7.7	99.1	9.3	-1.7	-11.8	-2.4	-11.3
	(ID, ID)	99.9	221.0	320.9	94.5	42.3	136.8	26.3	32.6	66.2	21.6	604.4
0	(D,ID)	0.0	216.0	216.0	189.9	81.6	270.9	34.1	80.9	56.4	72.5	730.8
	Δ	-99.9	-5.0	-104.9	94.8	39.3	134.1	7.8	48.3	-9.8	50.9	126.4

Table C4: Values of Components of Social Surplus at Various Location of Airport 1 under Regime G (Unit: Billion Yen)

x_1		Revenue	Consumer Surplus		Carriers' Profit		Social
			Service I	Service D	Service I	Service D	Surplus
			CS^I	CS^D	Π^I	Π^D	SW
	(ID, ID)	-1288.0	554.5	541.6	569.4	698.5	1076.0
-20	(D,ID)	-1287.7	539.0	551.8	561.2	709.8	1074.1
	Δ	0.3	-15.5	10.2	-8.2	11.3	-1.9
	(ID, ID)	-1268.5	550.3	532.9	564.4	685.6	1064.7
-10	(D,ID)	-1274.0	539.0	543.5	561.2	697.2	1066.9
	Δ	-5.5	-11.3	10.6	-3.2	11.6	2.2
	(ID, ID)	-1249.5	545.9	522.5	559.5	673.0	1051.4
0	(D,ID)	-1261.0	539.0	533.6	561.2	685.2	1058.0
	Δ	-11.5	-6.9	11.1	1.7	12.2	6.6