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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 present a spatial model of the metropolitan area in which two airports provide services for two types of air transportation (international and domestic). The model describes the user's airport choice, competition among carriers, and the pricing and service choices of airport operators. We examine three types of airport operation: separate operation by two private firms (PP), integrated operation by a single private firm (M), and integrated operation by the government (G). By means of numerical simulations based on realistic parameter values, we obtained the following results: i) allocation of services vary depending on the location of airports and types of operation; ii) welfare gain from the regulation of service choice is relatively small compared to regulation of airport charges.

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

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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 International 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. New airports have recently begun to be constructed and operated privately, while 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 private 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 some cities, airports closer to the CBD provide only domestic (or short-distance) flights, while the others serve 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 affect the allocation of services among multiple airports;

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[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] This kind of the allocation is observed in some cities, such as NYC, Paris, Seoul, Tokyo, and Osaka. In contrast, in Amsterdam and Melbourne, airports closer to the CBD provide both domestic and international flights while other airports provides only domestic.

how the different types of operation alter the allocation of services and affect the economic welfare; and how large the welfare gain from regulation of the service choice is.

In many real cases, the construction for new airports in a metropolitan area arises from the need for additional airports to address the shortage of capacity in existing airports. Therefore, 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 discuss the effect of congestion pricing at a single airport, but few focus the allocation of flights between airports. Pels et al. (2000) first developed a model to describe competition between multiple airports. Their model incorporates users' choice of airports and carriers' competition, but it assumes that airport operators set charges by average cost pricing. In practice, however, private airport operators may choose decision variables that maximize their profits, while public operators may determine choices that maximize social welfare. 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. These earlier works suppose a single type of service, so the allocation of services is not a consideration[3].

[3] 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

In this study we construct a model in which two airports may provide services for two types of air transportation (international and domestic)[4], and the allocation of services is variable. The model describes interaction among users choices, carriers' competition, and airport operators' service choices. 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 our model, the role of the airport operator is to choose the types of service and the level of airport charge. In reality, however, private operators are not necessarily free to choose these decision variables. They often face regulations on airport charges and types of services to be provided at airports[5]. Thus, we consider three cases that differ in the freedom of choice for airport operators. First, we consider the case of variable airport charges and service choices, in which airport operators set both airport charges and the services to be provided at their airports. The second case, the surplus-maximizing allocation, supposes that the government regulates the service

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examine alternative allocations.

[4] 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 (e. g., domestic or international flights) provided at an airport. Consequently, it is necessary to develop a model with multiple services at airports, and the problem is to obtain the combination of services provided at two airports.

In contrast, if airport congestion is absent, there is no interaction between different services at airports; therefore, the problem for each service is solved independently to determine the number of airports providing a particular type of 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.

[5] Several studies deal with the regulation of airports due to a growing number of privatized airports. Most of these studies focused on the regulation on pricing (e. g. Oum et al. (2004) and Czerny (2006)), and not only on service choices.

choices such that the social surplus is maximized, while airport operators are free to choose airport charges. The third case is that of parametric airport charges, where airport operators choose the services to be provided at their airports while airport charges are exogenously given.

The rest of the paper is organized as follows. Section 2 presents the model and describes the behaviors of users and carriers. Section 3 shows the simulation results for variable airport charges and service choices. Sections 4 and 5 report the results for the cases of surplus-maximizing allocation and parametric airport charges, respectively. Section 6 evaluates the welfare gains of regulations on the allocation and airport charges by comparing the results obtained in the proceeding three sections. Section 7 concludes the paper.

2.0 The Model

2.1 The Basic Setting

Suppose a linear space, as illustrated in Figure 1, which consists of the City and the Hinterland:

<<Figure 1: About here>>

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 $\rho_H < \rho_C$.

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: that is, $x_2 = b$. Airport 1 is congestible while airport 2 is free from congestion[6]. The congestion costs, including extra labor, fuel costs due to delay, and the like, are incurred by carriers.

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 ($a_j = I, D, ID, N$) 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, and $a_j = N$ 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). Table 1 summarizes the possible 16 allocations[7].

<<Table 1: About here>>

2.2 Users

The trip demand for service *S* ($S = I, D$) is inelastic at the individual level, but aggregate demand is elastic. Each individual makes type *S* trips d^S times per given period unless the trip cost exceeds the reservation price, $\bar{C}^S$ ($S = I, D$). All individuals have the same value of the reservation price

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

[7] 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 users of the services are not available at both airports and choose other modes, such as autos or railways.

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 a user located at *x* using airport *j* for trip of type *S*, which is defined as:

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

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*[8]. The last term, P_j^S, is the fare 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. Note that, in our model, the service is not necessarily provided at all airports. We set $C_j^S(x) = \infty$ if the service *S* is not available at the airport *j*. In addition, if she makes a trip of type *S*, the lower trip cost should be almost as high as the reservation price $\bar{C}^S$: that is, $\bar{C}^S \geq \min_j \left\{C_j^S(x)\right\}$. Therefore, the trip demand generated from *x* for service *S* at airport *j*, $q_j^S(x)$, is calculated by:

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

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

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 catchments 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, $p_j^S(\mathbf{F^S})$, where $\mathbf{F^S} = (F_1^S, F_2^S)$.

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 catchments 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 catchments areas share the boundary: that is, $\overline{z}_1^S = \underline{z}_2^S$. In this case, at this boundary, $\overline{z}_1^S = \underline{z}_2^S$, 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 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

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) 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[9]. Consequently, the frequency of service S at airport j perceived by users, F_j^S, is equal to f_j^{Sk}.

All flights from each airport are served with full capacity, σ. In addition, carrier k, providing service S at airport j, faces the inverse demand $p_j^S(\mathbf{f}^{\mathbf{Sk}} + \mathbf{f}^{\mathbf{Sl}})$ [10], in which $\mathbf{f}^{\mathbf{Sk}} = (f_1^{Sk}, f_2^{Sk})$ and $\mathbf{f}^{\mathbf{Sl}} = (f_1^{Sl}, f_2^{Sl})$, respectively, represent the vectors of frequencies provided by carriers k and l in market S. As a result, each carrier providing service S earns revenue equal to $p_j^S(\mathbf{f}^{\mathbf{Sk}} + \mathbf{f}^{\mathbf{Sl}})\sigma$ per flight from airport j. A carrier incurs the marginal cost m_j^S and the airport charge r_j^S for each flight. Since carriers encounter 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. Through the congestion cost at airport 1, the profits of carriers providing service S are affected by the number of flights for the other service, T. Therefore, the profit of carrier k providing service S from airport j, π_j^{Sk}, is,

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

where $\boldsymbol{f}^{-}$ is a vector composed of two types of elements: the number of flights at two airports

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

[10] Since $F_j^S = f_j^{Sk} + f_j^{Sl}$, the inverse demand $p_j^S(\mathbf{F}^{\mathbf{S}})$ is rewritten as:

$$p_j^S(\mathbf{F}^{\mathbf{S}}) = p_j^S(f_1^{Sk} + f_1^{Sl}, f_2^{Sk} + f_2^{Sl}) = p_j^S(\mathbf{f}^{\mathbf{Sk}} + \mathbf{f}^{\mathbf{Sl}}).$$

Detailed expressions are given in Appendix A.

provided by the other carrier *l* providing the same service *S*, f_j^{Sl}, and the number of flights provided by carriers in the other service market *T*, f_j^{Tk}:

$$\mathbf{f}^{-} = \left(f_1^{Sl}, f_2^{Sl}, f_1^{T1}, f_2^{T1}, f_1^{T2}, f_2^{T2} \right) \quad \text{for} \quad S, T = I, D, \qquad T \neq S.$$

In addition, we assume the quantity (Cournot) competition: each carrier chooses the frequency.

Each carrier chooses the vector $\mathbf{f}^{\mathbf{Sk}} = (f_1^{Sk}, f_2^{Sk})$ to maximize the sum of the profits from two airports, i.e., $\sum_j \pi_j^{Sk}(\mathbf{f}^{\mathbf{Sk}}, \mathbf{f}^{-})$. Let us denote by $\mathbf{f}^{\mathbf{Sk*}}$ carrier *k*'s Nash Equilibrium frequencies at two airports; then, it satisfies:

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

where $\mathbf{f}^{-*}$ is the vector of the Nash Equilibrium frequencies set by the other carriers[11]. 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 provided at both airports, a_j (j = 1, 2), the equilibrium frequency of carrier *k* providing service *S* at airport *j* is expressed as $f_j^{Sk*}(\mathbf{r}_1, \mathbf{r}_2; a_1, a_2)$.

2.4 Airports

An airport operator chooses the services to be provided at its airport and sets the level of airport charge. 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:

[11] 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.

Regime M: a single private firm operates two airports.

Regime G: the government operates two airports.

2.5 The Sequence of Decisions

The sequence of decisions is as follows. First, the services to be provided at each airport, a_j (j = 1, 2), are determined, then the airport operator(s) set the levels of airport charge, r_j^S. Next, carriers choose the number of flights at each airport, f_j^{Sk}, as described in Subsection 2.3. Finally, as explained in Subsection 2.2, users choose whether or not to use service S and the airport at which to use the service.

Considering the presence of government regulations, this study examines three possibilities regarding the freedom of choices for airport operators:

i) Variable Airport Charges and Service Choices: The airport operators are free to choose the services in the airports and the levels of airport charge.

ii) Surplus-Maximizing Allocation: The government chooses the services provided at two airports in order to maximize the social surplus. Then the airport operators set airport charges at their airports.

iii) Parametric Airport Charges: Airport charges are exogenously fixed. The airport operators solely set services to be provided at their airports.

Case ii) supposes that the government controls the types of services to be provided at each airport, and case iii) corresponds to the situation where the airport charges are regulated. Fixing some decision variables is useful for not only evaluating the effects of regulation, but also for investigating the effects of different decision variables separately. The analysis in ii) and iii) clarifies the effect of decentralized decision making on pricing and service choices, respectively. The result for the case i) is reported in Section 3, and Sections 4 and 5 discuss the allocations under the presence of regulations, i.e., the results of cases ii) and iii).

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

3.1.1 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, $R_j(\mathbf{r_j},\mathbf{r_i};a_j,a_i)$:

$$R_j\left(\mathbf{r_j},\mathbf{r_i};a_j,a_i\right)=\sum_{S=I,D}\sum_{k=1,2} r_j^S f_j^{Sk*}\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right). \tag{5}$$

Let us denote by $\mathbf{r}_\mathbf{j}^*\left(a_1,a_2;PP\right)$ the vector of the airport charges set by the operator j at Nash Equilibrium, and it satisfies[12]:

[12] In some locations of airport 1, x_1, we assume that each operator, j, plays the strategy that prevents undercutting

$$\mathbf{r}_j^*\left(a_1,a_2;PP\right)=\arg\max_{\mathbf{r}_j} R_j\left(\mathbf{r}_j,\mathbf{r}_i^*\left(a_1,a_2;PP\right);a_j,a_i\right). \tag{6}$$

Plugging Eq. (6) into Eq. (5), we have:

$$R_j\left(a_j,a_i\right)=R_j\left(\mathbf{r}_j^*\left(a_1,a_2;PP\right),\mathbf{r}_i^*\left(a_1,a_2;PP\right);a_j,a_i\right). \tag{7}$$

At the Nash Equilibrium of the service choice game, the service chosen by the operator *j*, $a_j^*\left(PP\right)$, is the best response against the choice of the other operator *i*, $a_i^*\left(PP\right)$. By using Eq. (7), this can be expressed as:

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

According to this, we obtain the allocation under Regime PP, $\left(a_1^*\left(PP\right),a_2^*\left(PP\right)\right)$.

3.1.2 Regime M

The monopolistic operator first sets the allocation, (a_1, a_2), and then airport charges, r_j^S, so as to maximize the sum of revenues, $R(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2)$:

$$R\left(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2\right)=\sum_{j=1,2}\sum_{S=I,D}\sum_{k=1,2} r_j^S f_j^{Sk*}\left(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2\right). \tag{8}$$

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

$$\left(\mathbf{r}_1^*\left(a_1,a_2;M\right),\mathbf{r}_2^*\left(a_1,a_2;M\right)\right)=\arg\max_{\mathbf{r}_1,\mathbf{r}_2} R\left(\mathbf{r}_1,\mathbf{r}_2;a_1,a_2\right). \tag{9}$$

By substituting (9) into (8), we define $R(a_1,a_2)$ as:

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

According to this, the allocation under Regime M, $(a_1^*(M),a_2^*(M))$, is derived as follows:

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by its competitor *i*. Alternatively, we solve problem (6) with the constraint $C_j^S(x_j)=C_i^S(x_j)$.

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

3.1.3 Regime G

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

$$SW\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right) = \sum_{S=I,D}\sum_{j=1,2}\int_{\underline{z}_j^S}^{\overline{z}_j^S} q_j^S\left(x\right)\left[\overline{C}^S - C_j^S\left(x\right)\right]dx + \sum_{S=I,D}\sum_{k=1,2}\pi^{Sk} + R\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right), \quad (10)$$

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 given allocation (a_1, a_2). By using the equilibrium condition, $Q_j^S = \int q_j^S\left(x\right)dx = \sum_k f_j^{Sk*}\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right)$, Eq. (10) is rewritten as:

$$\begin{aligned} SW\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right) &= \sigma\sum_{S,k,j}\overline{C}^S f_j^{Sk*}\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right) - \sum_{S,k,j}\omega^S f_j^{Sk*}\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right) \\ &\quad -t\sum_{S,j}\int_{\underline{z}_j^S}^{\overline{z}_j^S} q_j^S\left(x\right)\left|x_j - x\right|dx - \frac{vh\sigma}{4}\sum_S n^S\left(a_1,a_2\right) - c\left[\sum_{S,k} f_1^{Sk*}\left(\mathbf{r_1},\mathbf{r_2};a_1,a_2\right)\right]^2. \end{aligned} \quad (11)$$

The first two terms in the RHS respectively indicate the sum of the trip benefit and the operating cost. The last three terms are the aggregate access cost, the scheduling cost, and the congestion cost. In the fourth term of the RHS, $n^S(a_1,a_2)$ shows the number of airports providing service S under the allocation (a_1, a_2): for example, $n^S(ID,ID) = n^S(ID,S) = 2$ since service S is provided at two airports under both allocations (ID, ID) and (ID, S).

Under the allocation (a_1, a_2), the charges at each airport j set by the government, $\mathbf{r_j^*}\left(a_1,a_2;G\right)$, satisfy the following relationship:

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

By substituting Eq.(12) into Eq.(10), we define $SW(a_1,a_2)$ as:

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

According to this, the allocation under Regime G, $(a_1^*(G),a_2^*(G))$, is obtained as follows:

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

3.2 Allocations under Alternative Regimes

Allocations under the three alternative regimes are obtained by means of numerical simulation. We choose the values of parameters so that the solutions of the model fit the observed value in the real world. The size of the City is set as the segment of [–50, 50] according to the data of the Osaka Metropolitan Area. Other parameter values are summarized in Table 2[13]:

<<Table 2: About here>>

Figure 2 shows the allocations under the three alternative regimes:

<<Figure 2: About here>>

According to Figure 2, under Regime PP, the allocation (*ID*, *ID*) is realized regardless of the location of airport 1, x_1. On the other hand, the results under the Regimes M and G depend on the location (*ID*, *ID*) is emerged if x_1 is small, i.e., locations of the two airports are sufficiently distant from each other. As the distance between the two airports becomes shorter, the allocation changes from (*ID*, *ID*) to (*D*, *ID*), and then to (*N*, *ID*). The domain of (*ID*, *ID*) under Regime M is larger than

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

that under Regime G. This result implies that private operations lead to excessive entry of services (too many services provided).

Let us take a closer look at the mechanism underlying different results between regimes. For $y^M \leq x_1$ in Figure 2, (*ID*, *ID*) is realized under Regime PP while (*D*, *ID*) occurs under Regime M. This implies that changing from (*ID*, *ID*) to (*D*, *ID*) decreases the revenue in airport 1 while it increases the sum of revenue from the two airports. To see this, we decompose the difference in revenue at airport 1 between (*ID*, *ID*) and (*D*, *ID*), as follows:

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

where ΔR_j^S is the difference in the revenue from *S* (*S* = *I*, *D*) at airport *j* (*j* = 1, 2). In (13), ΔR_1^I is negative since revenue from service *I* at the airport under (*D*, *ID*) is zero. ΔR_1^D is positive since congestion at airport 1 is eased by changing from (*ID*, *ID*) to (*D*, *ID*), and this reduction of congestion induces an increase in demand for domestic flights at airports. However, the former effect dominates the latter for the whole range of x_1, so the RHS of Eq. (13) is negative. In other words, the operator of airport 1 does not have an incentive to stop providing service *I*.

On the other hand, the difference in the sum of revenues from two airports is

$$R\left(D, ID\right) - R\left(ID, ID\right) = \Delta R_1^I + \Delta R_1^D + \Delta R_2^I + \Delta R_2^D. \tag{14}$$

For $y^M \leq x_1$ in Figure 2, the RHS of (14) is positive, thus the monopolistic operator chooses (*D*, *ID*) instead of (*ID*, *ID*). In Eq. (14), ΔR_2^I is positive since service *I* is concentrated at airport 2 under the allocation (*D*, *ID*), while ΔR_2^D is negative due to the reduction in the congestion at airport 1[14]. The sum of these two terms, $\Delta R_2 = \Delta R_2^I + \Delta R_2^D$, is always positive because the increase in the revenue from service *I*, ΔR_2^I, dominates. Under Regime PP, recall that $\Delta R_1 = \Delta R_1^I + \Delta R_1^D < 0$: the operator of airport 1 always loses revenue by changing the service from *ID* to *D*. However, under Regime M, the monopolistic operator may earn more revenue by choosing (*D*, *ID*) instead of (*ID*, *ID*); it recovers the loss at airport 1, ΔR_1, by the gain at airport 2, ΔR_2. This difference leads to the different results in the allocations between two regimes, PP and M. As x_1 increases, changes in revenues at both airports, ΔR_1 and ΔR_2, increase[15]; subsequently, for $y^M \le x_1$, the monopolistic operator can increase the revenue by changing the allocation from (*ID*, *ID*) to (*D*, *ID*).

Let us look at the difference between Regimes M and G. For $y^G \le x_1 \le y^M$ in Figure 2, the allocation (*ID*, *ID*) emerges under Regime M while (*D*, *ID*) emerges under Regime G. This means that, within this range of x_1, changing from (*ID*, *ID*) to (*D*, *ID*) decreases the sum of revenue from two airports while it increases the social surplus. For $y^G \le x_1 \le y^M$, the sign of Eq. (14) is negative, since the loss of the revenue at airport 1, ΔR_1, exceeds the gain at airport 2, ΔR_2, thus the private operator chooses the allocation (*ID*, *ID*) instead of (*D*, *ID*).

The government considers the welfares of users and carriers as well as the revenue from airport

[14] When changing the allocation from (*ID*, *ID*) to (*D*, *ID*), the congestion at airport 1 is reduced. This reduction in the congestion induces service *D* carriers to reallocate flights between the two airports. Due to the advantage of location, service *D* flights at airport 1 always increase while those at airport 2 decrease.

[15] The values of ΔR_1 and ΔR_2 varies with the location of airport 1, and depends on the change in the revenue from service I at each airport *j* (i.e., $\Delta R_j \approx \Delta R_j^I$). As the distance between the two airports decreases, the catchments area of service I under (*D*, *ID*) approaches the one under (*ID*, *ID*). This implies that, as distance decreases, the loss in the catchment area of airport 1 shrinks while the gain in the catchment area of airport 2 expands. Alternatively, the changes in the revenues of the two airports, ΔR_1 and ΔR_2, increase as x_1 increases.

charges. The difference in the social surplus between the allocations (*ID*, *ID*) and (*D*, *ID*) is decomposed into three parts:

$$SW\left(D,ID\right)-SW\left(ID,ID\right)=\sum_{S=I,D}\Delta CS^{S}+\sum_{S=I,D}\Delta\pi^{S}+\sum_{j=1,2}\Delta R_{j}, \tag{15}$$

where 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 (15) is positive because the gains of users, $\sum_{S}\Delta CS^{S}$, and carriers, $\sum_{S}\Delta\pi^{S}$, dominate the decrease in the revenue, $\sum_{j}\Delta R_{j}$: therefore, the public operator chooses the allocation (*D*, *ID*) instead of (*ID*, *ID*).

Let us explain in detail the gains of users and carriers. Service *I* users receive the greatest gain of all users (i.e., $\sum_{S}\Delta CS^{S}\approx\Delta CS^{I}$); it is split into three parts:

$$\begin{aligned}\Delta CS^{I}&=CS^{I}\left(D,ID\right)-CS^{I}\left(ID,ID\right)\\&\approx\frac{vh\sigma}{4}+\sigma\bar{C}^{I}\Delta f^{I}+t\left[\sum_{j}\int_{\underline{z}_{j}^{I}}^{\bar{z}_{j}^{I}}q_{j}^{I}\left(x\right)\left|x_{j}-x\right|dx-\int_{\underline{z}_{2}^{I}}^{\bar{z}_{2}^{I}}q_{2}^{I}\left(x\right)\left|x_{2}-x\right|dx\right],\end{aligned} \tag{16}$$

where $\Delta f^{I}=\sum_{k}f_{2}^{Ik}\left(D,ID\right)-\sum_{j,k}f_{j}^{Ik}\left(ID,ID\right)$. In Eq. (16), the three terms of the RHS respectively represent the changes in the scheduling cost, the trip benefit, and the access cost[16]. The first term of the RHS in Eq. (16), the change in the scheduling cost, is always positive, and it is constant for the location of airport 1, x_1. In contrast, the last two terms are negative, and these terms decrease as x_1 increases (i.e., the distance between the two airports decreases) since the catchment area of service *I* under (*D*, *ID*) approaches that under (*ID*, *ID*). As a result, for $y^{G}\le x_{1}$ in Figure 2,

[16] In addition to these three components, the consumer surplus of service I is affected by the change in the fare. However, since the change in the fare affects service I carriers in the opposite direction, the effect of the change in the fare is cancelled when comparing the social surplus.

the sign of the RHS in Eq. (16) becomes positive.

Changing the allocation from (*ID*, *ID*) to (*D*, *ID*) affects the profits of both service *I* and service *D* carriers. The change in the service *I* carriers' profit is decomposed as:

$$\Delta\pi^I = \pi^I(D,ID) - \pi^I(ID,ID) \approx -\omega^I \Delta f^I + c\sum_{S,k} f_1^{Sk}(ID,ID) \times \sum_{k=1,2} f_1^{Ik}(ID,ID). \quad (17)$$

Eq. (17) shows the change in the profit of service *I* carriers, resulting from the reductions in operating cost (the first term of the RHS) and congestion cost (the second term of the RHS). Independent from the location of airport 1[17], the sum of these two effects is always positive[18].

The change in the profits of service *D* carriers is decomposed as:

$$\Delta\pi^D = \pi^D(D,ID) - \pi^D(ID,ID) \approx c\Delta f_1 \times \Delta f_1^D, \quad (18)$$

where

$$\Delta f_1 = \sum_{S,k} f_1^{Sk}(ID,ID) - \sum_k f_1^{Dk}(D,ID) \text{ and } \Delta f_1^D = \sum_k f_1^{Dk}(ID,ID) - \sum_k f_1^{Dk}(D,ID).$$

Eq. (18) indicates that the change in the profit of service *D* carriers is equal to the reduction in the congestion cost at airport 1. This reduction in the congestion cost always increases the profit of service *D* carriers, and this increases as airport 1 locates closer to airport 2. These gains by users and carriers are not considered in the private operator's decision making. This causes different allocations between two regimes, M and G, within the range of $y^G \le x_1 \le y^M$ in Figure 2.

[17] Although the value of x_1 does not affect the sign of $\Delta\pi^I$, the magnitudes of these two effects vary with the location of airport 1. As x_1 increases, the reduction in the congestion cost increases because airport 1 serves the larger area of the City, while the reduction in the operating cost decreases as the distance between two airports decreases because the difference in the catchment area between two locations becomes smaller.

[18] This does not imply that service I carriers always prefer operating at airport 2 than at two airports because we ignore the effect of the change in the fare, which is cancelled between users and carriers when we calculate the social surplus.

Table 3 compares the social surpluses and the airport charges under three regimes:

<<Table 3: About here>>

In Table 3, the government always sets negative airport charges in order to remedy the distortion from the market power of carriers. In addition, the airport charges under Regime M are always the highest among three regimes because the monopolistic operator abuses its market power in determining the airport charges. Note that for $x_1 = 0$ and 25, the allocation of services under Regime M coincides with that under Regime G, which is different from that of Regime PP. This suggests that the service choice under Regime M is more efficient than under Regime PP. Under Regime M, however, inefficiency in the determination of airport charges is dominant, making the social surplus lower than that under Regime PP.

4.0 Surplus-Maximizing Allocation: Regulation of the Service Choice

This section supposes that the government regulates the service choices, so that the allocation is chosen to maximize the social surplus while the airport charges are set by the operators. Alternatively, this section postulates the optimal regulation of the service choice. This type of regulation is observed in some metropolitan areas, such as Milan, Tokyo, Osaka, Seoul, and Shanghai.

As in Section 3, given the allocation, (a_1, a_2), the operator under Regime Z (Z = PP, M, G) sets the charges at airport j as $\mathbf{r}_{\mathrm{j}}^{*}(a_1, a_2; Z)$. Taking this into account, the surplus-maximizing allocation under Regime Z is derived as follows:

$$\left(a_1^O(Z), a_2^O(Z)\right) = \arg\max_{a_1, a_2} SW\left(\mathbf{r}_1^*\left(a_1, a_2; Z\right), \mathbf{r}_2^*\left(a_1, a_2; Z\right); a_1, a_2\right), \text{ for } Z = PP, M, G.$$

Recall that, under Regime G in Section 3, both the allocation and the airport charge are determined in order to maximize the social surplus. The surplus-maximizing allocation under Regime G becomes identical to the allocation under Regime G in Section 3.

Figure 3 shows the surplus-maximizing allocations under the three regimes:

<<Figure 3: About here>>

Comparing Figure 3 with Figure 2, we observe that there is little difference in the results concerning the allocation of services. The results for Regimes PP and G are the same as in Section 2, while the result for Regime M is different. Domain of (*ID*, *ID*) under Regime M in Figure 3 is smaller than that in Figure 2, while the domain of (*N*, *ID*) in Figure 3 is larger than that in Figure 2. However, the difference is insignificant.

Note that the results shown in both figures are obtained by assuming variable airport charges; i.e., airport operators choose the levels of airport charges. Therefore, if the allocation is identical, the levels of airport charges and consequently the social surpluses must be the same in Figures 2 and 3. This implies that the service choices of private operators yield almost the same results as the surplus maximizing allocation. In other words, the regulation of service choices has only a limited effect.

5.0 Parametric Airport Charges: Regulation of Pricing

This section supposes that airport operators determine the services to be provided at their airports while airport charges are exogenously fixed. This situation can be interpreted as the case where airport charges are regulated. Since airports are regarded as a local monopoly, the regulation of airport charges is justified to control their market power. In this case, the inefficiency due to private operation arises solely from the service choices of airport operators.

We first formulate the operators' decision making in Subsection 5.1. Subsection 5.2 shows the result based on airport charges in Kansai International Airport in Japan.

5.1 Decisions of Airport Operators under Alternative Regimes

5.1.1 Regime PP

In this regime, each airport is operated by a single private firm. Given the fixed airport charge for each service *S*, $\tilde{r}_j^S$, each operator *j* sets the service provided at its airport, a_j, so as to maximize the revenue, $R_j(\tilde{\mathbf{r}}_\mathbf{j},\tilde{\mathbf{r}}_\mathbf{i};a_j,a_i)$:

$$R_j\left(\tilde{\mathbf{r}}_\mathbf{j},\tilde{\mathbf{r}}_\mathbf{i};a_j,a_i\right)=\sum_{S=I,D}\sum_{k=1,2}\tilde{r}_j^S f_j^{Sk*}\left(\tilde{\mathbf{r}}_\mathbf{1},\tilde{\mathbf{r}}_\mathbf{2};a_1,a_2\right).$$

Let us denote by $\tilde{a}_j(PP)$ the services chosen by the operator of airport *j* (*j* = 1, 2) at the Nash Equilibrium, which is the best response to the choice of the other airport *i*, $\tilde{a}_i(PP)$, i.e.,

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

According to this, the allocation under Regime PP is derived as $(\tilde{a}_1(PP),\tilde{a}_2(PP))$.

5.1.2 Regime M

A single private firm operating two airports chooses the services provided at two airports, a_1 and a_2, so as to maximize the sum of revenue from two airports, $R(\tilde{\mathbf{r}}_1, \tilde{\mathbf{r}}_2; a_1, a_2)$:

$$R\left(\tilde{\mathbf{r}}_1, \tilde{\mathbf{r}}_2; a_1, a_2\right) = \sum_{j=1,2} \sum_{S=I,D} \sum_{k=1,2} \tilde{r}_j^S f_j^{Sk*}\left(\tilde{\mathbf{r}}_1, \tilde{\mathbf{r}}_2; a_1, a_2\right).$$

The allocation under Regime M, $(\tilde{a}_1(M), \tilde{a}_2(M))$, satisfies the following relationship:

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

5.1.3 Regime G

This regime supposes that the government operates two airports. The objective of the government is to maximize the social surplus, $SW(\tilde{\mathbf{r}}_1, \tilde{\mathbf{r}}_2; a_1, a_2)$, defined as follows:

$$SW\left(\tilde{\mathbf{r}}_1, \tilde{\mathbf{r}}_2; a_1, a_2\right) = \sum_{S=I,D} \sum_{j=1,2} \int_{\underline{z}_j^S}^{\overline{z}_j^S} q_j^S(x)\left[\overline{C}^S - C_j^S(x)\right]dx + \sum_{S=I,D} \sum_{k=1,2} \pi^{Sk} + R\left(\tilde{\mathbf{r}}_1, \tilde{\mathbf{r}}_2; a_1, a_2\right).$$

The allocation under Regime G, $(\tilde{a}_1(G), \tilde{a}_2(G))$ satisfies the following relationship:

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

5.2 Allocations under Alternative Regimes

Airport charges for service S ($S = I, D$) at airport j ($j = 1, 2$), r_j^S, are set as:

$\tilde{r}_1^I = \tilde{r}_2^I = 1537.39$ (thousand yen),

$\tilde{r}_1^D = \tilde{r}_2^D = 718.08$ (thousand yen).

These values are drawn from actual airport charges for services I and D at Kansai International Airport in Japan. Figure 4 shows the allocations of services under the three alternative regimes.

<<Figure 4: About here>>

In Figure 4, the domain of (*ID*, *ID*) is identical between the two private operations, Regimes PP and M. The identity of the domain of (*ID*, *ID*) is due to the choice of service *I* carriers; i.e., the service *I* carriers choose $f_1^{Ik} = 0$ (k = 1, 2) for $x_1 > \bar{y}$ in Figure 4, even though the operator of airport 1 allows service *I*. In fact, the operators' choices under these two regimes are different, but the carriers' choice is decisive in determining the allocation of services between airports[19]. The domain of (*ID*, *ID*) under Regime G is smaller than that under private operation (PP and M). This is explained similarly to the case of variable airport charges discussed in Section 3.

6.0 Comparison of Regulations of Service Choice and Airport Charges

In real cases, airport operators face the regulation of airport charges and of service choice. The regulation on levels of airport charges typically takes the form of the price cap regulation (e.g., London). Moreover, in some metropolitan areas, the service choices are regulated. For example, in East Asian cities (e.g., Tokyo, Osaka, Seoul, and Shanghai), airports closer to the CBD are allowed to serve only domestic flights. In addition, the perimeter rule implemented in some cities (e.g., NYC, Washington D.C, and Tokyo) can be another type of service choice regulation because it restricts airports closer to the CBD to serving flights operating within a certain range of distance. In this section, we evaluate the welfare effect of regulations described above.

[19] When carriers providing service I choose whether or not to operate at two airports, they face the tradeoff between the revenue and the congestion cost. If a carrier operates flights at two airports, the revenue of a carrier is larger because the number of flights is larger. However, operating at airport 1 imposes the congestion cost. For $x_1 > \bar{y}$ in Figure 4, even if private operators allow two services, *ID*, to airport 1, service I carriers choose $f_1^{Ik} = 0$ (k = 1, 2) because they can maximize their profits by avoiding the congestion cost.

In the three preceding sections, we have considered three situations where decision variables of operators differ: i.e., variable airport charges and service choices, surplus-maximizing allocation, and parametric airport charges. In the surplus-maximizing allocation, operators set levels of airport charges while service allocation maximizes the social surplus. The surplus-maximizing allocation can be interpreted as the optimal regulation of service choice. In the case of parametric airport charges, levels of airport charges are exogenously given while operators choose the service provided at airports. This situation corresponds to the case with the regulation of airport charges. Therefore, by comparing the social surplus under the three alternative situations, we can evaluate the welfare effect of regulations.

The welfare effect of the regulation of service choices, $\tilde{\Delta}(Z;\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2)$, is calculated as:

$$\tilde{\Delta}(Z;\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2) = SW\left(\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2;\tilde{a}_1(G),\tilde{a}_1(G)\right) - SW\left(\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2;\tilde{a}_1(Z),\tilde{a}_2(Z)\right),$$

where $\tilde{a}_j(G)$ and $\tilde{a}_j(Z)$, respectively, represent the service choices of airport *j* chosen by the government and by the private operator under Regime Z (Z = PP, M). $\tilde{\Delta}(Z;\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2)$ is the difference between the levels of social surplus for Regime G and the private operations (PP and M), supposing that the levels of airport charges are set at exogenously given level $\bar{\mathbf{r}}_\mathrm{j}$.

We compute the welfare effect of the regulation on levels of airport charges, $\Delta^*(Z;a_1,a_2)$, by:

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

where $\bar{\mathbf{r}}_\mathrm{j}$ denotes the regulated level of 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 between the regulated airport charges, $\bar{\mathbf{r}}_{\mathbf{j}}$, and the charges set by the operator under Regime Z (Z = PP, M), $\mathbf{r}_{\mathbf{j}}^*(Z)$.

Table 4 shows $\tilde{\Delta}(Z;\bar{\mathbf{r}}_{\mathbf{1}},\bar{\mathbf{r}}_{\mathbf{2}})$ and $\Delta^*(Z;a_1,a_2)$, at various locations of airport 1:

<<Table 4: About Here>>

In computing $\tilde{\Delta}(Z;\bar{\mathbf{r}}_{\mathbf{1}},\bar{\mathbf{r}}_{\mathbf{2}})$ and $\Delta^*(Z;a_1,a_2)$, we use the levels of parametric airport charge shown in Subsection 5.2 as the regulated airport charges[20]. According to Table 4, the welfare effects of the regulation on the airport charges, $\Delta^*(Z;a_1,a_2)$, reach at least 41.5 billion yen[21] while those of the regulation on the service choice, $\tilde{\Delta}(Z;\bar{\mathbf{r}}_{\mathbf{1}},\bar{\mathbf{r}}_{\mathbf{2}})$, reach at most 7.1 billion yen. This indicates that regulation of the levels of airport charges might have significant impact on the social surplus compared to regulation of the service choice. Also note that $\tilde{\Delta}(Z;\bar{\mathbf{r}}_{\mathbf{1}},\bar{\mathbf{r}}_{\mathbf{2}})$ has positive value only at $x_1 = 10$, straightforwardly from the results shown in Figure 4. Specifically, under the parametric airport charges, the allocations under private operation differ from that under Regime G within the narrow range of x_1, which implies that the regulation of the service choice has a limited effect in improving the social welfare[22]. Therefore, the rationale for the regulation of the service choice is

[20] Instead of parametric airport charges, the airport charge set by the government, $\mathbf{r}_{\mathbf{j}}^*(a_1,a_2;G)$, is the other candidate for the regulated level of airport charge. However, since $\mathbf{r}_{\mathbf{j}}^*(a_1,a_2;G) < 0$ as shown in Table 3, it is not practical to assume that the government sets the negative airport charges as the regulated level.

[21] In Table 4, the welfare effect of the regulation of airport charges is relatively large under Regime M compared to Regime PP, straightforwardly from Table 3. That is, the monopolistic operator has greater market power in determining the levels of airport charges, and the competition between the two airports is absent. Under Regime M, the regulation of airport charges mitigates these inefficiencies and generates a larger welfare effect.

[22] We can draw the same conclusion from the comparison of Figures 2 and 3. As explained in Section 4, the difference between Figures 2 and 3 arises solely from the difference in the service choice: i.e., in Figure 2, operators freely choose the service provided at their airports while, in Figure 3, the service is determined by the government to maximize the social surplus. By comparing these two figures, the difference in the allocation is observed only under Regime M within a limited range of x_1 (for $-10 \le x_1 < -5$), and the welfare effect is at most

questionable although this kind of regulation is widely implemented across the world.

7.0 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 vary depending on the locations of the airports and the types of airport operation. When the two airports are distant from each other, each airport provides two types of service, and the number of services provided at the airport closer to the CBD decreases as the distance between two airports decreases. The private operations (Regimes PP and M) lead to the excess entry of services in the airport closer to the CBD when operators are allowed to choose the services provided at their airports. Numerical simulations based on realistic parameter values provide quantitative insights on the effects of regulations. 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 is due to the difference among the airport charges. Section 4 shows that regulation of service choices has little effect on the allocation of services. Finally, Section 5 shows that welfare losses by deviation from optimal allocation of services are relatively small if the airport charges are fixed. As discussed in Section 6, the results above suggest that although the

2.3 billion yen. Also note that, under Regime PP, there is no effect of the optimal regulation because both airport charges and the service choice are identical. These results also suggest that the regulation of the service choice has a limited impact on the social welfare.

regulation of the service choice is effective in some situations, it has a limited impact on efficiency. On the other hand, the regulation of the levels of airport charges are essential.

Finally, we suggest topics for future research. First, it would be useful to deal with mixes of public and private operations in which one of two airports is operated by the government and the other by a private firm. There are some metropolitan areas where public and private airports coexist. Capacity choice is also an important issue. This is also relevant to practical policy because several metropolitan airports have undertaken the expansion of their capacity. In this case, 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* is calculated from the following:

$$\sigma \sum_k f_j^{Sk} = Q_j^S .$$

As we explained in Subsection 2.2, we have two cases of the relationship between boundaries. In case i), the inverse demand function $p_j^S(\mathbf{f}^{\mathbf{Sk}} + \mathbf{f}^{\mathbf{Sl}})$ is derived as follows:

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

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

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

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

Appendix B: Parameters

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 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 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 International 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>>

Figure 1: The Economy and the Locations of Airports

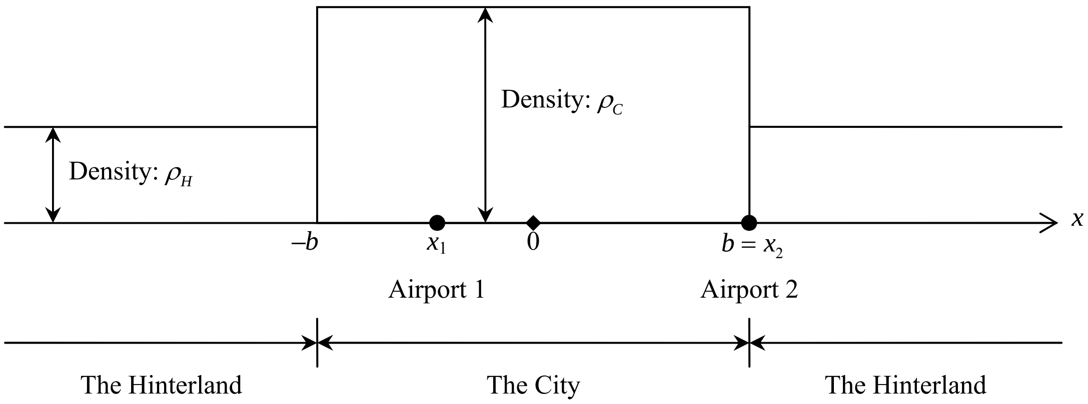

Figure 2: Allocations under Variable Airport Charges

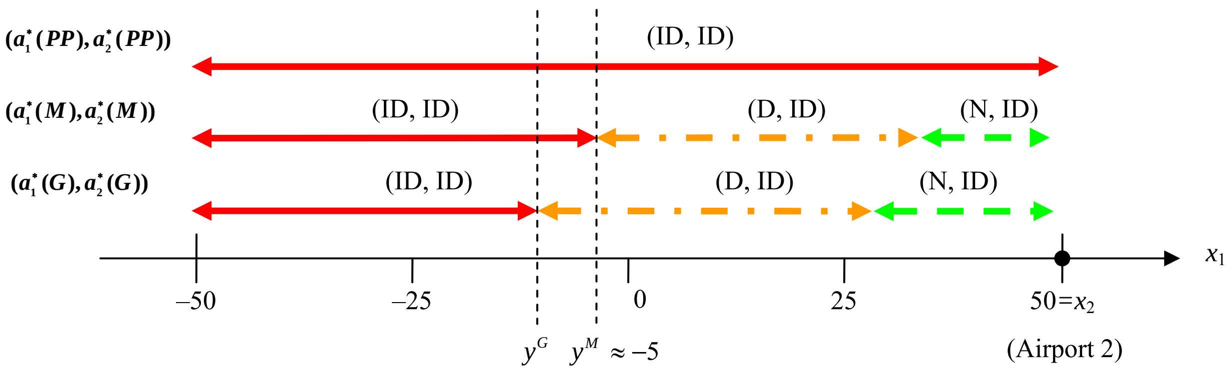

Figure 3: The Surplus-Maximizing Allocations

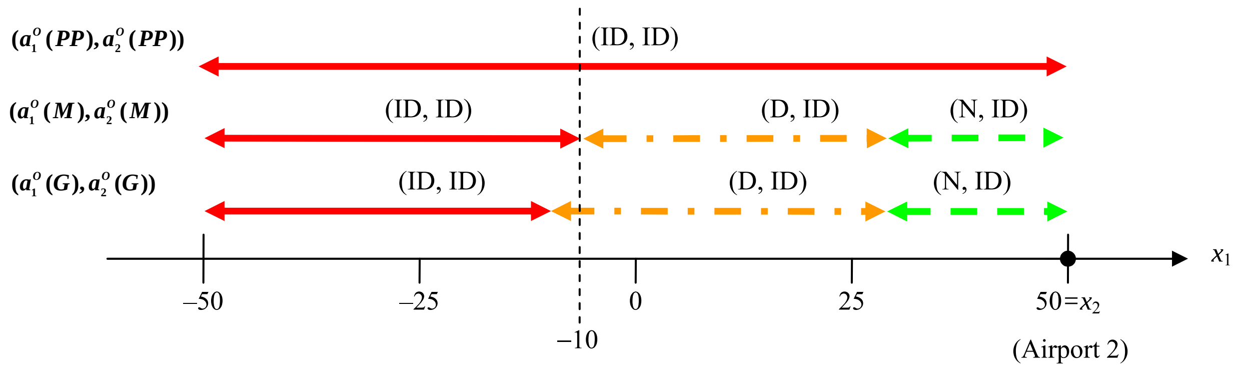

Figure 4: Allocations under Parametric Airport Charges

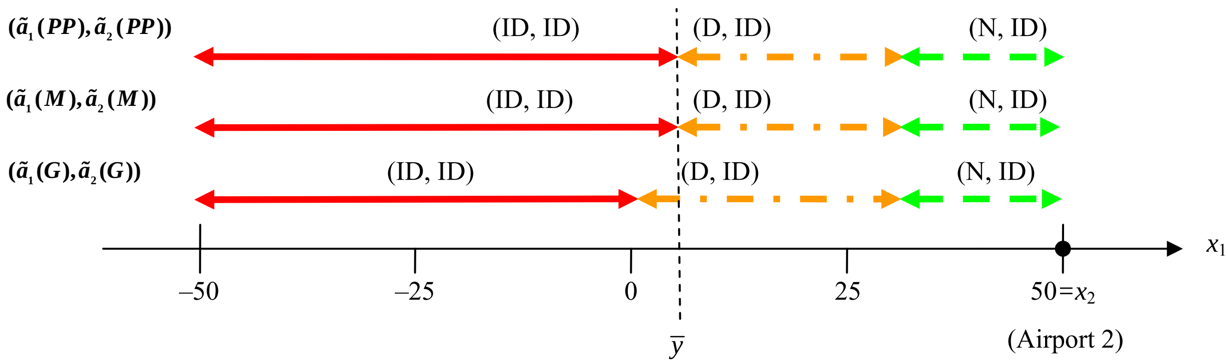

Table 1: Notations for the Allocations of Services between Two Airports

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)

Table 2: 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 3: Comparison of Social Surplus and Airport Charges

x_1	Regime PP SW (billion yen)	Regime PP r_1^I (thousand yen)	r_2^I	r_1^D	r_2^D	Regime M SW (billion yen)	Regime M r_1^I (thousand yen)	r_2^I	r_1^D	r_2^D	Regime G SW (billion yen)	Regime G r_1^I (thousand yen)	r_2^I	r_1^D	r_2^D
−50	808.9	7238	7412	3567	3775	692.2	18301	18301	6899	6899	1098.5	−17392	−18310	−8013	−8832
−25	804.2	7328	7186	3656	3547	732.1	18263	18017	5754	6617	1081.0	−17277	−18017	−7911	−8538
0	797.1	7418	6959	3746	3320	744.1	-	17630	5102	5488	1058.0	-	−17630	−8085	−8245
25	806.6	5995	6182	2216	2508	703.8	-	17630	4835	5028	1028.3	-	−17630	−8181	−7729

Table 4: Welfare Effects of Regulations at Various Locations of Airport 1 (Unit: billion yen)

x_1	Welfare effect of the regulation on service choice: $\tilde{\Delta}(PP;\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2)$	$\tilde{\Delta}(M;\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2)$	Welfare effect of the regulation on airport charges, Regime PP: $\Delta^*(PP;ID,ID)$	Regime PP: $\Delta^*(PP;D,ID)$	Regime M: $\Delta^*(M;ID,ID)$	Regime M: $\Delta^*(M;D,ID)$
−50	0.0	0.0	115.7	263.4	232.4	349.8
−30	0.0	0.0	109.0	252.9	234.4	347.1
−10	0.0	0.0	98.7	235.6	244.0	242.0
10	7.1	7.1	85.7	124.0	326.1	155.2
30	0.0	0.0	41.5	59.2	171.1	166.4

Note: $\Delta^*(Z;a_1,a_2)$ (Z = PP, M and (a_1, a_2) = (*ID*, *ID*), (*D*, *ID*)) measures the welfare effect of the regulation of the levels of airport charges while $\tilde{\Delta}(Z;\bar{\mathbf{r}}_1,\bar{\mathbf{r}}_2)$ captures the welfare effect of the regulation of the service choice. In calculating these deviations, we use the levels of parametric airport charges (shown in Section 5) as the levels of the regulated airport charges.

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

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