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Abstract. Airport operation costs are financed by charge revenues from airport users and funds transferred from general government funds. This study quantitatively optimizes the rates of three types of airport-related charges: per-passenger charges (e.g., passenger service facility charges), per-flight charges (e.g., landing fees), and aviation fuel tax, explicitly considering the marginal cost of public funds of the general funds. This study uses a route-level empirical structural model in which airlines with market power set both airfares and service quality (i.e., flight frequency). Our results show that it is optimal to increase the transfer from the general funds from the current amount and that the optimization increases social welfare by 19 percent. Even if the amount of the transfer is fixed at the current level, the social welfare can be increased by 10 percent only by adjusting the current rates of the airport-related charges. In particular, we show that charges should be adjusted so as to increase flight frequency on routes where small aircraft are used.

Key words: *Optimal taxation, Airport-related charge, Marginal cost of public funds, Discrete choice model, Endogenous quality*

JEL classification: H21; H41; L13; R48

1. Introduction

Airports are important infrastructure facilities for long-distance trips. For example, air trips account for 41 percent of all trips of 750-1,000km and 85 percent of trips over 1,000km in Japan.[1] Airport operation needs a lot of money for maintaining airport facilities (e.g., runways), controlling airport traffic, and so forth. For example, about 400 billion yen a year are spent on operation of the airports of Japan.[2] How should those costs be financed?

In practice, for example, in Japan, the costs of airport operation are financed mostly by charges (e.g., landing fees) and taxes (e.g., aviation fuel tax) paid by airport users, while being supplemented by the transfer from the general account.[3] The three main kinds of charges and taxes in the airline industry are per-passenger charges, per-flight charges, and aviation fuel tax (hereafter collectively referred to as "airport-related charges"). Per-passenger charges (e.g., passenger-service-facility and passenger-security-service charges) are usually collected by airlines at the time of sale of a ticket and then paid to airports. Per-flight charges are levied on airlines according to the number of flights. The aviation fuel tax is paid by airlines to the government according to fuel consumption. While per-passenger and per-flight charges prevail worldwide, the aviation fuel tax is unique to Japan.[4] The current paper ignores other charges, such as charges for parking, check-in counters, and boarding bridges because these have low shares of the total airport revenue (e.g., about seven percent in total in 2020).

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[1] The air trip shares are for 2010 and reported by the Ministry of Land, Infrastructure and Transport (MLIT) (https://www.mlit.go.jp/common/001005632.pdf, in Japanese, accessed December 12, 2022). It is also reported that air transport accounts for 4.7 % of all transportation in Japan.

[2] The Civil Aviation Bureau of the MLIT reports that the expenditure in the airport maintenance account amounts to 389 billion yen in 2017 (https://www.mlit.go.jp/common/001159187.pdf, in Japanese, accessed December 12, 2022).

[3] From the Civil Aviation Bureau of the MLIT, in 2017, the revenue for airport management is composed of airport-related charges, aviation fuel tax, transfer from the general funds, and other revenues (e.g. rental charges). These account for 58.2, 13.4, 7.3, and 21.1 percent, respectively (https://www.mlit.go.jp/common/001159187.pdf, in Japanese, accessed December 12, 2022).

[4] The Scheduled Airlines Association of Japan insists that the aviation fuel tax is unique to Japan and should be reduced (http://teikokyo.gr.jp/wordpress/wp-content/uploads/2019/11/191107_kaisei.pdf, in Japanese, accessed December 13, 2022).

This study quantitatively investigates the optimal way to finance airport operation costs. Specifically, we derive the optimal rates of airport-related charges and the optimal amount of transfer from the general account in the context of the domestic airline market of Japan. We use a route-level empirical structural model of the airline industry. The model is composed of passengers, oligopolistic airlines, and a government. Passengers make a discrete choice among airlines and the outside option (i.e., not traveling by air) to maximize utility. Each airline determines its airfares and flight frequency route by route to maximize its own profits on each route. The government determines the airport-related charge rates to maximize social welfare. The model incorporates the environmental externalities according to fuel consumption, and the slot constraints at congested airports.

A feature of our quantitative analysis is that the marginal cost of public funds (hereafter MCPF) is explicitly considered. The MCPF is the welfare loss incurred to raise additional government revenues. If airport-related charges are increased to finance airport expenditure, airlines with market power may increase airfares and decrease flight frequency. The welfare loss would be incurred accordingly by the distortion in the airline market. Also, if a shortage of revenues from the airport-related charges is supplemented by an increase in the transfer from the general funds (e.g., labor tax revenue), the general-fund-related markets (e.g., labor market) are more distorted and the society suffer additional welfare losses. When determining the optimal amount of transfer from the general funds to airport expenditure, we should compare the MCPF of the airport-related charges to that of the general funds. If the former is larger than the latter, it is socially efficient to fund airport expenditure with not only revenue from the airport-related charges, but also general government funds. In this sense, the optimal airport-related charges cannot be determined without considering the MCPF of the general funds.

We find that the optimal airport-related charges are far from the current levels, and that the optimization of the charges improves the welfare by about 19 percent of the current level. The optimal rates are far below the actual rates and even negative (i.e., subsidies) for some charges. These subsidies are necessary because oligopolistic airlines have market power and set inefficiently high airfares and low flight frequency. In particular, it is optimal to give subsidies so as to increase flight frequency on routes where small aircraft are used. This is because those routes have a small number of airlines due to small demand and suffer relatively large distortions originally. Most of those routes are to/from uncongested airports without slot constraints, so there is enough room to increase flight frequency. Although the increase in flight frequency owing to the subsidies results in larger environmental damage, the damage is not large relative to the increase in the total of consumer and producer surpluses (about eight percent). Finally, from the viewpoint of efficiency, the transfer from the general funds should be increased 14 times from the actual level.

In reality, however, it may be hard for the government to drastically increase the amount of transfer even if the MCPF of the airport-related charges is much larger than that of the general funds. We therefore optimize the charge rates under the constraint that the transfer remains at the current levels, too. In this situation, charges levied for large aircraft should be raised from the current rates, while those for small aircraft should be reduced. This implies that subsidies should be concentrated on routes with small aircraft to correct the severe distortion on the routes. Even given the current level of the transfer, the social welfare is improved by a remarkable ten percent only by optimizing the rates of the airport-related charges. This implies that adjusting the multiple airport-related charges matters for welfare improvements.

With the optimization under the constraint that the transfer from the general funds is fixed at the current amount, the MCPF of the airport-related charges is estimated to be 1.705. This is much larger than the MCPF of the labor tax in Japan, which is estimated to be 1.0-1.2 by Bessho et al. (2003). This implies that a larger transfer from the general funds to airport expenditure is socially desirable because the airport-related market suffers large distortions due to the market power of airlines. Additionally, when the assumed level of the MCPF is changed, the optimal rates of the airport-related charges are changed nonuniformly (i.e., some rates are increased, while others are decreased). This means that it is important to properly consider the MCPF of the general funds when the optimal charge system is investigated, since it may alter the results not only quantitatively (i.e., the absolute level of charges) but also even qualitatively (i.e., the relative balance across charges).

Related Literature.

To the best of our knowledge, our study is the first to provide an empirical framework in which airport-related charges are optimized in consideration of MCPFs. Previous studies theoretically investigate the optimal system of airport-related charges. For example, Oum and Fu (2007) compare two forms (specific or ad valorem) of per-passenger charges. Recently, the optimal combination of per-passenger and per-flight charges has been investigated by, for example, Silva and Verhoef (2013), Silva et al. (2014b), Czerny and Zhang (2015), Lin and Zhang (2016), and Czerny et al. (2017). The previous studies, however, are purely theoretical and do not take account of MCPFs. For an empirical optimization, it is important to explicitly consider MCPFs of both airport-related charges and the general funds. The current study therefore develops an empirical framework incorporating them.

Another contribution of our study is that we simultaneously optimize three kinds of airport-related charges: per-passenger charges, per-flight charges, and aviation fuel tax. Since the aviation fuel tax is unique to Japan, previous studies optimize at most two kinds of charges (per-passenger and per-flight charges). Our results indicate that the optimal fuel tax is not zero and thus fuel tax is an effective charge and worth adding to a system of airport-related charges.

In the literature on car-related taxes and tolls, many studies consider the MCPF to empirically optimize their rates (Parry and Small, 2005; Kawase, 2010; De Borger and Mayeres, 2007; Kono et al., 2021). There are, however, no studies which explore optimal airport-related charges with the MCPF. Unlike the road market with atomistic players (i.e., drivers), the suppliers of the air market (i.e., airlines) has market power due to oligopolistic competition. The distortions and reactions to a change in charges therefore arise in a more complex way in the air market than those in perfectly competitive markets. Previous studies reveal that the market power of non-atomistic airlines plays an important role in setting airport-related charges (e.g., Daniel, 1995; Brueckner, 2002; Pels and Verhoef, 2004; Brueckner and Van Dender, 2008; Brueckner and Verhoef, 2010; Silva et al., 2014a).

We follow previous studies using an empirical structural model of the airline market (e.g., Peters, 2006; Armantier and Richards, 2008; Berry and Jia, 2010), applying a standard model in the field of empirical industrial organization that consists of discrete-choices of consumers and oligopolistic firms. Specifically, we extend a model in which airlines set not only airfares but also flight frequency as in Doi and Ohashi (2019) and Doi (2022), extending it by incorporating the three kinds of airport-related charges and the MCPF of the general funds to empirically investigate the optimal system of the charges. Our results show that in contrast to the road market, negative charges (i.e., subsidies) are optimal in the air transport market to deal with the distortions caused by the market power of oligopolistic airlines.

More broadly, the current study relates to the vast literature on policy analyses based on an empirical structural model (e.g., among many others, analyses of trade policy in Berry et al., 1999, comparison of specific and ad valorem taxes in Griffith et al., 2018, and liquor pricing regulation in Miravete et al., 2020). In the usual welfare analyses of policies, the government surplus/deficit is simply added to the social surplus. This means that the MCPF of the general funds is assumed to be one, which is unrealistic. Our framework incorporates the MCPF of the general funds into the standard model of the field of empirical industrial organization. The results show that the assumption on the MCPF may qualitatively change the results on the optimal policies. This implies that it is important to explicitly consider the non-one MCPF when empirically investigates optimal policies.

Structure of the paper

The rest of the paper is organized as follows. Section 2 develops the model. Section 3 derives the formula for the optimal airport-related charges. Section 4 sets the parameters of the formula using real data. Section 5 quantitatively optimizes the airport-related charges. Section 6 concludes the paper.

2. Model

This section constructs a model of the Japanese air transport market. We extend the model of Doi (2022), incorporating two policy instruments, aviation fuel tax and labor tax, in addition to the per-passenger and per-flight airport charges. The model is static and represents monthly decision making of airlines (supply side), consumers (demand side), and a tax-and-charge collection agency (government), which are explained in subsections 2.1, 2.2, and 2.3, respectively. The model also includes environmental costs of fuel consumption in subsection 2.4. This section describes a simpler version of the model to theoretically characterize the optimal system of the taxes and charges. In the quantitative analysis in later sections, the model is modified according to the actual situation of the Japanese air transport market.

2.1. Supply

The current study explores a static Nash equilibrium. Airlines maximize their own profits, simultaneously deciding their airfares and flight frequency on each route. Throughout the paper, a route is defined as the combination of the two endpoint airports of a flight regardless of the direction of the journey.

The maximization problem of airline j on route r at time t is assumed as

$$\begin{aligned} \max_{p_{jrt}, f_{jrt}} \pi_{jrt} = {} & \left(p_{jrt} - \overline{mc^{Q}}_{jrt} - AFC^{Q}_{jrt}\right) q_{jrt}(\boldsymbol{p}_{rt}, \boldsymbol{f}_{rt}) \\ & - \left\{\overline{mc^{F}}_{jrt} + AFC^{F}_{jrt} + \left(\overline{pFuel}_{t} + TFuel_{t}\right)\overline{cFuel}_{jrt}\right\} f_{jrt} \\ & s.t.\ \sum\nolimits_{r \in R_{Haneda,t}} f_{jrt} \leq \overline{slot}_{j,Haneda,t}\,, \end{aligned} \tag{1}$$

where π_{jrt} is the profit, p_{jrt} is airfare, f_{jrt} is flight frequency, $q_{jrt}(\boldsymbol{p}_{rt}, \boldsymbol{f}_{rt})$ is the passenger demand function specified in the next subsection, $\boldsymbol{p}_{rt}$ is a vector consisting of airfares of all airlines that operate on route r at time t, and $\boldsymbol{f}_{rt}$ is a similarly defined vector of flight frequencies. Variables with upper bars are exogenous and set to be fixed in our simulations; $\overline{mc^Q}_{jrt}$ is the marginal cost with respect to the number of passengers, $\overline{mc^F}_{jrt}$ is the marginal cost with respect to flight frequency, $\overline{pFuel_t}$ is fuel price, and $\overline{cFuel_{jrt}}$ expresses fuel consumption per flight. Variables starting with a capital letter are policy instruments: AFC_{jrt}^Q is a per-passenger charge, AFC_{jrt}^F is a per-flight charge, and $TFuel_t$ is aviation fuel tax. Note that these three instruments are collectively referred to as "airport-related charges."

The model incorporates slot constraints at Haneda Airport, the most congested airport in Japan, $R_{Haneda,t}$ is the set of routes to/from Haneda Airport and $\overline{slot}_{j,Haneda,t}$ is the takeoff and landing slots allocated to airline j. Airlines can adjust the routes for which the allocated slots are used. At the other airports, airlines are assumed to freely choose their flight frequencies. We do not consider takeoff or landing delays.[5]

In this study, aircraft characteristics such as size are treated as exogenous. In the dataset used in the quantitative analysis of the current study, the size of aircraft used on a route does not change significantly with a change in flight frequency on the route (Doi, 2022). Hence, we suppose that the choice of aircraft type is a longer-term decision than that of flight frequency, which is adjusted in a shorter term given the aircraft used. The current study focuses on the effects of airport-related charges on airfares and flight frequency, as in Doi (2022).

The first-order conditions of airlines' profit maximization problem (1) are as follows.

$$\frac{\partial \pi_{jrt}}{\partial p_{jrt}} = q_{jrt}(\cdot) + \left(p_{jrt} - \overline{mc^Q}_{jrt} - AFC_{jrt}^Q\right)\frac{\partial q_{jrt}}{\partial p_{jrt}} = 0 \tag{2}$$

$$\frac{\partial \pi_{jrt}}{\partial f_{jrt}} = \left(p_{jrt} - \overline{mc^Q}_{jrt} - AFC_{jrt}^Q\right)\frac{\partial q_{jrt}}{\partial f_{jrt}} - \left\{\overline{mc^F}_{jrt} + AFC_{jrt}^F + \left(\overline{pFule_t} + TFuel_t\right)\overline{cFuel_{jrt}}\right\} = 0 \tag{3}$$

$$\frac{\partial \pi_{jrt}}{\partial f_{jrt}} = \left(p_{jrt} - \overline{mc^Q}_{jrt} - AFC_{jrt}^Q\right)\frac{\partial q_{jrt}}{\partial f_{jrt}} - \left\{\overline{mc^F}_{jrt} + AFC_{jrt}^F + \left(\overline{pFule_t} + TFuel_t\right)\overline{cFuel_{jrt}}\right\} - \phi_{jt} = 0 \tag{3'}$$

[5] Flight Stats, a data service company focused on commercial aviation, showed that the two major airlines in Japan, Japan Airlines and All Nippon Airways, achieved the highest and the second highest on-time performance of major world airlines.

Eqs. (2) and (3) are the first-order conditions with respect to airfares and flight frequency for routes which do not use Haneda Airport. Airlines decide their airfares and flight frequency to satisfy these two equations. For Haneda routes, while the first-order condition of airfare is the same (Eq. (2)), that of flight frequency is slightly changed to Eq. (3)', where ϕ_{jt} is the Lagrange multiplier for the slot constraint at Haneda Airport.

The first-order conditions indicate that the airport-related charges affect airfares and flight frequency. The per-passenger charge, AFC^{Q}_{jrt}, works in a similar way to the marginal cost with respect to the number of passengers, $\overline{mc^{Q}}_{jrt}$. The changes in the per-flight charge, AFC^{F}_{jrt}, and the aviation fuel tax, $TFuel_t$, work in a similar way to the marginal cost with respect to flight frequency, $\overline{mc^{F}}_{jrt}$. Although AFC^{F}_{jrt} and $TFuel_t$ do not appear in the first-order conditions with respect to airfare, Eq. (2), they affect airfares as well as flight frequency. The change in flight frequency caused by a change in AFC^{F}_{jrt} or $TFuel_t$ affects the number of passengers, q_{jrt}, and demand sensitivity to airfares, $\frac{\partial q_{jrt}(\cdot)}{\partial p_{jrt}}$, which are included in the first-order condition of airfare, Eq. (2).

Policy variables $TFuel_t$ and AFC^{F}_{jrt} can affect the total amount of per-flight payments by airlines, which appears in the curly braces in Eq. (1), differently across routes with different distance and aircraft characteristics in the following manner. The effects of $TFuel_t$ on the per-flight payments depend on the fuel consumption per flight on a route, $\overline{cFuel}_{jrt}$, which depends on the route distance and aircraft used on the route. As for AFC^{F}_{jrt}, this paper supposes that AFC^{F}_{jrt} is set according to the maximum take-off weight of the aircraft following the way in the real world. Per-weight rates of AFC^{F}_{jrt} affect the total amount of per-flight payments differently across routes depending on the weight of aircraft. Subsection 4.1 explains in more detail the per-weight rates in reality and its optimization in our quantitative analysis.

2.2. Demand

A consumer decides their travel, consumption of composite goods, and leisure time with their budget and time constraints. The travel decision is modeled as a nested logit model. Discrete choice models including nested logit models are widely used for describing air travel demand (e.g., Peters, 2006; Armantier and Richards, 2008; and Berry and Jia, 2010). When those models are used, the model description often starts with a conditional indirect utility function. In contrast, to incorporate labor tax in the model and to consider its MCPF, we start with a direct utility function with budget and time constraints and then derive the indirect utility.

Consumers decide whether to travel by air or not and, if travelling, decide which airline they use. A consumer living near airport a makes decisions for every route $r \in R_{at}$, where R_{at} is the set of the routes from airport a at time t. If traveling by air on route r at time t using airline j, a passenger pays airfares p_{jrt} and spends travel time $T_{jrt}(f_{jrt})$. Travel time $T_{jrt}(f_{jrt})$ is a function of flight frequency f_{jrt}, because as flight frequency increases, the possibility of the passenger traveling on flights with departure and arrival times that suit their schedule increases (Douglas and Miller, 1974).[6] If deciding not to travel by air, a consumer chooses an outside option (e.g. travel by train), which is denoted as $j = 0$, and spends $\bar{p}_{0rt}$ and $\bar{T}_{0rt}$.

The budget constraint for consumer i living near airport a at time t is

$$\sum_{r \in R_{at}} \left\{ \sum_{j \in J_{rt}} d^i_{jrt} p_{jrt} + d^i_{0rt} \bar{p}_{0rt} \right\} + z^i_t = (\bar{w}^i_t - \tau_t) L^i_t \, , \tag{4}$$

where $d^i_{jrt} \in \{0, 1\}$ expresses consumer i's decision on traveling, where $d^i_{jrt} = 1$ means that consumer i chooses an alternative j (an airline or the outside option) on route r at time t, and $d^i_{jrt} = 0$ means that consumer i does not choose it. A consumer chooses an alternative from the choice set, that is, $\sum_{j \in \{0, J_{rt}\}} d^i_{jrt} = 1$ where J_{rt} is the set of airlines operating on route r at

[6] The literature has recognized that flight frequency affects air travel demand and is an important index of service quality of airlines (e.g., Brueckner (2004), Brueckner and Flores-Fillol (2007), Brueckner (2010), Brueckner and Luo (2014), and Brueckner and Flores-Fillol (2020)).

time t. z_t^i represents consumption of composite goods, the price of which is normalized to one. The income of consumer i is $(\bar{w}_t^i - \tau_t)\, L_t^i$, where $\bar{w}_t^i$ is pretax wage, τ_t is labor tax, and L_t^i is labor time.

Consumers work for L_t^i and enjoy leisure time y_t^i, given their available time $\bar{H}$. Accordingly, the time constraint for consumer i is

$$L_t^i + y_t^i + \sum_{r \in R_{at}} \left\{ \sum_{j \in J_{rt}} d_{jrt}^i T_{jrt}(f_{jrt}) + d_{0rt}^i \bar{T}_{0rt} \right\} = \bar{H}. \tag{5}$$

A consumer makes decisions on traveling d_{jrt}^i on every route, quantity of composite goods z_t^i, and leisure time y_t^i to maximize utility. We assume that the direct utility function for consumer i is expressed in a quasi-linear form:

$$U(\boldsymbol{X_t}, \boldsymbol{d_t^i}, \boldsymbol{\varepsilon_t^i}) + \Theta(y_t^i, Y_t^i) + \alpha z_t^i, \tag{6}$$

where $\boldsymbol{X}_t$ is a set of $\boldsymbol{x}_{jrt}$, which is a vector of the airline and route characteristics, such as the aircraft size and the route distance. $\boldsymbol{d}_t^i$ is a vector of the travel decision of consumer i, d_{jrt}^i. $\boldsymbol{\varepsilon_t^i}$ is a vector of a random utility component ε_{jrt}^i that represents consumer specific tastes. α is the marginal utility of consumption of the composite goods.

$\Theta(y_t^i, Y_t^i)$ expresses consumer i's utility from leisure time y_t^i and total travel time. Y_t^i represents non-labor time, which is the total of leisure time y_t^i and total travel time, that is, the second and third terms of the left-hand side of time constraint (5). y_t^i and Y_t^i are supposed to be separate variables of the utility function because leisure time y_t^i and travel time may affect the utility differently. To simplify the following analysis, $\Theta(y_t^i, Y_t^i)$ is assumed to be linear in y_t^i: $\Theta(y_t^i, Y_t^i) = \eta y_t^i + \theta(Y_t^i)$, where η is a constant. Owing to this specification, the non-labor time, Y_t^i, that maximizes the utility, and accordingly labor time is determined separately from the decisions on traveling, as shown in the next paragraph. In the real world, labor time is considered to be unaffected by trip decisions in most cases. In addition, together with the quasi-linear form of the utility function, travel decisions are independent for each route as shown below.

Substituting Eqs. (4) and (5) into Eq. (6) to cancel out L_t^i and z_t^i yields

$$
\begin{aligned}
&U(\boldsymbol{X_t}, \boldsymbol{d_t^i}, \boldsymbol{\varepsilon_t^i}) + \eta y_t^i + \theta(Y_t^i) \\
&\qquad + \alpha\left(\overline{w}_t^i - \tau_t\right)\left[\overline{H} - y_t^i - \sum_{r\in R_{at}}\left\{\sum_{j\in J_{rt}} d_{jrt}^i T_{jrt}(f_{jrt}) + d_{0rt}^i \overline{T}_{0rt}\right\}\right] \\
&\qquad - \alpha\sum_{r\in R_{at}}\left\{\sum_{j\in J_{rt}} d_{jrt}^i p_{jrt} + d_{0rt}^i \overline{p}_{0rt}\right\}.
\end{aligned}
\tag{7}
$$

The first-order condition with respect to y_t^i, $\frac{\partial\Theta(y_t^i, Y_t^i)}{\partial y_t^i} = \eta + \theta'(Y_t^i) - \alpha(\overline{w}_t^i - \tau_t) = 0$, determines the optimal amount of non-labor time: $Y_t^{i*} = Y^*\left(\left(\overline{w}_t^i - \tau_t\right)\right)$. The optimal leisure time y_t^{i*} is Y_t^{i*} minus the total travel time across all routes. Substituting these into Eq. (7) yields

$$
\begin{aligned}
&U(\boldsymbol{X_t}, \boldsymbol{d_t^i}, \boldsymbol{\varepsilon_t^i}) + \eta\left(Y_t^{i*} - \sum_{r\in R_{at}}\left\{\sum_{j\in J_{rt}} d_{jrt}^i T_{jrt}(f_{jrt}) + d_{0rt}^i \overline{T}_{0rt}\right\}\right) + \theta(Y_t^{i*}) \\
&\qquad + \alpha\left(\overline{w}_t^i - \tau_t\right)\left(\overline{H} - Y_t^{i*}\right) - \alpha\sum_{r\in R_{at}}\left\{\sum_{j\in J_{rt}} d_{jrt}^i p_{jrt} + d_{0rt}^i \overline{p}_{0rt}\right\}.
\end{aligned}
\tag{8}
$$

This model is consistent with discrete choice models, which are often used to estimate air travel demand, if utility obtained from a trip on each route is additive, that is, $U(\boldsymbol{X_t}, \boldsymbol{d_t^i}, \boldsymbol{\varepsilon_t^i}) = \sum_{r\in R_{at}}\sum_{j\in\{0,J_{rt}\}} d_{jrt}^i\, u(\boldsymbol{x_{jrt}}, \varepsilon_{jrt}^i)$ where $u(\boldsymbol{x_{jrt}}, \varepsilon_{jrt}^i)$ is the conditional utility from choosing alternative j on route r at time t. For each route, a consumer chooses the alternative with the highest conditional indirect utility:

$$
\max_{j\in\{0,J_{rt}\}} u(\boldsymbol{x_{jrt}}, \varepsilon_{jrt}^i) - \eta T_{jrt}(f_{jrt}) - \alpha p_{jrt}. \tag{9}
$$

Depending on the functional form of $u(.)$ and distribution of ε_{jrt}^i, this demand model can integrate discrete choice models, such as logit models.

This study uses a nested logit model in which airlines are placed in the inner nest, while the outside option is added to the outer nest. The conditional utility is specified as follows:

$$
u(\boldsymbol{x_{jrt}}, \varepsilon_{jrt}^i) = \boldsymbol{\beta}'\boldsymbol{x_{jrt}^{obs}} + \xi_{jrt} + \nu_{rt}^i + (1-\sigma_r)\epsilon_{jrt}^i, \tag{10}
$$

where $\boldsymbol{x_{jrt}} = (\boldsymbol{x_{jrt}^{obs}}, \xi_{jrt})$ and $\varepsilon_{jrt}^i = (\nu_{rt}^i, \epsilon_{jrt}^i)$. The airline-route characteristics $\boldsymbol{x_{jrt}}$ is divided into observed variables ($\boldsymbol{x_{jrt}^{obs}}$) and an unobserved variable (ξ_{jrt}), which represents, for example, passengers' evaluation of the safety level, and is treated as an error term in estimating the model (Berry, 1994). The random utility component ε^i_{jrt} consists of ϵ^i_{jrt}, which independently follows the Type I Extreme Value distribution, and ν^i_{rt}, which is distributed such that a distribution of $\nu^i_{rt} + (1-\sigma_r)\epsilon^i_{jrt}$ also follows the Type I Extreme Value distribution. Parameter σ_r determines the correlation in unobserved individual-specific utility between airlines. When σ_r is zero, the model is a standard logit model. As σ_r approaches one, the substitutability between airlines becomes high. The mean utility of the outside option is standardized to zero.

The number of passengers on route r at time *t* by choosing airline *j* can be described as

$$q_{jrt}(\boldsymbol{p}_{rt}, \boldsymbol{f}_{rt}) = \overline{M}_{rt} \frac{\exp\left(\frac{\beta' x^{obs}_{jrt} + \xi_{jrt} - \eta T_{jrt}(f_{jrt}) - \alpha p_{jrt}}{1-\sigma_r}\right)}{V_{rt}^{\sigma_r}\,(1 + V_{rt}^{1-\sigma_r})}, \tag{11}$$

$$\text{where } V_{rt} = \sum_{k \in J_{rt}} \exp\left(\frac{\beta' x^{obs}_{krt} + \xi_{krt} - \eta T_{krt}(f_{krt}) - \alpha p_{krt}}{1-\sigma_r}\right).$$

$\overline{M}_{rt}$ is the potential market size. The fraction which is multiplied by $\overline{M}_{rt}$ is the probability of a passenger selecting airline *j*.

2.3. Government

We assume that government expenditure for airports ($\overline{GE}^{AIR}_t$) and other expenditure ($\overline{GE}^{OTHER}_t$) should be financed by revenues from airport-related charges ($GR^{AIR}_t = \sum_r \sum_{j \in J_{rt}} \{AFC^Q_{jrt} q_{jrt}(\cdot) + (AFC^F_{jrt} + TFuel_t\,\overline{cFuel}_{jrt}) f_{jrt}\}$) and labor tax ($GR^{LABOR}_t = \tau \sum_i L^*_i$). The government budget constraint is

$$\overline{GE}^{AIR}_t + \overline{GE}^{OTHER}_t = GR^{AIR}_t + GR^{LABOR}_t\,. \tag{12}$$

The government expenditure, $\overline{GE}^{AIR}_t$ and $\overline{GE}^{OTHER}_t$, are treated as exogenous. Two scenarios are considered in the following analysis.

Scenario 1: The government can freely use the labor tax revenues for airport-related expenditure. Specifically, the government determines per-passenger charges, per-flight charges, fuel tax, and labor tax so as to maximize social welfare under the budget constraint of Eq. (12).

Scenario 2: The total amount of the transfer from the labor tax revenues to airport-related expenditure is determined exogenously. The government needs to adjust revenues from airport-related charges to satisfy the following constraint:

$$\overline{GE_t^{AIR}} = GR_t^{AIR} + \overline{transfer_t}, \tag{13}$$

where $\overline{transfer_t}$ is the transfer from the labor tax revenue. Specifically, in Scenario 2, the government maximizes social welfare under the two constraints of Eqs. (12) and (13).

2.4. Environmental externality

Flights consume a lot of fuel, which has harmful effects on the environment. The model therefore includes environmental externalities, which are assumed to be proportional to fuel consumption: $E_{jrt} = \bar{E} \cdot \overline{cFuel}_{jrt} \cdot f_{jrt}$ where $\bar{E}$ is the monetary value of environmental damages caused by a unit of fuel consumption. The environmental damages are deducted from the social welfare.

3. Optimization of Tax and Charges

This section theoretically investigates the optimal system of airport related charges for two scenarios denoted in Subsection 2.3. In the analysis of this section, per-passenger and per-flight charges are assumed to be uniform across all routes. In the quantitative analysis of the subsequent sections, these may be different across routes as in reality.

The social welfare (SW_t) is composed of airlines' profit (π_{jrt}), consumer surplus (CS_{rt}), the sum of consumers' utility from non-labor time ($\eta Y_t^{i*} + \theta(Y_t^{i*})$), and environmental externality (E_{jrt}):

$$SW_t = \sum_r \sum_{j \in R_{rt}} \pi_{jrt} + \sum_r CS_{rt} + \sum_i \{\eta Y_t^{i*} + \theta(Y_t^{i*})\} + \sum_r \sum_{j \in R_{rt}} E_{jrt}\,. \tag{14}$$

The consumer surplus CS_{rt} in the nested logit model of air travel decision is

$$CS_{rt} = \frac{\bar{M}_{rt}}{\alpha} \ln\left[1 + \left\{\sum_{j \in J_{rt}} \exp\left(\frac{\boldsymbol{\beta}' \boldsymbol{x_{jrt}} - \eta T_{jrt}(f_{jrt}) - \alpha p_{jrt}}{1 - \sigma_r}\right)\right\}^{1-\sigma_r}\right]. \tag{15}$$

In the remainder of this section, we derive the optimal conditions for Scenario 1. Those of Scenario 2 can be derived in a similar manner. The Lagrangian formulation of the maximization problem in Scenario 1 is represented by

$$\Phi = \sum_r \sum_{j \in R_{rt}} \pi_{jrt} + \sum_r CS_{rt} + \sum_i \{\eta Y_t^{i*} + \theta(Y_t^{i*})\} + \sum_r \sum_{j \in R_{rt}} E_{jrt} \\ + \varphi(GR_t^{AIR} + GR_t^{LABOR} - \overline{GE}_t^{AIR} - \overline{GE}_t^{OTHER}), \tag{16}$$

where φ is the Lagrange multiplier for the government budget constraint. The first-order conditions are given by taking the derivative of the Lagrangian function with respect to policy variables, AFC_t^Q, AFC_t^F , $TFuel_t$ and τ_t:

$$\frac{\partial \Phi}{\partial c} = \frac{\partial\left(\sum_r \sum_{j \in R_{rt}} \pi_{jrt} + \sum_r CS_{rt} + \sum_r \sum_{j \in R_{rt}} E_{jrt}\right)}{\partial c} + \varphi \frac{\partial GR_t^{AIR}}{\partial c} = 0 \\ where\ \ c = \left\{AFC_t^Q, AFC_t^F, TFuel_t\right\}, \tag{17}$$

$$\frac{\partial \Phi}{\partial \tau_t} = \frac{\partial\left(\sum_i \{\eta Y_t^{i*} + \theta(Y_t^{i*})\}\right)}{\partial \tau_t} + \varphi \frac{\partial GR_t^{LABOR}}{\partial \tau} = 0\,. \tag{18}$$

Note that owing to the assumptions of the demand model, the optimal non-labor time (Y_t^{i*}) is determined independently from decisions on air travel. This means that the labor tax revenue (GR_t^{LABOR}) is independent of the airport-related charges and that the revenue from the airport-related charges (GR_t^{AIR}) is also independent of the labor tax. The optimal tax/charge rates and the corresponding value of the Lagrange multiplier (φ) are determined by the simultaneous equations of (12), (17), and (18).

The social welfare costs arise when the government raises the revenue necessary for its expenditure, because any taxes and charges generate deadweight losses. The marginal social cost of public funds (MCPF hereafter) of a policy instrument is defined as (the absolute value of) the marginal decrease in social welfare divided by the marginal increase in government revenue. The first-order conditions (17) and (18) indicate that the MCPF of all taxes and charges should be equated to the Lagrange multiplier (φ):

$$-\frac{\frac{\partial\left(\sum_r \sum_{j\in R_{rt}} \pi_{jrt} + \sum_r CS_{rt} + \sum_r \sum_{j\in R_{rt}} E_{jrt}\right)}{\partial c}}{\frac{\partial GR_t^{AIR}}{\partial c}} = \varphi, \quad c = \left\{AFC_t^Q, AFC_t^F, TFuel_t\right\}, \tag{17'}$$

$$-\frac{\frac{\partial\left(\sum_i \left\{\eta Y_t^{i*} + \theta\left(Y_t^{i*}\right)\right\}\right)}{\partial \tau_t}}{\frac{\partial GR_t^{LABOR}}{\partial \tau}} = \varphi\ . \tag{18'}$$

The left-hand sides of Eqs. (17)' and (18)' express the MCPF of the airport-related charges and the labor tax, respectively. The numerator is the change in welfare in terms of money, while the denominator is the change in the government revenue. The right-hand sides of both equations are φ, the Lagrange multiplier. This indicates that at the optimal, the MCPF of taxes/charges should be balanced, as suggested by the well-known optimal tax theory (for a detailed discussion, see Auerbach and Hines, 2002, p. 1,385).

The first-order conditions also indicate that the government should simultaneously, not individually, optimize airport-related charges. To clarify this, the denominator of the first-order condition (17)' is expanded for each charge:

$$\begin{aligned}\frac{\partial GR_t^{AIR}}{\partial AFC_t^Q} = \sum_r \sum_{j\in J_{rt}} \Bigg\{ & q_{jrt} + AFC_t^Q \cdot \sum_{k\in J_{rt}} \left(\frac{\partial q_{jrt}}{\partial p_{krt}} \cdot \frac{\partial p_{krt}}{\partial AFC_t^Q} + \frac{\partial q_{jrt}}{\partial f_{krt}} \cdot \frac{\partial f_{krt}}{\partial AFC_t^Q}\right) \\ & + \left(AFC_t^F + TFuel_t \cdot \overline{cFuel}_{jrt}\right) \cdot \frac{\partial f_{jrt}}{\partial AFC_t^Q} \Bigg\},\end{aligned} \tag{19-a}$$

$$\begin{aligned}\frac{\partial GR_t^{AIR}}{\partial AFC_t^F} = \sum_r \sum_{j\in J_{rt}} \Bigg\{ & AFC_t^Q \cdot \sum_{k\in J_{rt}} \left(\frac{\partial q_{jrt}}{\partial p_{krt}} \cdot \frac{\partial p_{krt}}{\partial AFC_t^F} + \frac{\partial q_{jrt}}{\partial f_{krt}} \cdot \frac{\partial f_{krt}}{\partial AFC_t^F}\right) + f_{jrt} \\ & + \left(AFC_t^F + TFuel_t \cdot \overline{cFuel}_{jrt}\right) \cdot \frac{\partial f_{jrt}}{\partial AFC_t^F} \Bigg\},\end{aligned} \tag{19-b}$$

and

$$\begin{aligned}\frac{\partial GR_t^{AIR}}{\partial TFuel_t} = \sum_r \sum_{j\in J_{rt}} \Bigg\{ & AFC_t^Q \cdot \sum_{k\in J_{rt}} \left(\frac{\partial q_{jrt}}{\partial p_{krt}} \cdot \frac{\partial p_{krt}}{\partial TFuel_t} + \frac{\partial q_{jrt}}{\partial f_{krt}} \cdot \frac{\partial f_{krt}}{\partial TFuel_t}\right) \\ & + \overline{cFuel}_{jrt} \cdot f_{jrt} + \left(AFC_t^F + TFuel_t \cdot \overline{cFuel}_{jrt}\right) \cdot \frac{\partial f_{jrt}}{\partial TFuel_t} \Bigg\}.\end{aligned} \tag{19-c}$$

All airport-related charges appear in all equations. For example, (19-b) represents the marginal revenue change caused by an increase in per-flight charges, AFC_t^F. When AFC_t^F is increased, the revenue is directly increased as much as its charge base, flight frequency. This is expressed in the second term in the curly parentheses, f_{jrt}. An increase in the charge, however, reduces flight frequency, $\frac{\partial f_{jrt}}{\partial AFC_t^F}$, which in turn reduces revenues from the fuel tax as well as per-flight charges (the third term in the curly parentheses). This revenue-reducing effect depends on the level of the fuel tax. In addition, if the frequency reduction accompanies the decrease in air travelers, revenues from per-passenger charges are also reduced (the first term). This effect depends on the level of per-passenger charges. The revenue change caused by the increase in AFC_t^F is therefore determined by the other airport-related charges. The same discussion holds for the other charges. Hence, when optimizing the airport-related charges, the government should adjust them simultaneously, taking into account their interdependency.

We can summarize these theoretical properties as follows. When optimizing multiple interdependent charges, there are two points: Point 1) the marginal cost of a charge is expressed by the ratio of the change in the total social welfare (in this study, consumer and producer surpluses minus environmental externalities) associated with the change in the charge rate to the change in the total revenue from the interdependent charges with respect to the change in the charge rate, and Point 2) the marginal cost of each charge should be equalized in order to optimize the levels of multiple interdependent charges.

4. Setting of Quantitative Analysis

Applying the formulas derived in Section 3 to real data, we numerically estimate the efficient level of airport-related charges in the Japanese air travel market. The purpose of this analysis is to illustrate to what extent the current airport-related charge rates are different from the efficient levels in the two scenarios, and to show how the interrelation among policy instruments affects the determination of the optimal airport-related charge level. In addition, we quantitatively explore how much welfare gain can be expected in the two scenarios.

This section describes the setting of the quantitative analysis, the results of which are explained in the next section. Subsection 4.1 explains the system of airport-related charges in the Japanese market. Subsection 4.2 describes the data. Subsection 4.3 explains our estimates of the structural model parameters. Subsection 4.4 clarifies the calculation procedure to derive the optimal charge rates.

4.1. Airport-related charges in Japan

For a quantitative analysis, we derive the optimal rates of the airport-related charges in the Japanese air transport market in October 2005. In Japan, aviation fuel tax is imposed in addition to per-passenger and per-flight charges. Following Doi (2022), we analyze the situation in October 2005, which is the timing of a change in airport-related charges in the market: per-flight charges were reduced in October 2005, while the first per-passenger charge was introduced in the previous year.

In October 2005, 26 of Japan's 97 airports were operated by the national government. The remaining 71 included three company-operated airports and those operated by local governments. Because most major airports were operated by the national government, in this study, most routes depart from and/or arrive at the national airports. Among 245 routes with scheduled flights, 204 routes are to/from national airports, while only 41 routes are between non-national airports. Per-passenger and per-flight charges of an airport are set by its operating entity. The aviation fuel tax, however, is set by the national government and levied at all airports including non-national ones. In our quantitative analysis, we optimize the per-passenger and per-flight charges at the national airports and the aviation fuel tax.

The per-flight charges depend on the maximum take-off weight of aircraft. As Figure 1 shows, the per-flight charge of the national airports increases proportionally according to the weight, though the increase by an additional ton differs according to the weight range. As of October 2005, 1,000, 1,400, 1,550, and 1,650 yen per ton is charged for each additional ton from one to 25 tons, from 25 to 100 tons, from 100 to 200 tons, and 200 tons and above, respectively. For example, if a 120-ton aircraft is used, the per-flight charge is 161,000 yen ($= 25 \times 1{,}000 + 75 \times 1{,}400 + (120 - 100) \times 1{,}550$). In the quantitative analysis, in addition to the per-ton rates of each weight range, the base rate, which is zero in reality, is optimized. If the base rate is non-zero and the per-ton rates are all zero, uniform per-flight charges are levied regardless of aircraft size. In optimization, per-ton rates are allowed to differ across two ranges of weights, from one to 100 tons, and 100 tons and above, rather than the four ranges in the actual system. This is because the computation time is increased exponentially as the number of variables increases.

[Figure 1 around here]

Per-flight charges at non-national airports have a similar structure to those at national airports. The per-ton rates are, however, not necessarily aligned with those of national airports and can differ across airports. In the quantitative analysis, the rates at non-national airports are fixed at the actual level.

The aviation fuel tax is a unique tax in Japan (Scheduled Airlines Association of Japan, 2019). As of October 2005, 26,000 yen per kiloliter of fuel is levied, while the rate is reduced for routes to/from isolated islands (19,500 yen) and Okinawa Prefecture (13,000 yen). The aviation fuel tax is levied for all routes including those between non-national airports.

4.2. Data

The quantitative analysis of this study is based on the same dataset and demand model estimated in Doi (2022). This subsection describes the dataset, which is monthly data by route and airline from 2000 to 2005. The dataset mainly consists of three sources. The first is the

Annual Report on Air Transport Statistics by the Ministry of Land, Infrastructure and Transport. This reports the number of passengers, flight frequency, and the number of seats per flight.

Second, the airfare data by route are primarily obtained from the timetables published monthly by JTB Publishing, Inc. Because these airfare data represent normal fares and do not consider discounts, they may be somewhat different from the actual fares paid by passengers. Unfortunately, there are only very limited data on actual airfares for Japanese domestic routes. We therefore adjust the normal airfares by using the discount rate following the Travel Survey for Domestic Air Passengers for 2003 and 2005. The survey provides data on actual fares for a couple of days and is conducted once every two years. Details of the adjustment are explained in Doi (2022).

Third, the data on aircraft characteristics are obtained from the Statistics of the Japanese Airline Industry and the Statistics of Airplanes in Japan. Aircraft characteristics, the maximum take-off weight and noise level of an aircraft, are needed to calculate per-flight charges. The timetable reports the type of aircraft making each flight.

Table 1 presents the summary statistics. The average number of airlines operating on a route is 1.4. This means that the market power of airlines is relevant in this market. Per-passenger charge is 0.02 thousand yen on average, which is about 0.1 percent of airfares. Because the average number of seats per flight is about 200, the total amount of per-passenger charge per flight is about 4 thousand yen on average if seats are full. Per-flight charge and aviation fuel tax per flight are 123.1 and 78.6 thousand yen on average, respectively. Therefore, per-passenger charge, per-flight charge, and fuel tax account for about 2 %, 60 %, and 38 % of all the airport-related charge payments that airlines have to pay per flight.

[Table 1 around here]

4.3. Parameter estimates

This subsection explains the parameter values of the structural model that is used in the quantitative analysis. The air travel demand model, marginal costs of airlines, the MCPF of labor tax, and environmental externalities are described in order.

We use the demand model estimated in Doi (2022), specifying the functions of the demand model presented in Subsection 2.2 in terms of the following three points. First, the term regarding flight frequency, $\eta \cdot T(f_{jrt})$, are specified as $\gamma \cdot f_{jrt}^{\rho}$, where coefficient ($\gamma$) and exponent ($\rho$) are parameters to be estimated. Second, the vector of observed characteristics ($\boldsymbol{x}_{jrt}^{obs}$) includes the route distance, its squared and cubed terms, a dummy variable that takes the value of one if an endpoint of route r is Haneda Airport, the number of seats per flight, and airline-specific and month-specific dummy variables. Third, nest parameter (σ_r) is allowed to take a different value for long distance routes: $\sigma_r = \sigma + \sigma_{long} longdist_r$ where $longdist_r$ is a dummy variable that takes one if the distance of route r is over 1,000km, and σ and σ_{long} are parameters to be estimated.

The estimation results of Doi (2022) are replicated in Table 2. The average own-price elasticity is -2.01, which is in the range of estimates by previous studies (e.g., Peters, 2006; Armantier and Richard, 2008; Berry and Jia, 2010). Both coefficient (γ) and exponent (ρ) of flight frequency are negative. This result indicates that marginal utility of flight frequency is positive and decreasing. The average flight frequency elasticity is 0.91. Adding one daily departure to all airlines on all routes increases aggregate demand by 17 percent. From a similar analysis, Berry and Jia (2010) report that aggregate demand in the U.S. market has grown by 6–16 percent.

[Table 2 around here]

As for cost variables, marginal costs with respect to the number of passengers ($\overline{mc^{Q}}_{jrt}$), marginal costs with respect to flight frequency ($\overline{mc^{F}}_{jrt}$), and fuel consumption per flight

($\overline{cFuel}_{jrt}$) are required to conduct simulation analysis. The fuel consumption is not publicly available and thus estimated using the same method as Suzuki and Muromachi (2009), which is based on the data on the aircraft and distance of each route. Because the marginal costs are also not publicly available, their values are estimated by using the first-order conditions of the airline's maximization problem as in, for example, Peters (2006), Berry and Jia (2010), and Doi (2022). Specifically, we solve $\overline{mc^Q}_{jrt}$ and $\overline{mc^F}_{jrt}$ by substituting the demand estimates, the fuel consumption per flight, and the data on airfares, flight frequency, the number of passengers, and airport charges into Eqs. (2) and (3).

For routes to/from Haneda Airport, however, marginal costs with respect to flight frequency ($\overline{mc^F}_{jrt}$) cannot be estimated by the above-mentioned method. Because the first-order condition for the routes is Eq. (3)' instead of Eq. (3), the marginal costs cannot be identified from the Lagrangian multiplier of the slot constraints (ϕ_{jt}). The marginal costs are therefore estimated as follows. First, the marginal costs at non-Haneda routes are estimated from the corresponding first-order condition, Eq. (3). Second, they are regressed on route and aircraft characteristics. Lastly, the marginal costs on Haneda routes are estimated as predicted values from the regressed model by substituting the characteristics of Haneda routes. The appendix explains the procedure in more detail.

In the model, labor supply is a function of the labor tax. The MCPF of the labor tax is determined by the form of the labor supply function. The MCPF of the labor tax in Japan is estimated to be 0.96–1.23 by Bessho et al. (2003). As in Kono et al. (2021), we suppose that the labor supply function has a form from which the MCPF becomes constant and equal to 1.2. This method is taken mainly because it is hard to estimate a labor supply curve.

The environmental externalities are calculated based on the fuel consumption per flight. We follow the concepts and values of environmental externalities of Parry and Small (2005). The value of the externalities is assumed to be \$20 per ton of carbon following Nordhaus and Boyer (1999). Economists have attempted to estimate future damage from global warming. A well-known study by Nordhaus and Boyer (1999) estimates the expected global costs of 2.5° Celsius warming in 2100 at about 2% of world gross domestic product (GDP). Half of this arises from the risk of catastrophic or unstable climate change, which they estimate based on subjective expert judgment about the likelihood of major disruptions to GDP. Another component of damage is health effects, which are from the possible spread of tropical diseases, such as malaria. Overall, Nordhaus and Boyer conclude that the marginal damage is $20 per ton of carbon, although this rises over time. Other literature reviews, for example, Tol (2005), suggest that marginal damage is below $50 per ton of carbon. Global warming effects include highly unexpected future factors. Accordingly, the estimated costs vary greatly. At this stage, we cannot say which estimate is correct. In this study, we use the Nordhaus and Boyer (1999) value. A gallon of gasoline contains 0.0024 tons of carbon (National Research Council, 2002). From these values, we set damage at 24 dollars/kiloliter (roughly equivalent to 2,400 yen/kiloliter) of gasoline.

4.4. Calculation of the optimal rates

In the quantitative analysis, we maximize the difference between the Lagrangian function value under the actual airport-related charge system and that under a modified system. For example, the difference in the case of Scenario 1 is as follows:

$$\Phi - \Phi' = \sum_r \sum_{j \in R_{rt}} \left(\pi_{jrt} - \pi'_{jrt}\right) + \sum_r (CS_{rt} - CS'_{rt}) + \sum_r \sum_{j \in R_{rt}} \left(E_{jrt} - E'_{jrt}\right) + \varphi(GR_t^{AIR} - GR_t^{AIR\prime}) , \tag{20}$$

where superscript $'$ represents the values under the actual system. The government expenditure $\overline{GE}_t^{AIR}$ and $\overline{GE}_t^{OTHER}$ are fixed and canceled out in the difference. Due to the assumptions of the demand model and constant MCPF of the labor tax, the difference of the labor tax revenues (GR_t^{LABOR}) multiplied by MCPF ($= \varphi$) of the labor tax is equal to the difference of the sum of utilities from non-labor time ($\sum_i \{\eta Y_t^{i*} + \theta\left(Y_t^{i*}\right)\}$) and is thus canceled out, too.

The revenues and expenditure of non-national airports are included in GR_t^{AIR} and $\overline{GE}_t^{AIR}$, respectively, in the budget constraint of the government, Eq. (12). Although per-passenger and per-flight charges at non-national airports are fixed in our simulation analysis as discussed above, the revenues are changed by a change in the fuel tax and charges at national airports. We assume that if a non-national airport does not have enough revenue to cover its expenditure, the national government covers the shortage.

We use the grid search method for numerical maximization. For Scenario 1, the search range (step width) of each policy variable is as follows: [-4.0, 1.0] (0.1 thousand yen) for per-passenger charge; [-200, 100] (5), [-10.0, 10.0] (0.5), and [-10.0, 20.0] (0.5) for the base rate, the per-ton rate for no more than 100 tons, and the per-ton rate for 100 tons and above, respectively, of per-flight charge; and [-200, 50] (5) for fuel tax.

For Scenario 2, we calculate the solution as follows. We add to the objective function a term representing the "penalty" for an increase in the transfer from the general fund, $\lambda\left(GR_t^{AIR} - GR_t^{AIR'}\right)$, where λ is the penalty for a transfer increase of one yen. We search for the value of λ with which the amount of the transfer at the optimal rates is close to the actual amount (40 billion yen). For example, the transfer at the optimal is 123.2 billion yen, 43.9 billion yen, and -48.7 billion yen with λ = 0.4, 0.5, and 0.6, respectively. Judging from these results, we attempt λ = 0.505. This yields the optimized rates with the transfer of 41.2 billion yen, which are reported as the results of Scenario 2 in the next section.[7] To bring the optimized transfer as close to the actual amount as possible, we ultimately use finer step widths for Scenario 2: 0.025 (thousand yen) for per-passenger charge, 1.25 and 0.25 for the base rate and per-ton rates, respectively, of per-flight charge, and 2.5 for fuel tax.

[7] Exactly speaking, 41.2 billion yen is slightly above the actual transfer from the general fund, 40 billion yen. Actually, it is very hard to match them exactly because this amount is determined as the result of our simulation. It takes a long time (roughly 2-3 weeks) to obtain a one-time simulation result because we use the grid search method for maximization.

5. Results of Quantitative Analysis

This section presents the results of the quantitative analysis. Subsection 5.1 shows that the MCPF of each airport-related charge in the actual charge system differs significantly, indicating that there is room to optimize the system. Subsection 5.2 discusses the optimal rates in Scenario 1, that is, the first-best scenario. Subsection 5.3 explains the optimal rates in Scenario 2, in which the transfer from the labor tax revenues to airport-related expenditure is restricted.

5.1. MCPF in the actual charge system

Before deriving the optimal charge system, we estimate the MCPF of each airport-related charge in the actual charge system. To calculate the MCPF of a charge, we change its rate so as to increase revenues from the charge by 0.1 percent, calculating the airfares, flight frequency, and the number of passengers in the new equilibrium under the changed charge system. The change in the social welfare divided by the change in the government revenue, that is, the left-hand side of Eq. (17)', is the MCPF.

The results show that the MCPF differs markedly across charges. The MCPF of per-passenger charge is 2.35. The MCPF of per-flight charge is 2.48, 4.18, and 3.12 for the base rate, the per-ton rate applicable for 100 tons or less, and that for above 100 tons, respectively. The MCPF of fuel tax is 4.31. As discussed in Section 3, MCPF should be balanced at optimal as suggested by the optimal tax theory. This wide dispersion in MCPF implies large benefits from optimizing the charge system.

5.2. Optimal charges in Scenario 1

In Scenario 1, the airport-related charges are optimized under the government budget constraint, Eq. (12). In this scenario, revenues from labor tax can be freely used for airport-related expenditure. The MCPF of the labor tax is supposed to be 1.2 based on the estimates of Bessho et al. (2003) as discussed in Subsection 4.3.

The results are summarized in Table 3. Its second column presents the results of Scenario 1, including the optimal airport-related charge rates, the averages of airfares and flight frequency, and welfare. For comparison, the first column presents the values associated with the actual charge system. The number in parentheses is the change rate from the actual value.

[Table 3 around here]

The column indicates that some of the optimal rates are negative (i.e., subsidies to airlines) in Scenario 1. The optimal per-passenger charge is -2.2 thousand yen (*cf.* 0.1 of the actual system). As for per-flight charges, the optimal rate is negative for the base rate and the per-ton rate applicable for small aircraft. The optimal per-flight charge for each aircraft size is shown in Figure 1, which shows that it is negative for aircraft with maximum take-off weights of under 110 tons. The optimal aviation fuel tax is also negative and -129,000 yen/kiloliter (*cf.* 26,000 in the actual system). As shown by the profit function of airlines, Eq. (1), the fuel tax is levied for each flight like per-flight charges. Figure 2 presents the total payment per flight, that is, the sum of per-flight charges and the fuel tax, for each aircraft size. In the figure, the amount of the fuel tax is calculated based on the average fuel consumption of each aircraft size. Figure 2 shows that the total payment is negative for aircraft of 180 tons or smaller. The optimal policy could be subsidies due to the market power of airlines on the monopoly and oligopoly routes. This is consistent with theoretical results of previous studies (e.g., Pels and Verhoef, 2004; Verhoef, 2010).

[Figure 2 around here]

In Scenario 1, the average flight frequency under the optimal rates is about two times as much as that under the actual rates, while the average airfare changes slightly. These results imply that in the analyzed market, the market power of airlines results in severe distortion in quality (flight frequency) relative to that in prices (airfares). From the viewpoint of social welfare, the actual flight frequency is not sufficient and should be increased by subsidies.

In particular, Figures 1 and 2 show that subsidies per flight should be larger for smaller aircraft. Accordingly, the optimization increases flight frequency more on routes with small aircraft (about 135%) than on those with large aircraft (about -0.4%). This indicates that flight frequency is insufficient especially on routes with small aircraft. The reason is twofold. First, small aircraft tend to be used on routes where demand is small and therefore only one airline serves as a monopolist. The distortion on such routes is large due to the large market power of the monopolist airline. Second, routes with large aircraft include many routes to/from Haneda airport. Flight frequency on Haneda routes cannot be increased even if per-flight charges are reduced due to the slot constraints. In other words, flight frequency on Haneda routes is already sufficiently provided given the constraints.

Table 4 shows how the optimal rates change if we assume that the MCPF of labor tax is 1.0 instead of 1.2 (the baseline assumption). The assumption of MCPF = 1.0 corresponds to the usual partial equilibrium analysis where government deficit/surplus is simply subtracted/added to the social welfare. A smaller MCPF of labor tax means smaller costs to transfer money from the general budget to airport expenditure. If a smaller MCPF decreases the optimal rates uniformly across all charges, it has only monotonous impacts on the optimal charge system. However, if a smaller MCPF decreases the optimal rates of some charges but increases those of others, the assumption on MCPF affects not only the level of the optimal rates but also the optimal balance of charges. Since the airport-related charges are interdependent, as indicated in Eqs. (19-a)-(19-c), a reduction of MCPF does not necessarily reduce the optimal rates uniformly across all charges.

[Table 4 around here]

Table 4 shows that when the MCPF is assumed to be 1.0, the optimal rates could be both decreased and increased relative to the baseline case with the MCPF of 1.2. The optimal rates of per-passenger charge and fuel tax are decreased from -2.2 to -3.5 thousand yen and from -129 to -179 thousand yen, respectively. That is, when the MCPF of labor tax is lower, it is optimal to increase the subsidy. However, the optimal per-ton rates of per-flight charges are *increased* from -0.5 to 0 and from 13.5 to 18.0 for small and large aircraft, respectively, while the base rate is decreased from -75 to -125. As a result, the optimal amounts of per-flight charges for large aircraft are *increased* when the MCPF is lower (Figure 3). This is probably because the decreases of per-passenger and fuel tax weaken the sensitivity of flight frequency to per-flight charges on routes with large aircraft. This result reveals that the direction in which the optimal rate of a charge is changed by considering MCPF is not necessarily uniform across charges.

[Figure 3 around here]

The optimization increases the total surplus in the market by 19%. Subsidies funded from the government's general budget drastically increase the consumer and producer surpluses by 83% and 94%, respectively. However, the transfers from the general budget to the airport-related expenditure increase by 1,383% and accordingly increase the welfare loss caused by distortion in the labor market. In addition, the increased flight frequency generated by the subsidies increases environmental damage by 1,394%, although the estimated values of this change are not large relative to the other components of the total surplus (about eight percent of the change in the sum of the consumer and producer surpluses). In summary, subsidies funded by the labor tax can increase the total surplus in the airline market. The transfer from the labor tax revenue to the airport-related budget, however, might not be easily increased in reality. The next subsection therefore focuses on the results of Scenario 2, in which the amount of the transfer is fixed at the actual level.

5.3. Optimal charges in Scenario 2

In Scenario 2, we optimize the airport-related charges with the constraint that the transfer for the airport-related expenditure from labor tax revenue is fixed at the current level. Specifically, the optimization is conducted under the constraints of Eqs. (12) and (13). The MCPF of labor tax is assumed to be 1.2 as in Scenario 1. The results are shown in the third column of Table 3. Because of the limited transfer from labor tax revenue, the optimal per-passenger charge becomes positive (0.325 thousand yen) to raise revenue for subsidies for flight frequency. In addition, the amount of the subsidies through per-flight charges and fuel tax becomes modest in most ranges of aircraft size (Figure 2).

Figure 2 also shows that, in comparison with the actual rates, while the total payment per flight (i.e., the sum of per-passenger charges and fuel tax) for aircraft of about 190 tons and above is increased, that for the smaller aircraft is decreased. In particular, subsidies are optimal for aircraft of about 110 tons or less. This result indicates that the government should give priority to addressing insufficient flight frequency on routes with small aircraft when the possible transfer from the general fund is limited.

The optimization of Scenario 2 increases the total surplus by 10 percent of the actual level. The consumer and producer surpluses rise by 20% and 5%, respectively. The environmental damage is increased slightly (5%), while the amount is small relative to the total surplus. This result implies that the government can improve the social surplus by just adjusting the airport-related charge rates without increasing transfers from the general budget to airport-related budget. Since the MCPF varies across charges in the actual system as shown in Subsection 5.1., a proper adjustment of the system can improve the social welfare.

After the optimized charge system in Scenario 2, the MCPF of the airport-related charges, which can be calculated by using Eq. (17)’, is equated to 1.705. This result implies that increasing the transfer from labor tax revenue to the airport-related budget is socially desirable, since the MCPF of labor tax is estimated to be smaller (1.0-1.2). Since the airline industry is in oligopoly with a few large airlines, airlines have market power to raise airfares and reduce flight frequency. Thus, the charges levied on airlines, which further worsen the situation by increasing airfares and decreasing flight frequency, result in a large welfare loss.

6. Conclusion

This study is the first to quantitatively investigate the optimal airport-related charges. We first theoretically derive the formula for the optimal rates of three kinds of charges: per-passenger charges, per-flight charges, and aviation fuel tax. The formula takes account of the marginal cost of public funds (MCPF). The MCPF is the ratio of the change in the social welfare to the change in the government revenue associated with a change in the charge rate. The MCPFs of charges should be balanced at the optimal, as suggested by the optimal tax theory. A change in a charge influences the MCPFs of other charges because it affects airlines' decisions on airfares and flight frequency, which appear in both the numerator and denominator of the MCPFs. The simultaneous optimization of those multiple charges is therefore essential.

This study then quantitatively optimizes the airport-related charges in the context of the Japanese domestic market. We calculate the optimal rates in two scenarios. Scenario 1 is the first-best scenario in which the transfer from the government general funds to airport expenditure can be freely increased from the present amount. In Scenario 2, the amount of the transfer is fixed at the present level.

A contribution to the literature is showing how much welfare gain can be expected by simultaneously optimizing the airport-related charges. The result of Scenario 1 indicates that the optimization increases social welfare by 19 percent from the present level. Even in Scenario 2 with the fixed transfer from the general funds, the optimization increases the social welfare by 10 percent. This implies that even if it is difficult to increase the transfer from the general funds from the present amount, the social welfare can be increased by just adjusting the rates of the airport-related charges while considering interdependency among them.

The MCPF of the airport-related charges after the optimization in Scenario 2 is about 1.705. The MCPF of the labor tax, which largely consists of general government funds, is estimated to be 1.0-1.2 by previous studies (e.g., Bessho et al., 2003). These results recommend that the transfer from the general funds should be increased from the current amount.

Furthermore, the optimization results imply that the distortion due to market power of airlines is especially large on routes where small aircraft are used. Flight frequency on those routes is much larger under the optimized charge system than under the actual system. This is because small aircraft tend to be used on the routes with small demand, on which a small number of airlines operate. Additionally, since most of such routes are to/from uncongested airports without the slot constraints, there is enough room to increase flight frequency.

We have not considered many potentially relevant considerations. First, we do not consider externalities of congestion. If the total number of flights at an airport increases, delay of landing or takeoff may become a significant problem. Although we take account of the slot constraints at two congested airports in Japan (Haneda Airport and Fukuoka Airport), the congestion externalities at the other airports are not considered. Second, we focus on short-term effects. Aircraft characteristics (e.g., the number of seats per flight) are exogenous in our model and fixed in the optimizations. In the long term, however, airlines may change the type of aircraft as a reaction to a change in airport-related charges. Additionally, the numbers of landing slots at the congested airports, which are fixed in the analyses of this paper, may be increased in the long term along with a change in the airport-charge system. Extending the empirical structural model to consider these aspects of the airline market is an interesting direction for future work.

Appendix: Marginal cost estimates at the airport with slot constraints

This appendix explains the estimation method of marginal costs with respect to flight frequency ($\overline{mc^F}_{jrt}$) on routes to/from Haneda Airport, the airport of which slot constraint is binding. If the slot constraints are not binding, marginal costs can be estimated by solving the simultaneous equations of the first-order conditions (Eqs. (2) and (3)). When the binding constraint is added, the first-order condition with respect to flight frequency is changed to (3)', containing the Lagrange multipliers (ϕ_{jt}) as an additional unknown variable. These Lagrange multipliers cannot be observed directly, so should be estimated. What we can obtain from solving the simultaneous equations of Eqs. (2) and (3)' is the values of $\overline{mc^F}_{jrt} + \phi_{jt}$.

The marginal costs with respect to flight frequency on routes to/from Haneda Airport are estimated as follows. First, the marginal costs on non-Haneda routes are estimated based on the first-order conditions. Second, they are regressed on route and airline characteristics. Lastly, the marginal costs on Haneda routes are estimated based on the predicted values that are obtained from substituting the values of the characteristics of Haneda routes into the estimated regression model. The details are explained below.

Using the values of $\overline{mc^F}_{jrt}$ on non-Haneda routes that are obtained from the first-order conditions, the following regression model is estimated.

$$\overline{mc^F}_{jrt} = \boldsymbol{\beta}^{\boldsymbol{mcF}\prime} \boldsymbol{x}_{\boldsymbol{jrt}}^{\boldsymbol{mcF}} + e_{jrt}^{mcF}, \tag{A1}$$

where $\boldsymbol{x}_{\boldsymbol{jrt}}^{\boldsymbol{mcF}}$ include the route distance (with its squared and cubic terms), the number of seats (in logarithm), the sum of the areas of endpoint airports, airline dummies, and month dummies. The variable of airport size is included to capture economies of scale and transformed by the Box-Cox transformation. e_{jrt}^{mcF} is the error term. The model is estimated using the ordinary least squares (OLS) estimator.

Table A1 shows the estimation results. The coefficients of distance and distance squared are significant and indicate that the marginal costs are increasing in distance for the most part of the sample. The coefficient of the number of seats is positive. This means that as the number of seats increases, so does the cost. A reason would be that a larger aircraft requires more crew members. The airport size coefficient is significantly negative, indicating economies of scale.

Using the estimated model, we estimate the marginal costs on Haneda routes as follows. First, the predicted values of the marginal costs are obtained by substituting route and airline characteristics on Haneda routes into the estimated model. Second, values of $\overline{mc^F}_{jrt} + \phi_{jt}$ are obtained from solving the simultaneous equations of the first-order conditions. Third, we estimate ϕ_{jt} of airline j in time t as the differences between them. Specifically, we calculate the average of the values of $\overline{mc^F}_{jrt} + \phi_{jt}$ minus the predicted value of $\overline{mc^F}_{jrt}$ for each airline and time combination. Finally, $\overline{mc^F}_{jrt}$ is estimated as $\overline{mc^F}_{jrt} + \phi_{jt}$ minus the estimated value of ϕ_{jt}.

[Table A1 around here]

The estimated values of ϕ_{jt} for the time point of simulation analysis (October 2005), however, are negative for some airlines, ranging from -335.2 to 160.3 thousand yen. The Lagrangian multiplier should be positive by definition. A possible reason of negative estimates would be that the regression model estimated based on the sample of non-Haneda routes could not fully capture the economies of scale that are specific to Haneda Airport, though the airport size variable partly represents them. To reflect the economies of scale at Haneda Airport, we adjust the estimates of ϕ_{jt}, raising them by 335.2, the minimum value of them. The adjusted values can be seen as the lower bound of ϕ_{jt} and range from 0 to 495.5. In the simulation analysis, we use the values of $\overline{mc^F}_{jrt}$ that are estimated as $\overline{mc^F}_{jrt} + \phi_{jt}$ minus these adjusted ϕ_{jt}.

Table A2 shows the summary statistics of the estimate values of $\overline{mc^F}_{jrt}$ separately for Haneda and non-Haneda routes. The mean of the marginal costs on Haneda routes is larger than that on non-Haneda routes. This is because, though the larger size of Haneda Airport reduces marginal costs, the larger aircraft used on the routes increase costs per flight.

[Table A2 around here]

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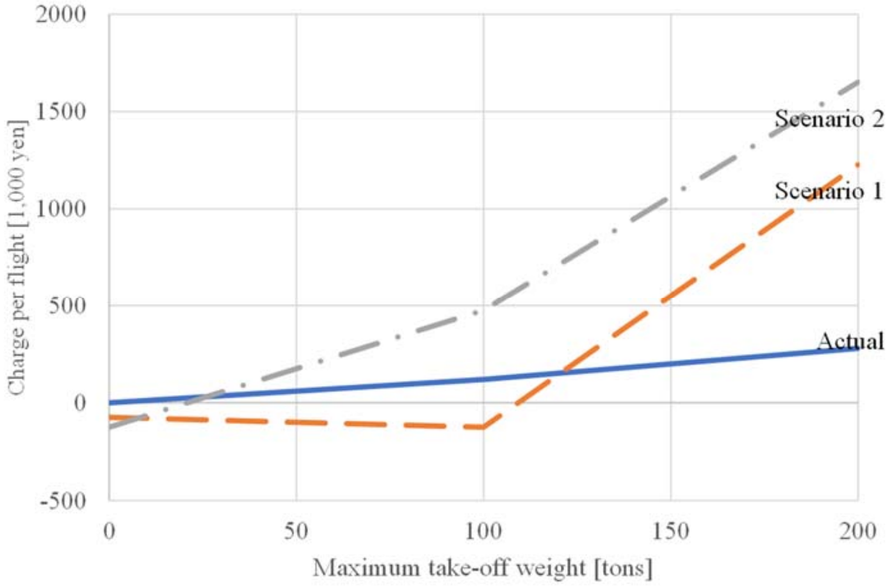

Figure 1 Per-flight charges

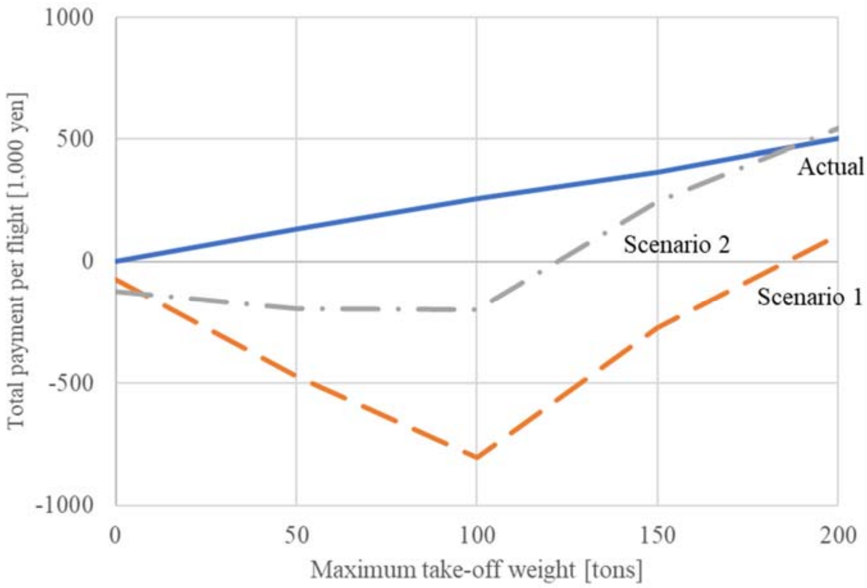

Figure 2 Sum of per-flight charges and fuel tax

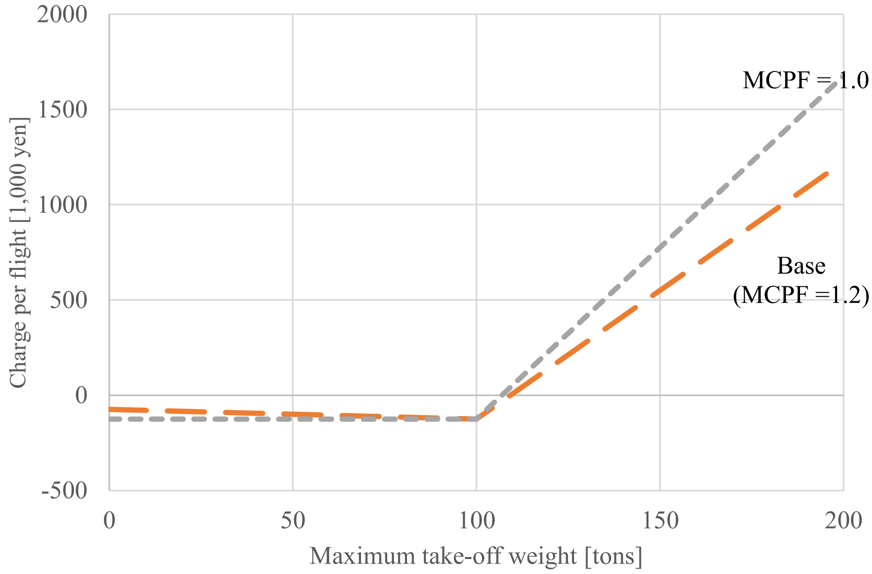

Figure 3 Scenario 1 with different values of the MCPF of labor tax

Table 1 Summary statistics

Variables [unit]	Mean	Std.	Min	Max
Route characteristics				
Number of airlines	1.4	0.7	1.0	4.0
Distance [km]	830	368	153	2418
Population around endpoint airport [millions]	3.3	3.6	0.25	19.6
Haneda Airport dummy	0.3	0.4	0.0	1.0
Airline characteristics				
Airfare [1,000 yen]	22.3	6.4	8.6	46.6
Flight frequency [round trips per day]	3.0	2.8	0.07	23.6
Number of passengers [1,000]	28.52	46.5	0.28	445.8
Available seats per flight	201.6	109.5	29.3	568.0
Maximum take-off weight [tons]	98.7	65.5	6.2	412.8
Engine compression ratio	27.5	6.6	6.4	40.0
Airport-related tax and charges				
Per-passenger charge [1,000 yen]	0.02	0.06	0.00	0.50
Per-flight charge (landing fee) [1,000 yen]	123.1	87.4	13.8	554.4
Fuel consumption [kL per flight]	3.3	2.4	0.3	16.4
Aviation fuel tax [1,000 yen per flight]	78.6	53.8	8.7	425.8

Note: Sample size is 5,675.

Table 2 Demand estimation results

Airfare		-0.084
		(0.008) ***
Flight frequency	Coefficient (β)	-3.63
		(0.70) ***
	Exponent (ρ)	-0.31
		(0.08) ***
Nesting parameter	Base (σ)	0.04
		(0.12)
	Additional for long routes (σ^{long})	0.29
		(0.06) ***
Sample size		5,680
R^2		0.52
Chi -square statistics [d.f.]		8.58 [4] *
First-stage F-statistics [d.f.]		86.7 [9, 5650] ***
Own-price elasticity [Sta. dev.]		-2.00 [0.66]
Own-frequency elasticity [Sta. dev.]		0.96 [0.23]

Notes: The estimation results are a reproduction of column (5-2) of Table V of Doi (2022). The numbers in parentheses are heteroskedasticity-robust standard errors. All estimations include the route distance, its squared and cubed terms, the number of seats per flight, the Haneda dummy variable, and airline- and month-specific dummy variables, which are not reported in the table. The *Chi* -square statistics are for a test of overidentifying restrictions. The First-stage F-statistics provide the average explanatory power of the instruments, conditional on exogenous variables. *** and * denote 1- and 10-percent significance, respectively.

Table 3 Optimization results

	Actual	Scenario 1		Scenario 2	
Airport-related charges					
Per-passenger charge [1,000 yen]	0.1	-2.2		0.325	
Per-flight charge [1,000 yen]					
Base	0	-75.0		-125.0	
Per-ton rate for 1-100 tons	1.0 / 1.4	-0.5		6.0	
Per-ton rate for >100 tons	1.55 / 1.65	13.5		11.8	
Fuel tax [1,000 yen per kL]	26.0	-129.0		-127.5	
Averages					
Airfare [1,000 yen]	22.9	21.6	(-6%)	23.1	(1%)
Flight frequency [flights per day]	3.35	6.73	(101%)	4.29	(28%)
Routes with small aircraft	1.88	6.71	(257%)	4.06	(116%)
Routes with large aircraft	6.92	6.89	(-0.4%)	5.84	(-16%)
Welfare [billion yen]					
Consumer surplus [a]	237.6	435.1	(83%)	284.7	(20%)
Airline profits [b]	762.0	1,478.9	(94%)	799.8	(5%)
Environmental externalities [c]	-5.4	-80.7	(1394%)	-5.7	(5%)
Transfer from the labor tax revenues [d]	40.0	593.3	(1383%)	41.2	(3%)
Total: [a] + [b] + [c] - MCPF×[d]	946.2	1,121.3	(19%)	1,037.6	(10%)

Notes: The numbers in parentheses are the change ratios from the actual charge system. The per-ton rate in the actual system is 1,000 yen for 0-25 tons, 1,400 yen for 25-100 tons, 1,550 yen for 100-200 tons, and 1,650 yen for 200 tons and over.

Table 4 Scenario 1 with different values of the MCPF of labor tax

MCPF of labor tax	Base (replication from Table 3) 1.2	1.0
Per-passenger charge [1,000 yen]	-2.2	-3.5
Per-flight charge [1,000 yen]		
Base	-75.0	-125.0
Per-ton rate for 1-100 tons	-0.5	0.0
Per-ton rate for >100 tons	13.5	18.0
Fuel tax [1,000 yen per kL]	-129.0	-179.0

Table A1 Estimation results of the marginal cost model

Variables	Estimates (p value)
Distance [1,000 km]	-312.7
	(0.05)
Distance^2	363.0
	(0.02)
Distance^3	-39.1
	(0.37)
The number of seats [in logarithm]	677.2
	(0.00)
Airport size	-37.2
	(0.01)
Sample size	4130
R^2	0.574

Notes: The airport size variable is the sum of areas (in square kilometers) of two endpoint airports of a route and transformed by the Box-Cox transformation. The estimation includes airline- and month-specific dummy variables.

Table A2 Summary statistics of estimated marginal cost of flights

	Mean	Sta. dev.	Min.	Median	Max
Marginal cost of flight [1,000 yen per flight]					
Non-Haneda routes	875.9	465.6	-268.6	936.9	2,501.0
Haneda routes	1,313.4	265.2	571.5	1,326.9	2,074.5
Route characteristics					
Distance [1,000 km]					
Non-Haneda	0.89	0.26	0.44	0.89	1.69
Haneda	0.81	0.40	0.15	0.75	2.42
Number of seats [per flight]					
Non-Haneda	166.1	90.9	29.3	163.0	568.0
Haneda	296.5	98.0	125.6	285.3	567.9
Sum of areas of endpoint airports [km^2]					
Non-Haneda	689	384	192	526	1,924
Haneda	1,774	217	1,527	1,693	2,583

Note: The number of observations for Haneda and non-Haneda routes are 1,545 and 4,130, respectively.