The Organization of Multiple Airports in a Metropolitan Area with Users Heterogeneity

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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 incorporates the users' heterogeneity in the value of time. We examine two types of policies, the optimal pricing and the regulation of the service choice. It is analytically shown that: i) the optimal airport charges are equal to the marginal congestion cost, and ii) the optimal allocation of services is equivalent to the no regulation. Moreover, by means of numerical simulations based on realistic parameter values, we obtained the result such that: i) the welfare gain of the regulation on the allocation is observed if two airports are relatively close; ii) the welfare gain of the regulation on the allocation of services is quantitatively smaller than the optimal pricing.

Keywords: Allocation of services, users' heterogeneity, location of airports, regulation

1. Introduction

It is observed that several metropolitan areas have multiple airports, such as NYC, Tokyo and Osaka. Moreover, in some cases, each airport within the same metropolitan area has a different role. For example, in case of Osaka, Japan, Osaka International Airport provides only domestic flights while Kansai International Airport provides both international and domestic flights. We call such a division of roles among multiple airports as the *allocation of services*. The allocation of services is sometimes as a result of the regulation by the government. In case of Osaka or other East Asian cities, the central government directly regulates the services provided at two airports while, in NYC or other major cities in the U.S., the allocation of services is indirectly regulated through a perimeter rule, which prohibits the airport serving flights operating within a certain range of distance. Also note that the locations of airports might affect the regulation on the service choice. For example, the airport closer to the CBD is allowed to serve only domestic (or short-distance) flights while the airport further away from the CBD is allowed to serve both domestic and international (or both short-distance and long-distance) flights.

Although the regulation of the service choice is implemented in several cities, Mun and Teraji (2010) show that the regulation of the service choice improves the economic welfare, but its welfare gain is quantitatively smaller than the regulation of the pricing. However, since Mun and Teraji (2010) assume that users are homogenous in the value of time, the homogeneity assumptions might underestimate the role of the pricing. Once incorporating the heterogeneity in the value of time, the optimal pricing might improve the welfare of high value of time users, and the economic welfare more through the segregation of users by the pricing; i.e. users who have relatively high value of time utilize the airport where the levels of airport charges are higher, and can reduce the time cost to utilize airports.

In many real cases, the shortage of the capacity at the existing airport leads to the construction of a new airport, and as a result, some of metropolitan areas have multiple airports: therefore, the congestion at airports is an essential factor to study about multiple airports in a metropolitan area. There is substantial literature about the congestion at airports (Brueckner (2002), Pels and Verhoef (2004), Zhang and Zhang (2006)), but most of them discuss about the effect of the congestion pricing at a single airport. Few literatures (Pels et al. (2000), De Borger and Van Dender (2006), and Basso and Zhang (2007)) studied about the setting of multiple airports in a metropolitan area. These literatures, however, mainly focus on users' choice of airports or pricing and capacity choice of airport operators. Moreover, they assume that airports provide a single service, so the allocation of services is not a consideration. Van Dender (2005) developed the model where multiple airports provide multiple services, but he focuses on the case that each facility provides all types of services, and so does not examine alternative allocations.

Our study extends Mun and Teraji (2010) by incorporating the heterogeneity in the value of time among users, and we construct a model in which two airports can provide two types of services (international and domestic flights), and the allocation of services is variable. By using this model, we consider the following issues. First, we evaluate the welfare gain of the optimal pricing and the service choice. In addition, we measure the incidence of the welfare gain among heterogeneous users and the effect of the change in the degree of the heterogeneity on the optimal outcomes. Second, given the levels of airport charges, we evaluate the welfare effect of the regulation on the service choice by comparing the social surplus among alternative allocation of services. Moreover, we check the effect of the distance between two airports on the rationale for the regulation of the service choice.

This paper is organized as follows: Section 2 explains the model. Section 3 formulates the social planner's problems at the optimum and the second best. At the second best, we consider the case where the optimal pricing is infeasible, and the social planner chooses the allocation of services. Section 4 gives the results of the numerical simulation at the social optimum and at the second best. In this section, we show the results of the comparison between two alternative policy regimes and the results of sensitivity analyses. This section also provides the specification of the model and parameter values. Finally, Section 5 concludes.

2. The Model

2.1. Basic Settings

Suppose a city which has the population *n*. The population is heterogeneous in the value of time, *w*. The distribution of *w* is represented by the density function $\rho(w)$, and this suffices:

$$\int \rho(w)\,dw = n.$$

In addition, we assume that the value of time, w, is equivalent to the wage per hour. Each type of user makes two types of air trip, international and domestic trips, which are hereafter denoted by I and D respectively. Moreover, we assume that trips from/ to the city is generated from a single point, the city center; in other words, it is the origin of all trips.

The city has two airports, named as airports 1 and 2: two airports can provide two types of services, I and D. 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).

The locations of two airports are exogenously given, and airport 1 is located at the city center while airport 2 is located at the distance, x, from the city center. Figure 1 summarizes the geographic feature of the city:

<<Figure 1: About Here>>

Two airports are congestible and the congestion cost is incurred by users, such as delays of departures or arrivals.

Finally, we set up the following sequence of decisions:

i) Airport charges and the allocation are determined;

ii) Users choose the number of trips for each service *S* and the airport for each service if the service is provided at two airports.

Also note that we assume carriers are perfectly competitive, and we omit the formulation of carriers' behavior.

2.2. Users

Each type of user makes two decisions, the number of trips and airport choice. Type *w*'s airport choice for service *S* is to minimize the generalized cost. Type *w*'s generalized cost for service *S* (*S*=*I*, *D*) at airport *j* (*j*=1, 2) is given by:

$$g_j^S(w) = p_j^S + f^S + \tau_j + wt_j^S \text{ for } S = I, D \text{ and } j = 1, 2, \tag{1}$$

where f^S and p_j^S are the fare per service *S* trip and the airport charge for service *S* at airport *j* respectively[1]. The third term of Eq. (1), τ_j, is the monetary cost to access airport *j*, and the last term is type *w*'s time cost to make a service *S* trip at airport *j*, and t_j^S is defined as:

$$t_1^S = \bar{t}^S + c_1 Q_1, \tag{2-1}$$

$$t_2^S = \bar{t}^S + c_2 Q_2 + ax. \tag{2-2}$$

In Eqs (2), the first term of the RHS, $\bar{t}^S$, is the fixed amount of time for service *S* trip, which includes the time of flights, stays at the destination, etc. The second term of the RHS in Eqs (2) captures the time of delay due to the congestion at airports, and we assume airport 1 is more

[1] Note that this formulation is equivalent to the case where the airport charges are imposed on carriers. Specifically, according to the assumption of the perfect competition of carriers, we can apply the zero profit condition on the fare setting by carriers. Consequently, carriers set the fare as the marginal cost plus the airport charges. In other words, the formulation (1) corresponds to both cases where the airport charges are directly imposed on users, and where the fare includes the airport charges.

congestible than airport 2; namely, $c_1 > c_2$. The third term of Eq. (2-2) is the time to access to airport 2, and a>0.

Let us denote by $\delta_j^S(w)$ type w's airport choice for service S: $\delta_j^S(w)$ equals to one if type w uses airport j for service S, and equals to zero otherwise. According to the comparison of generalized costs for service S at two airports, type w's airport choice is given by:

$$\delta_j^S(w) = \begin{cases} 1 & \text{if } g_j^S(w) \le g_k^S(w), \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

By using, $\delta_j^S(w)$, type w's generalized cost for service S, $g^S(w)$, and the number of trips, $g^S(w)$, are derived as:

$$g^S(w) = \sum_j \delta_j^S(w) g_j^S(w),$$

In consideration of the airport choice, users maximize their utility $U(z, q^I, q^D)$ by choosing the consumption of composite good, z, and the number of trips for two services, q^I and q^D. Since the value of time, w, is equivalent to the wage per hour, type w's budget constraint is given by:

$$w\bar{h} = z + \sum_S g^S(w) q^S, \tag{4}$$

where $\bar{h}$ is the initial endowment of the time. According to Eqs (3) and (4), type w's utility maximization problem is formulated as:

$$\max_{z, q^I, q^D} U(z, q^I, q^D) \text{ subject to (3) and (4).} \tag{5}$$

Solving the problem (5), we get type w users' demand functions:

$$z(w) = z\left(w\bar{h}, g^I(w), g^D(w)\right), \tag{6-1}$$

$$q^S(w) = q^S\left(w\bar{h}, g^I(w), g^D(w)\right) \text{ for } S = I, D. \tag{6-2}$$

Plugging these demand functions into the utility, type *w*'s indirect utility is derived as $V\left(w\bar{h}, g^I(w), g^D(w)\right)$.

According to Eqs (3) and (6-2), the aggregate demand for service *S* (*S*=*I*, *D*) at airport *j* (*j*=1, 2), Q_j^S, is computed by:

$$Q_j^S = \int_{\underline{w}}^{\bar{w}} \rho(w)\delta_j^S(w)q^S(w)dw.$$

3. Social Optimum and the Second Best

This section formulates two types of the social planner's problem. Subsection 3.1 considers the social planner's problem at the social optimum, and characterizes the optimal outcomes. Subsection 3.2 considers the second best policy under the situation where the optimal pricing is infeasible. In this situation, the social planner chooses the allocation of services to maximize the social surplus.

3.1. Social Optimum

There are various formulations of the problem to obtain the social optimal allocation. This model has two kinds of agents, users and the airport operator. Users' welfare is represented by the utility level that is not measurable by monetary unit. The operator's welfare is represented by the revenue from airport charges, measured in monetary terms. Therefore, we cannot define the social planner's objective by aggregating the welfare of two kinds of agents. Furthermore, it is necessary to aggregate the utility of users having different value of time.

In order to deal with these problems, we formulate the social planner's problem as follows. First, we require that each type of users to achieve a target utility level, $u(w)$. The social optimum attains when the social surplus is maximized under the utility constraint described above. The social surplus is defined by the total income of users minus the social cost, such as the consumption of the composite goods, the monetary access cost to airports, and the time cost to make air trips: i.e.,

$$\int_{\underline{w}}^{\bar{w}} \rho(w)\left[w\bar{h} - z(w) - \sum_{S,j} \delta_j^S(w)\left(\tau_j + wt_j^S\right)q^S(w)\right]dw, \tag{7}$$

The utility constraint is:

$$u(w) = V\left(w\bar{h} + b(w), g^I(w), g^D(w)\right), \tag{8}$$

where $b(w)$ is the compensating variation to achieve the target utility level, $u(w)$. Moreover, the optimal allocation must satisfy the following constraints on the airport choice and on the population:

$$\delta_1^S(w) + \delta_2^S(w) = 1, \tag{9-1}$$

$$\delta_j^S(w) = 1 \text{ or } \delta_j^S(w) = 0, \tag{9-2}$$

$$\int \rho(w)\,dw = n. \tag{9-3}$$

Notice that at the optimum, type *w*'s budget constraint suffices:

$$\sum_{S,j}\delta_j^S\left(w\right)p_j^S q^S\left(w\right)-b\left(w\right)=w\overline{h}-z\left(w\right)-\sum_{S,j}\delta_j^S\left(w\right)\left(wt_j^S+\tau_j\right)q^S\left(w\right).$$

Summing over all types' budget constraints,

$$\int_{\underline{w}}^{\overline{w}}\rho\left(w\right)\left[w\overline{h}-z\left(w\right)-\sum_{S,j}\delta_j^S\left(w\right)\left(wt_j^S+\tau_j\right)q^S\left(w\right)\right]dw=\sum_{S,j}p_j^S Q_j^S-\int_{\underline{w}}^{\overline{w}}\rho\left(w\right)b\left(w\right)dw. \tag{10}$$

The social surplus is equivalent to the airport charge revenue net of compensating variations. By replacing the objective function by using Eq. (10), we formulate the social planner's problem as:

$$\max_{p_k^T,b(w),\delta_k^T(w)}\ \sum_{S,j}p_j^S Q_j^S-\int_{\underline{w}}^{\overline{w}}\rho\left(w\right)b\left(w\right)dw, \tag{11}$$

subject to (8), (9-1), (9-2), (9-3),

where control variables are the levels of airport charges, p_j^S, each type's airport choice, $\delta_j^S\left(w\right)$, and the compensation, $b(w)$. The first order conditions are:

$$b\left(w\right):\lambda\left(w\right)=\frac{1}{\partial V/\partial y}, \tag{12-1}$$

$$p_k^T:Q_k^T+\sum_{S,j}p_j^S\frac{dQ_j^S}{dp_k^T}+\int_{\underline{w}}^{\overline{w}}\lambda\left(w\right)\rho\left(w\right)\left[\sum_{S,j}\delta_j^S\left(w\right)\frac{\partial V}{\partial g^S}\frac{\partial g^S}{\partial p_k^T}\right]dw=0, \tag{12-2}$$

$$\begin{aligned}\delta_k^T\left(w\right):\lambda\left(w\right)\rho\left(w\right)\frac{\partial V}{\partial g^T}\frac{\partial g^T}{\partial\delta_k^T\left(w\right)}+\mu^T\left(w\right)-\mu_k^T\left(w\right)=0 &\quad \text{if } \delta_k^T\left(w\right)=1,\\ \lambda\left(w\right)\rho\left(w\right)\frac{\partial V}{\partial g^T}\frac{\partial g^T}{\partial\delta_k^T\left(w\right)}+\mu^T\left(w\right)<0 &\quad \text{if } \delta_k^T\left(w\right)=0,\end{aligned} \tag{12-3}$$

where $\lambda\left(w\right)$ is the Lagrange multiplier for type *w*'s utility constraint, (8). In Eq. (12-3), $\mu^T\left(w\right)$ and $\mu_k^T\left(w\right)$ are the Lagrange multipliers for constraints (9-1) and (9-2) respectively.

Plugging Eq. (12-1) into Eq. (12-2) and applying the Roy's Identity, Eq. (12-2) is rewritten as:

$$\sum_{S,j}\left[p_j^S - c_j\sum_{S'}\tilde{w}_j^{S'}Q_j^{S'}\right]\frac{dQ_j^S}{dp_k^T} = 0, \text{ for } S = I, D \text{ and } j = 1, 2, \tag{13}$$

where $\tilde{w}_j^{S'}$ is the average value of time among service S' users at airport j:

$$\tilde{w}_j^{S'} \equiv \int_{\underline{w}}^{\overline{w}} \rho(w) \times \frac{w\delta_j^{S'}(w)q^{S'}(w)}{Q_j^{S'}}dw.$$

Notice that, at the optimum, Eq. (13) must hold for two services at two airports. Let us denote by superscript * the optimal solutions, then the optimal airport charge for service S at airport j is derived as:

$$p_j^{S*} = c_j\sum_{S'}\tilde{w}_j^{S'*}Q_j^{S'*}, \text{ for } S = I, D \text{ and } j = 1, 2. \tag{14}$$

Eq. (14) says that, at the optimum, the airport charge for service S at airport j should be equal to the marginal congestion cost at airport j. Moreover, at the optimum, the charges for two services at the same airport should be equalized.

Substituting Eq. (12-1) into Eq. (12-3) and arranging Eq. (12-3), we have:

$$\delta_j^{S*}(w) = 1 \text{ and } \delta_k^{S*}(w) = 0 \Leftrightarrow g_j^{S*}(w) = \frac{\mu^{S*}(w) - \mu_j^{S*}(w)}{\rho(w)} < g_k^{S*}(w),$$

$$\delta_j^{S*}(w) = 0 \text{ and } \delta_k^{S*}(w) = 1 \Leftrightarrow g_j^{S*}(w) > \frac{\mu^{S*}(w)}{\rho(w)} = g_k^{S*}(w) + \frac{\mu_j^{S*}(w)}{\rho(w)}.$$

These two conditions solely request that, at the optimum, all users should minimize their generalized cost for each service S when they choose the airport. Moreover, since the optimal airport charge is identical between two services at the same airport, we have three kinds of the optimal allocation of services: i) two airports provide two services, (*ID*, *ID*); and ii) one of two airports is closed, (*ID*, *N*) or (*N*, *ID*). Let us exclude the trivial cases, (*ID*, *N*) and (*N*, *ID*), which are single airport cases. Above results imply the regulation of the service choice such as, (*ID*, *D*), (*D*, *ID*), etc, are not necessary as long as the optimal pricing is feasible.

3.2. The Regulation of the Service Choice as the Second Best

This subsection formulates the social planner's problem under the circumstance where the optimal airport charges are infeasible. Specifically, we treat the levels of airport charges as exogenously given, $p_j^S = \bar{p}_j^S$. In such case, the social planner maximizes the social surplus by choosing the type of services allowed in each airport, a_j. In other words, the social planner maximizes the social surplus by regulating the service choice of the airport operator.

As a result of the regulation, each type's airport choice, $\delta_j^S(w)$, is determined: if the service provided at airport *j* is regulated to the service $T \neq S$,

$$\delta_j^S(w) = 0 \quad \text{and} \quad \delta_k^S(w) = 1 \quad \text{for all } w.$$

In order to treat the allocation of services, (a_1, a_2), explicitly, let us denote by $\delta_j^S(w \mid a_1, a_2)$ type *w*'s airport choice under the situation where the allocation of service is regulated to (a_1, a_2). For example, under the allocation (*D*, *ID*), where airport 1 is prohibited to provide service *I*, $\delta_j^S(w \mid D, ID)$, must satisfy:

Service *I*: $$\delta_1^I(w \mid D, ID) = 0 \quad \text{and} \quad \delta_2^I(w \mid D, ID) = 1 \quad \text{for all } w,$$

Service *D*: $$\delta_j^D(w \mid D, ID) = \begin{cases} 1 & \text{if } g_j^D(w) \leq g_k^D(w), \\ 0 & \text{otherwise.} \end{cases}$$

In other words, users' airport choices for service *I* is restricted to airport 2 under the regulation of the allocation (*D*, *ID*) while airport choices for service *D* is not regulated and users can choose the airport to minimize the generalized cost.

Therefore, the planner's problem is equivalent to maximize the social surplus by choosing the regulation of the service choice, (a_1, a_2), with the constraint such that type *w*'s airport choice is regulated. Let us denote by (a_1^{SB}, a_2^{SB}) the second best allocation of services, then it suffices:

$$\left(a_1^{SB}, a_2^{SB}\right) = \arg\max_{a_1, a_2} \left\{ \sum_{S,j} \overline{p}_j^S Q_j^S - \int_{\underline{w}}^{\overline{w}} \rho\left(w\right) b^{SB}\left(w\right) dw \,\middle|\, \text{s.t. } \delta_j^S\left(w\right) = \delta_j^S\left(w \mid a_1, a_2\right) \right\}, \tag{15}$$

where $b^{SB}\left(w\right)$ is the compensating variation at the second best.

4. The Numerical Simulation

This section shows the outcomes at the social optimum and under the regulation of the service choice through the numerical simulation. Subsection 4.1 provides the specification of the model and parameter values. Subsection 4.2 reports the result of the numerical simulation at the optimum. This subsection also evaluates the effect of the change in the heterogeneity of users. Subsection 4.3 reports the result of the regulation of the service choice, and compares with the optimum.

4.1. Specification and Parameter Values

We specify the distribution of the value of time as the log-normal distribution: i.e. the population of type w users are given by:

$$\rho(w) = \frac{n}{\sqrt{2\pi\sigma^2}w} \exp\left[\frac{(\log w - \mu)^2}{2\sigma^2}\right],$$

where μ and σ respectively represent the average and the standard deviation of the distribution[2]. The preference of users is represented by the Cobb-Douglas utility function:

$$U\left(z, q^I, q^D\right) = z^{1-\left(\beta^I+\beta^D\right)} q^{I\beta^I} q^{D\beta^D},$$

where β^S captures the expenditure share for service S (S=I, D).

Parameter values are summarized in Table 1:

<<Table 1: About Here>>

The population, n, is equal to that of Osaka Metropolitan Area, in Japan. Parameters of the density function, μ and σ, are chosen so that the distribution of the value of time in this model fits the distribution of the labor income in Japan. Figure 2 plots the probability density, $\rho(w)/n$ against the value of time, w:

<<Figure 2: About Here>>

The fare for each service, f^S (S=I, D), is based on the realistic value. The value of $\bar{t}^S$ includes the time of flights (4 hours for service D and 30 hours for service I) and stays at destination (36 hours for both services). The distance between the City and Airport 2, x, is equal

[2] Under the log-normal distribution, let us denote by w^m the average value of time, then $w^m = \exp(\mu)$. The standard deviation, σ, measures the degree of the heterogeneity, and an increase in σ implies that the degree of the heterogeneity increases.

to the one between the CBD of Osaka and Kansai Airport, and the time per distance, *a*, is equal to the ratio between the access time and the distance from CBD to Kansai Airport.

The expenditure share for service *S*, β^S, and the marginal delay time at airport *j* (j=1, 2), c_j, are calibrated so that the outcome of the model fits the actual number of users at two airports in Osaka Metropolitan Area. In case of Osaka, however, since the allocation of service is regulated to (*D*, *ID*), we cannot calibrate four parameters (β^S and c_j) according three observable data. In order to avoid this problem, we set the marginal delay time at airport 1 is equal to 1.7 times[3] as the marginal delay time at airport 2. Table 2 summarizes the result of the calibration and the actual number of users in 2004:

<<Table 2: About Here>>

Hereafter, we call the result summarized in Table 2 as the benchmark case, and we set each type's target utility level, $u(w)$, as the level at the benchmark case. Figure 3 plots the differential of the generalized cost for service *D*, $g_1^D(w) - g_2^D(w)$, at the benchmark case against the value of time, *w*:

<<Figure 3: About Here>>

In Figure 3, $\hat{w}$ represents the type who is indifferent between utilizing airport 1 and airport 2. Figure 3 shows that, in the benchmark case, individuals who have relatively high value of time use airport 2 (located far away from the city center) while those who have low value of time use

[3] This is the ratio of operating hours at two airports.

airport 1 (located close to the city center). This result stems from the fact that, as shown in Table 3, the level of airport charge at airport 1 (more congestible) is lower than at airport 2 (less congestible), and as a result, airport 1 is heavily congested. Therefore, individuals who have relatively high value of time prefer to use less congested airport even though they need to incur the access cost.

4.2. The Social Optimum

In this subsection, we report optimal solutions computed through the numerical simulation. First, we report the results of the base case, in which parameter values are set as shown in Table 1, and then we consider how the changes in the degree of the heterogeneity affect the optimal solutions, and the incidence of the welfare improvement among heterogeneous users.

The Base Case

Table 3 below summarizes the optimal levels of airport charge and the number of users at each airport for two services:

<<Table 3: About Here>>

Figure 4 plots the differentials of the generalized cost for service *D*, at the social optimum, $g_1^{D*}(w) - g_2^{D*}(w)$, and at the benchmark, $g_1^{D}(w) - g_2^{D}(w)$, against the value of time, *w*:

<<Figure 4: About Here>>

In Figure 4, $\hat{w}^*$ is the type who is indifferent between utilizing two airports at the optimum. According to Figure 4, individuals who have relatively high value of time utilize airport 1 at the optimum. This result is referred from the fact shown in Table 4: i.e. the levels of airport charge at airport 1 (more congestible) are higher than at airport 2 (less congestible). Consequently, the congestion at airport 1 is relaxed, and the delay time at airport 1 is shortened. Therefore, individuals who have relatively high value of time prefer to use airport 1, the more easily accessible airport.

To measure the change in the economic welfare, we compute the social surplus according to Eq. (11). Table 4 compares the social surplus between the benchmark case and the social optimum:

<<Table 4: About Here>>

As shown in Table 4, the social surplus is improved through implementing the optimal policy. Notice that the value of compensating variation is negative in the row of Social Optimum in Table 4. This implies that in order to achieve the benchmark utility level, $u(w)$, the most of users are willing to pay; in other words, the most of users are better off by the optimal policy. Therefore, the improvement of the social surplus stems from the fact that the improvement of users' welfare, measured by the compensating variation, dominates the loss of the operator, the decrease in the sum of revenues.

Although the welfare of users is improved at the aggregated level, the incidence of the welfare improvement among users varies with types. In order to measure the incidence of the welfare improvement among users, we use the optimal level of the compensating variation, $b^*(w)$. If the optimal policy reduces the generalized cost for trips, $g^S(w)$, the compensating variation, $b^*(w)$, takes the negative value. Figure 5 plots the compensating variation, $b^*(w)$, against the value of time, w:

<<Figure 5: About Here>>

As shown in Figure 5, since $b^*(w)$ is negative for all types, the optimal policy improves the welfare of all users.

The degree of the improvement, however, varies with types, and we can divide the population into several groups according to the change in the airport utilization. Let us denote by Group (i, j) a group of users who change to use airport j at the optimum from airport i at the benchmark case, then we have Groups (1, 2), (2, 2), and (2, 1) according to Figure 4. Group (1, 2) users have the relatively low value of time $w < \hat{w}$, and within this range of the value of time, the compensating variation, $b^*(w)$, is decreasing for low value of time while it is constant for high value of time. This is explained by the comparison of Tables 3 and 4: for low value of time users, the improvement of the welfare is generated from the reduction in the level of airport charge for service I (from 5.70 to 2.07); for high value of time users, although the reduction in the airport charge for service I improves their welfares, the increase in the number of users at the same airport as their airport choice (from 9,742 to 12,169 for service D and from 7,684 to 12,169 for service I) reduces the welfare improvement.

Group (2, 2) users have the value of time $\hat{w} < w < \hat{w}^*$, and their welfares are improved through the optimal policy. However, for this range, the compensating variation, $b^*(w)$, increases as the value of time, w, increases. According to the comparison of Tables 3 and 4, we can conclude that this result stems from the increase in the number of airport 2 users (from 7,684 to 12,169). Due to the increase in the number of users, the delay time is lengthened, and as the value of time increases the time cost, wt_2^S, increases.

Group (2, 1) users have relatively high value of time, $w > \hat{w}^*$, and their welfares are also improved at the social optimum. Also note that, for this range, the compensating variation, $b^*(w)$, is monotonically decreasing as the value of time, w, increases. Through the comparison of Tables 3 and 4, this result is generated from the decrease in the number of users at the same airport as their airport choice (from 7,684 to 5,896).

The Effect of the Degree of the Heterogeneity

The degree of the heterogeneity is measured by the standard variation, σ, of the density function, $\rho(w)$, and the degree of the heterogeneity expands as σ increases. We evaluate the effect of the degree of the heterogeneity by increasing σ from 0.3 to 0.5. By increasing σ from 0.3 to 0.5, the value of time at 99 percentile rises from 6.5 thousand yen to 9.6 thousand yen. Table 5 compares the optimal outcomes at $\sigma = 0.3$ and $\sigma = 0.5$:

<<Table 5: About Here>>

As shown in Table 5, although the levels of airport charges at both airports rise as σ increases, the number of users at airport 1 decreases while the number of users at airport 2 increases. This is explained by the difference in the rise of airport charge at two airports. The distribution of users' value of time directly is affected by the difference in the levels of charges in absolute value. Therefore, since the increase in the airport charge at airport 1 is much larger than the increase at airport 2, the distribution of users' value of time at airport 1 shifts rightward as σ increases. Moreover, this shift explains the rise in the level of airport charges. At airport 1, since the distribution of users' value of time moves rightward[4], the average value of time, $\tilde{w}_1^S$, increases, and consequently the level of airport charges rises. This distribution shift at airport 1 induces the change in the distribution of users' value of time at airport 2; this leads to the rise in the charges at airport 2.

The changes in the social surplus shown in Table 5 are qualitatively similar to the base case: i.e. the social surplus is improved through implementing the optimal policy. However, at $\sigma = 0.5$, the degree of the improvement of users' welfare is lower than at $\sigma = 0.3$ while the decrease in the revenue is mitigated. This is explained by the change in the levels of airport charges. As σ increases, the optimal level of the airport charge rises due to the change in the distribution of users' value of time at both airports. As a result, the improvement of the users' welfare shrinks and the decrease in the revenue is mitigated.

Figure 6 compares the compensating variations, $b^*(w)$, at $\sigma = 0.5$ and $\sigma = 0.3$:

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[4] At each case, $\hat{w}^*$ is given by:

$$\hat{w}^*\big|_{\sigma=0.3} = 3.4 < \hat{w}^*\big|_{\sigma=0.5} = 3.9.$$

<<Figure 6: About Here>>

As shown in Figure 6, at both cases, all types of users are improved through implementing the optimal policy, and the incidence of the welfare improvement is qualitatively similar. However, most of users are less improved when σ changes from 0.3 to 0.5; this is induced by the rise in the levels of airport charges. In contrast, top 10% of the population is more improved when σ changes from 0.3 to 0.5. These users, who have relatively high value of time and utilize airport 1, receive the benefit from the reduction in the number of users at airport 1.

4.3. The Regulation of the Service Choice

In this subsection, we report the results of the numerical simulation for the regulation of the service choice. The regulation of the service choice is characterized by the situation where the social planner chooses the allocation of services while the levels of airport charges are exogenously given. In the numerical simulation, we set the levels of airport charges as the current level. Also note that, although there are 16 types of allocations, based on the results of Mun and Teraji (2010), we limit our focus on two types of the allocation, (*ID*, *ID*) and (*D*, *ID*). In Mun and Teraji (2010), we show that the allocation of services changes from (*ID*, *ID*) to (*N*, *ID*) via (*D*, *ID*) as the distance between two airports decreases.

This subsection is organized as follows: first, we compare the outcomes under the no regulation, (*ID*, *ID*), and the regulation, (*D*, *ID*), at the base case where parameters are given is Subsection 4.1. Then, we consider how the distance between the city center and airport 2 affect the social surplus under two types of allocation; finally, we compare the social surplus among three alternative policies, the optimal pricing, the regulation of the service choice, (*D*, *ID*) ,and the no regulation, (*ID*, *ID*).

The Base Case

Table 6 compares the results under the regulation of the service choice, (*D*, *ID*), and of no regulation, (*ID*, *ID*), at the current level of airport charges:

<<Table 6: About Here>>

According to Table 6, the social surplus is improved through the regulation of the service choice. Since the revenue increases through the regulation, the operator is better off through the regulation of the service choice. In contrast, since the compensating variations take negative value at no regulation, (*ID*, *ID*), the regulation of the service choice worsens the welfare of the uses. However, since the gain of the operator dominates the loss of users, the regulation of the service choice improves the social surplus. This result indicates that when the optimal pricing is infeasible, regulating the allocation to (*D*, *ID*) has some rationale.

Figure 7 plots the compensating variations at no regulation, (*ID*, *ID*), against the value of time:

<<Figure 7: About Here>>

In Figure 7, $\hat{w}(D, ID)$ and $\hat{w}(ID, ID)$ are the types who are indifferent between using two airports under corresponding allocations. Figure 7 shows that all users are better off through the removal of the regulation of the service choice. According to Figure 7, users are divided into three groups according to the change in the airport choice: Groups (1, 1), (1, 2), and (2, 2). By changing the allocation from (*D*, *ID*) to (*ID*, *ID*), the welfare improvement among Group (1, 1) users is generated from the reduction in the airport charge for service *I* (from 5.7 to 5.0 according to Table 6). In contrast, the welfare improvement among users in Groups (1, 2) and (2, 2) stems from the decrease in the number of users at the same airport as their choice.

The Effect of the Distance between City Center and Airport 2

At the Base Case, the regulation of the service choice is justified since the social surplus under (*D*, *ID*) is greater than the social surplus under (*ID*, *ID*). In this part, we evaluate the effect of the distance between the city center and airport 2, *x*, on the justification of the regulation. Figure 8 plots the social surpluses under two alternative allocations:

<<Figure 8: About Here>>

As shown in Figure 8, the social surplus under (*ID*, *ID*) exceeds the one under (*ID*, *ID*) for $x > \hat{x}$, and for this domain, the regulation of the service choice cannot be justified. This result is qualitatively similar to Mun and Teraji (2010). In Mun and Teraji (2010), we show that the optimal regulation of the service choice varies with distance between two airports. Moreover, as the distance between two airports increases, the optimal regulation changes from (*D*, *ID*) to (*ID*, *ID*).

Also note that Figure 8 shows that the social surpluses under two allocations move differently: the social surplus under (*D*, *ID*) is relatively constant over the distance, *x*. In contrast, the social surplus under (*ID*, *ID*) fluctuates over the distance, x; for $x<35$, the social surplus under (*ID*, *ID*) decreases as the distance, x, increases while for $x>35$, the social surplus under (*ID*, *ID*) increases as x increases. The movement of the social surplus under (*D*, *ID*) is explained as follows. As the distance between the city center and airport 2, x, increases, the number of service *D* users at airport 2 decreases. This decrease in the service *D* users induces the increase in the number of service *I* users, and service *D* users at airport 1. In summary, although the loss of the revenue from service *D* at airport 2 increases as x increases, it is recovered through the increase in the revenue from service *I* at airport 2 and service *D* at airport 1.

The fluctuation of the social surplus under (*ID*, *ID*) is generated from the changes in the sum of revenues at two airports and the compensating variations. As x increases, the more users utilize airport 1, where the levels of the airport charges are lower, and consequently the sum of revenues decrease. In contrast, the increase in the number of users at airport 1 induces the decrease in the compensating variation for high value of time users since they are improved more as the number of users at the same airport as their choice, airport 2. As a result, the compensating variation in absolute value increases as x increases. For $x>35$, the increase in the compensating variation dominates the decrease in the sum of the revenue, and the social surplus increases.

The Comparison with the Social Optimum

Return to the Base Case, Table 7 compares the outcomes at the social optimum, the regulation of the service choice, (*D*, *ID*), and the no regulation, (*ID*, *ID*):

<<Table 7: About Here>>

Table 7 shows that changing the allocation from (*D*, *ID*) to (*ID*, *ID*) always improves the welfare of users. Without the optimal pricing, the gain of users cannot recover the loss of the operator, and consequently, the social surplus at the no regulation becomes smaller than that of the regulation of the service choice. In other words, the regulation of the service improves the social surplus compared to the no regulation case. However, once implementing the optimal pricing, the welfare gain of users dominates the loss of operator, and as a result, the social surplus at the optimal pricing exceeds that of the regulation of the service choice. To put it differently, the welfare gain of the optimal pricing dominates that of the regulation of the service choice. This indicates that the regulation of the service choice is justified if the optimal pricing is infeasible.

5. Conclusion

This paper extends the model of Mun and Teraji (2010) by introducing the heterogeneity among users with respect to the value of time. We consider two types of policies, the optimum and the regulation of the service choice. The optimal policy is characterized by the following: i) the optimal airport charge is equal to the marginal delay cost, and it is identical between services at the same airport; ii) it is unnecessary to implement the regulation of the service choice. Moreover, in Subsection 4.2, by means of numerical simulation, we show that the optimal policy improves the welfare of users and worsens that of the operator. Also note that the levels of the optimal airport charges rise as the degree of the heterogeneity increases. As a result, the welfare gain of users shrinks and the loss of the operator is mitigated.

At the regulation of the service choice, we consider the case where the optimal pricing is infeasible. In Subsection 4.3, we show that the regulation of the service choice improves the economic welfare. However, the welfare gain of the regulation of the service choice is observed as long as the distance between two airports is relatively close. Moreover, the welfare gain of the regulation is quantitatively smaller than that of the optimal policy. These results are qualitatively similar to Mun and Teraji (2010), and suggest that the regulation of the service choice is justified if the optimal pricing is infeasible.

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<<FIGURES>>

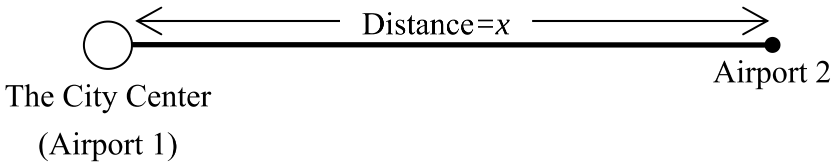


Figure 1: The Geographic Feature of the City

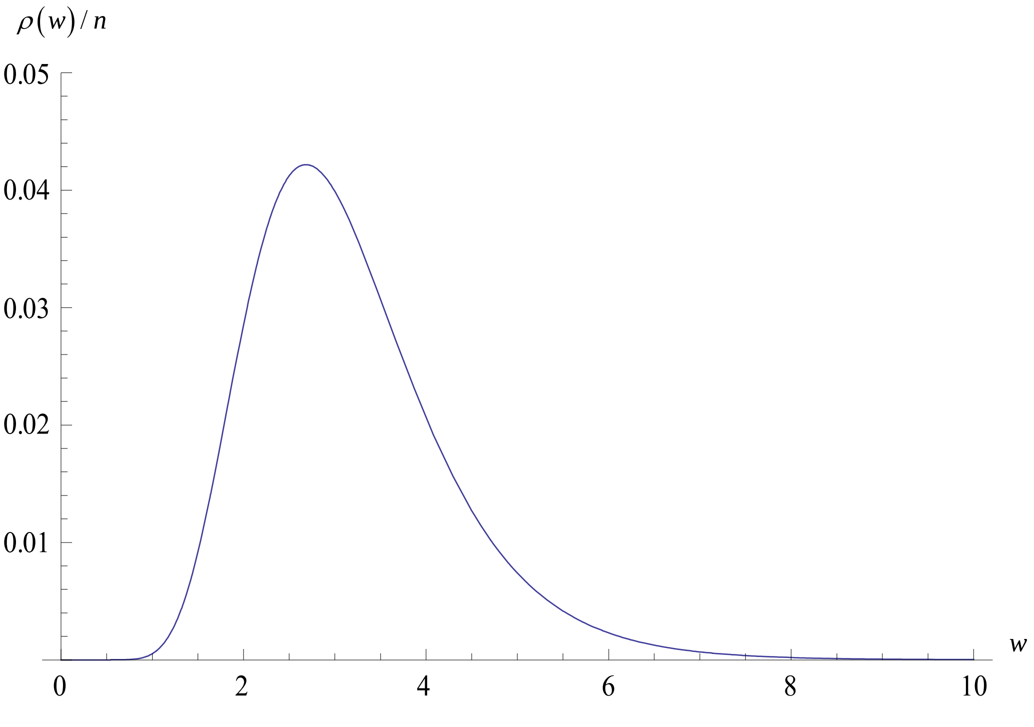


Figure 2: Distribution of the Value of Time

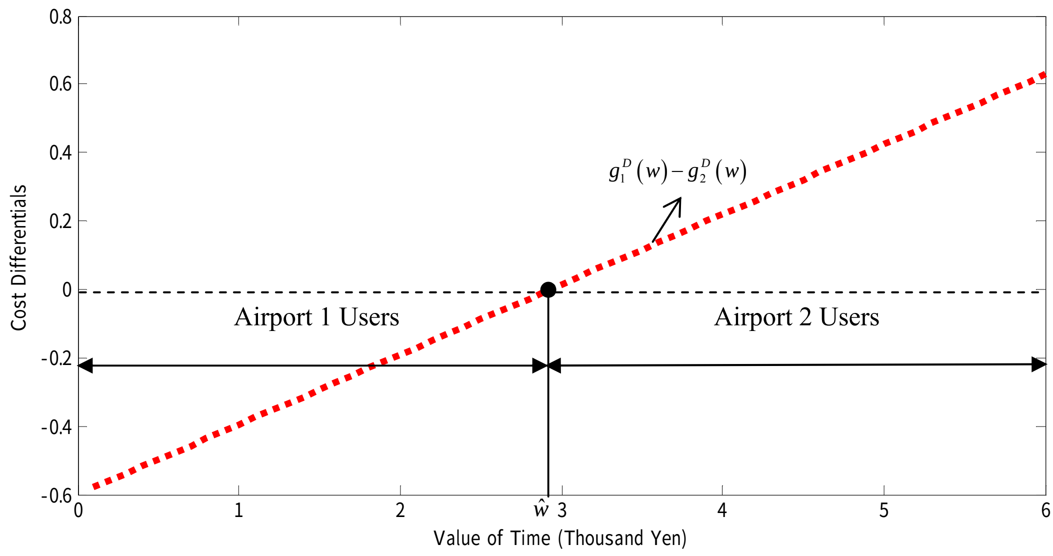
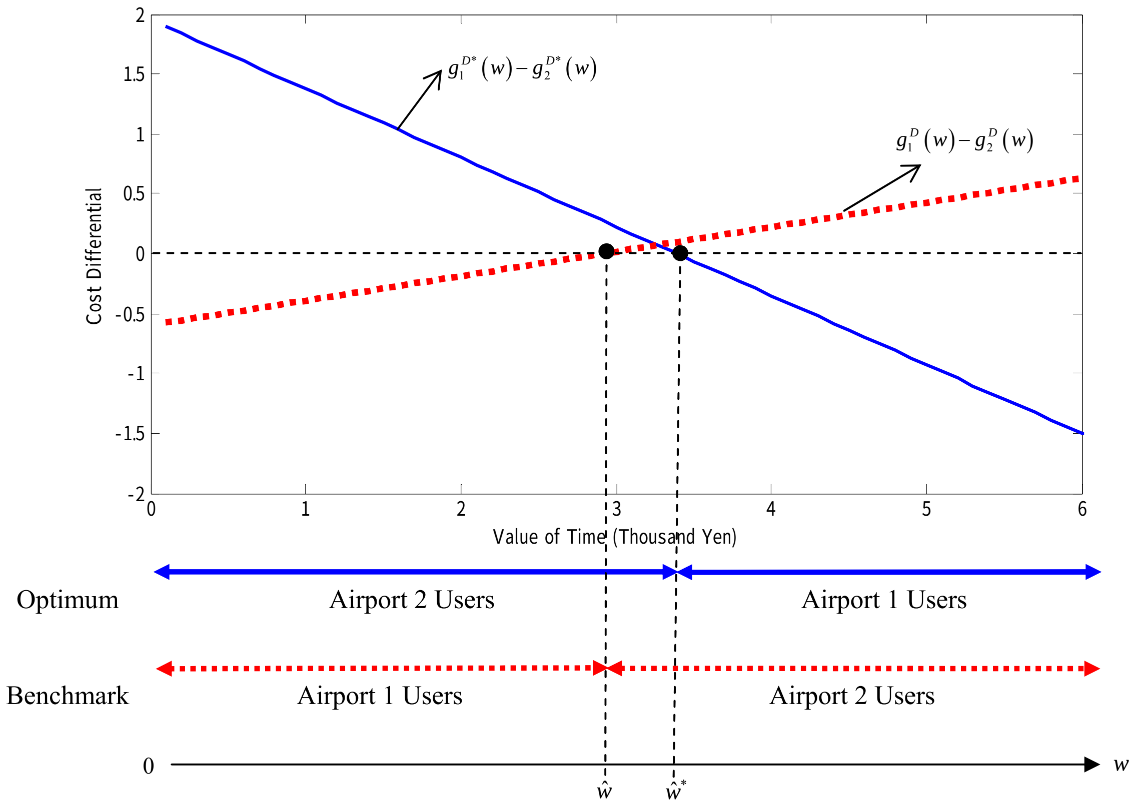


Figure 3: Differential of the Generalized Cost for Service *D* at Two Airports (benchmark)



Note: The dashed line graph indicates the cost differential at the benchmark case while the continuous line corresponds to the cost differential at the optimum.

Figure 4: Differentials of the Generalized Cost for Service *D* at Two Airports
(The Optimum and the Benchmark Case)

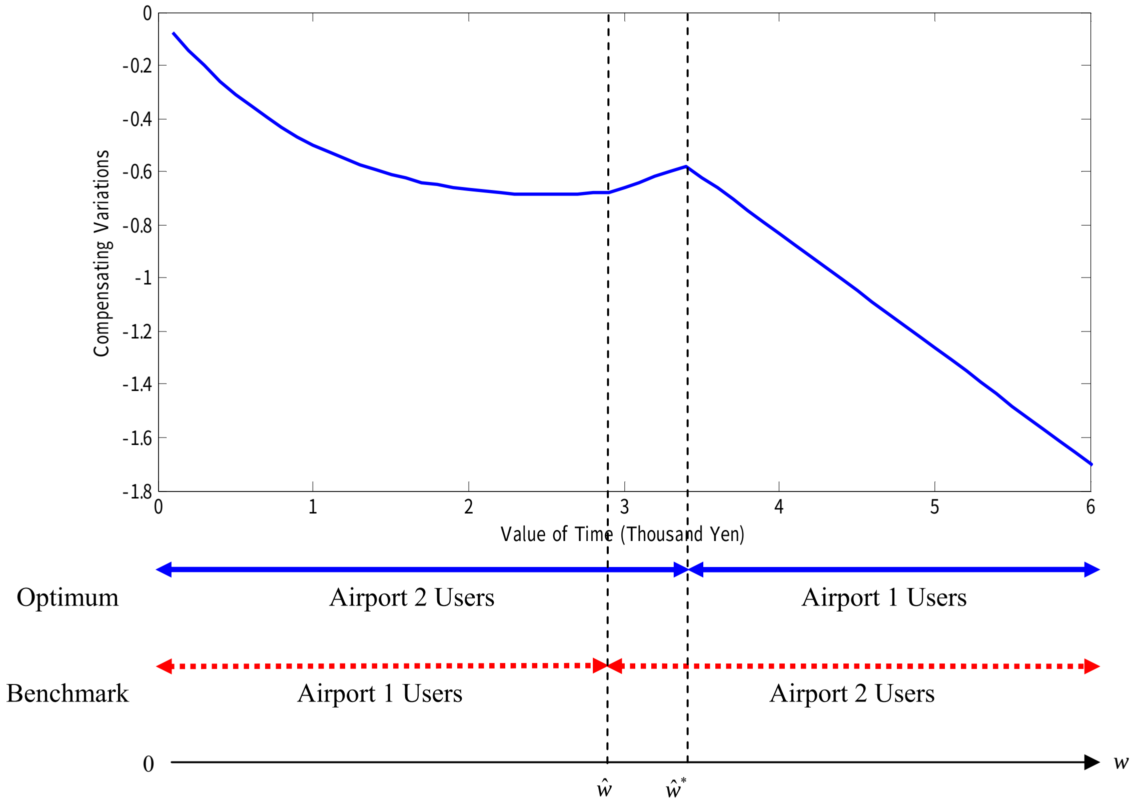


Figure 5: the Compensating Variations (unit: Thousand Yen)

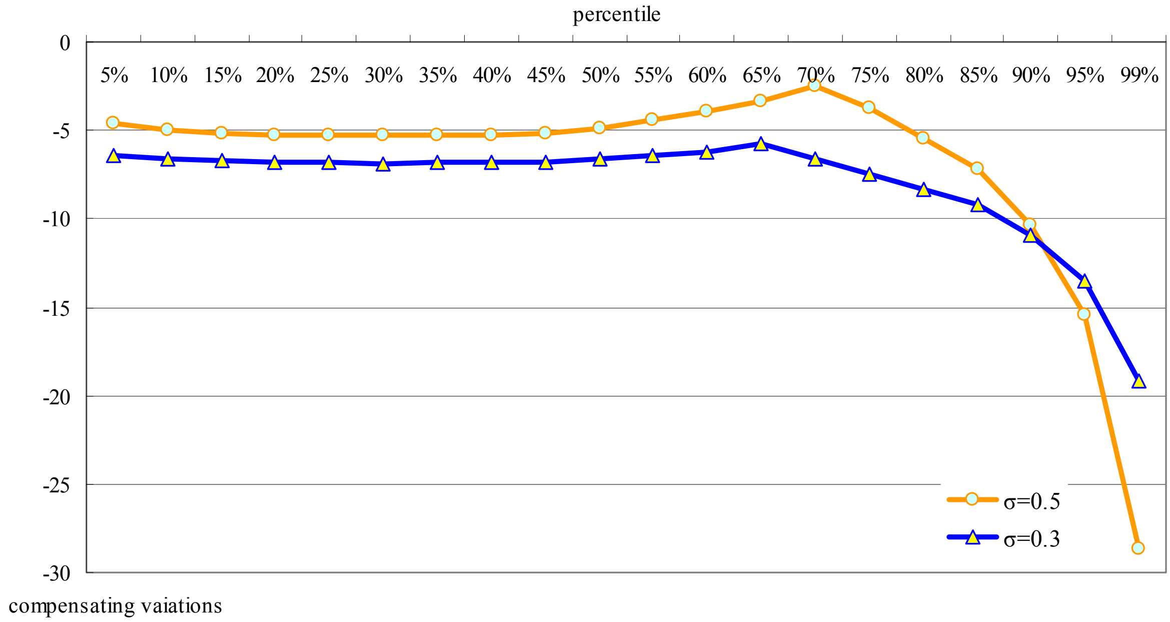


Figure 6: the Comparison of Compensating Variations (unit: Thousand Yen)

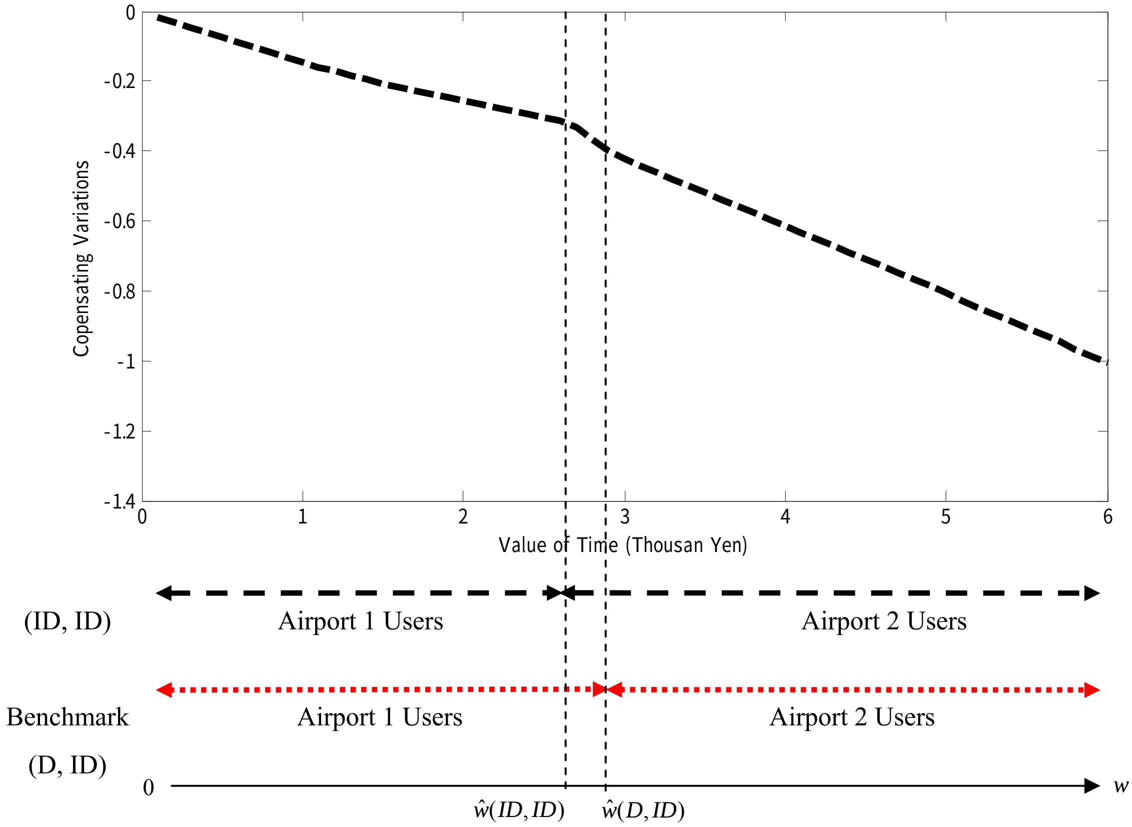


Figure 7: the Compensating Variations under (*ID, ID*) (unit: Thousand Yen)

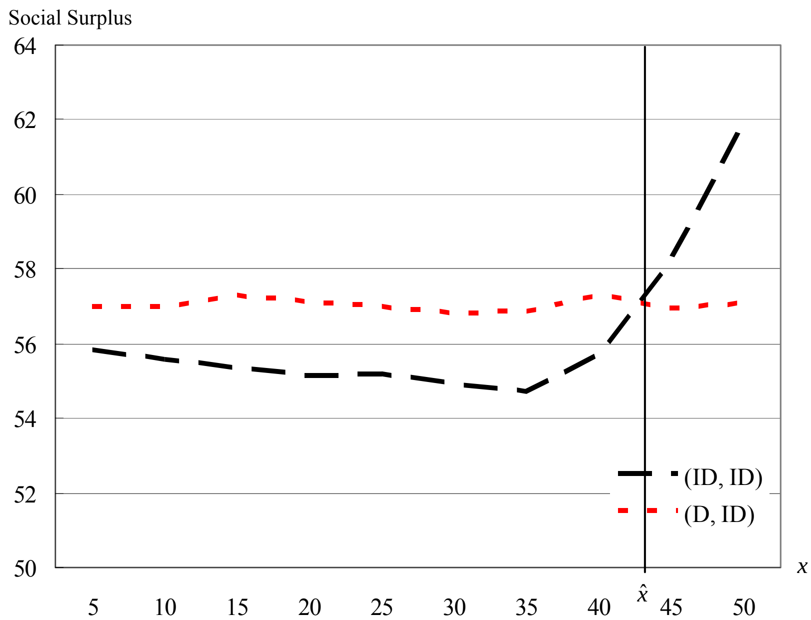


Figure 8: the Comparison of Social Surplus (unit: Billion Yen)

<<TABLES>>

Table 1: Parameter Values at the Base Case

Parameter	Explanation	Value	Unit
n	Population of the City	1,640,000	persons
μ	Average of the Log-Normal Distribution	3.40	
σ	Standard Deviations of the Log-Normal Distribution	0.30	
β^I	Expenditure Share for Service *I* Trips	1.10×10^{-2}	
β^D	Expenditure Share for Service *D* Trips	0.88×10^{-2}	
$\overline{h}$	Initial Endowment of Time	4,380	hours
f^I	Fare for Service *I* Trips	199.86	thousand yen
f^D	Fare for Service *D* Trips	29.63	thousand yen
τ_1	Monetary Access Cost for Airport 1	0.8	thousand yen
τ_2	Monetary Access Cost for Airport 2	1.5	thousand yen
$\overline{t}^I$	Fixed Amount of Time for Service *I* Trips	66	hours
$\overline{t}^D$	Fixed Amount of Time for Service *D* Trips	40	hours
x	Distance b/w the City and Airport 2	30	kilometers
a	Travel Time per Distance	1.67×10^{-1}	hours/kilometers
c_1	Marginal Delay Time at Airport 1	1.30×10^{-7}	hours/persons
c_2	Marginal Delay Time at Airport 2	0.73×10^{-7}	hours/persons

Table 2: The Results of the Calibration

	Data in 2004				Calibration	
	Airport Charges (Thousand Yen)		Number of Users (Thousand Persons)		Number of Users (Thousand Persons)	
	International	Domestic	International	Domestic	International	Domestic
Airport 1 (Osaka)	-	1.90	-	9742	-	9742
Airport 2 (Kansai)	5.70	2.60	5596	2088	5596	2088

Table 3: The Optimal Airport Charges and the Number of Users

	Optimal Airport Charge (Thousand Yen)		Number of Users (Thousand Persons)	
	International	Domestic	International	Domestic
Airport 1	4.02	4.02	2140	3997
Airport 2	2.07	2.07	3756	8172

Table 4: The Social Surplus at the Optimum and the Benchmark (unit: billion yen)

	Social Surplus	Revenue $\sum_{s,j} p_j^s Q_j^s$	Compensating Variations $\int_{\underline{w}}^{\overline{w}} \rho(w) b(w) dw$
Social Optimum	62.02	49.36	-12.66
Benchmark	55.84	55.84	-
Differentials	6.18	-6.48	12.66

Table 5: The Results at $\sigma = 0.3$ and $\sigma = 0.5$

			$\sigma = 0.3$		$\sigma = 0.5$	
			Optimum	Benchmark	Optimum	Benchmark
Number of Users (Unit: thousand persons)	*I*	Airport 1	2140	-	2131	-
		Airport 2	3756	5596	3763	5232
	D	Airport 1	3997	9742	3784	
		Airport 2	8172	2088	8282	2757
Airport Charge (Unit: thousand yen)	*I*	Airport 1	4.02	-	4.60	-
		Airport 2	2.07	5.70	2.20	5.70
	D	Airport 1	4.02	1.90	4.60	1.90
		Airport 2	2.07	2.60	2.20	2.60
Social Surplus			62.02	55.84	63.93	54.76
Revenue			49.36	55.84	53.71	54.76
Compensating Variation			-12.96	-	-10.22	-

Table 6: The Results at Two Alternative Allocation of Services

			(*ID*, *ID*) No Regulation	(*D*, *ID*) Regulation
Number of Users (Unit: thousand persons)	*I*	Airport 1	2871	-
		Airport 2	1897	5596
	D	Airport 1	6189	9742
		Airport 2	3783	2088
Airport Charge (Unit: thousand yen)	*I*	Airport 1	5.00	-
		Airport 2	5.70	5.70
	D	Airport 1	1.90	1.90
		Airport 2	2.60	2.60
Social Surplus			54.58	55.84
Revenue			53.89	55.84
Compensating Variation			-0.69	-

Table 7: The Results at Three Alternative Policies

			Optimal Pricing (*ID*, *ID*)	Regulation of the Service Choice (*D*, *ID*)	No Regulations (*ID*, *ID*)
Number of Users (Unit: thousand persons)	*I*	Airport 1	2140	-	2871
		Airport 2	3756	5596	1897
	D	Airport 1	3997	9742	6189
		Airport 2	8172	2088	3783
Airport Charge (Unit: thousand yen)	*I*	Airport 1	4.02	-	5.00
		Airport 2	2.07	5.70	5.70
	D	Airport 1	4.02	1.90	1.90
		Airport 2	2.07	2.60	2.60
Social Surplus			62.02	55.84	54.58
Revenue			49.36	55.84	53.89
Compensating Variation			-12.96	-	-0.69