Multi-Airport Complementation Policy for Metropolitan Areas : A Case Study of Subsidy Input during Temporary Functional Decline

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Multi-Airport Complementation Policy for Metropolitan Areas: A Case Study of Subsidy Input during Temporary Functional Decline

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Abstract

Metropolitan areas often have multiple airports. We investigate potential policies to elicit their complementary functions in emergencies. An economic model is constructed for a metropolis that is served by two airports (a main hub and a secondary facility) connected to a local city. In our simulated emergency scenario, the main hub's capacity is restricted for some reason. While applying a simple economics model that includes passengers, a dominant airline, and airports, we discuss the effectiveness of a subsidy for a secondary airport when the main airport function is degraded. Main findings obtained from the simple analysis presented herein indicate that a subsidy for the secondary airport can encourage the recovery of the passenger volume originally served by the main airport.

Keywords: Airport policy, Airport management, Hub airport, Sustainable network

1. Introduction

Two or more airports are often situated in a single large city or metropolitan area. For instance, John F. Kennedy International, Newark Liberty, and LaGuardia airports mainly serve the New York metro area. Charles de Gaulle, Orly, and Bovetire airports serve Paris. Heathrow, Gatwick, and others serve the London area. Similarly, in Japan, Haneda and Narita airports serve the Tokyo metropolitan area. Osaka International (Itami), Kansai International, and Kobe airports all serve the Osaka metropolitan area known as “Kansai”. These airports mutually compete in the same area. However, they sometimes function complementarily, e.g. one airport is used mainly as an international airport whereas others are for domestic service. A single airport, with only limited capacity, could not adequately serve metropolitan areas that have large transport volume. The existence of multiple airports in a metropolitan area can be helpful for consumers because consumers can choose their travel routes flexibly. Consumers can also save travel expenses if some airports are available as alternatives.

In the event of an airport-related emergency such as a typhoon, earthquake, volcanic eruption, or technical accident, multiple airports would be able to provide alternatives for passengers, airlines, and government. If an airport were damaged by an accident, passengers could use the others as alternative airports. Actually, such a situation recently occurred in Japan. The Kansai metropolitan area, which is the largest area in western Japan, has three airports, i.e., Itami (Osaka International), Kansai International, and Kobe airports. Kansai International Airport, on the coast, provides hub functions for air passengers, cargo services, and international lines. Itami Airport is a large domestic airport in western Japan. Kobe Airport is also a domestic facility. On September 4, 2018, Typhoon 21 of the season caused great damage to western Japan. Kansai International Airport was closed because of flooding and power failure. Furthermore, the bridge connecting the airport island to Osaka was damaged. Because of this damage, the airport was forced to operate at reduced capacity for about two weeks. During this period, the Japanese government (the Ministry of Land, Infrastructure and Transport) requested, via a temporary arrangement, that Itami Airport and Kobe Airport receive some domestic flights destined for Kansai International Airport. This arrangement established the feasibility of Itami Airport and Kobe Airport as alternative facilities to Kansai Airport.

As might be apparent in the case described above, we explore the complementary operations of multiple airports in a hub city. Additionally, we discuss the effectiveness of government policies to encourage cross-subsidization by which the functioning airport can compensate for the impaired functionality of the damaged airport. We assume the simplest situation, in which the dominant airline provides flight services for one airport and another in a hub city. Then we describe our development of a simple theoretical economic model. For the hub city, we assume that two airports operate respectively as a main airport and as a secondary facility. Our counterfactual scenario posits that the capacity of the main airport in the hub city is damaged because of an emergency. The secondary airport is then used as an alternative airport to recover the volume of transportation. Moreover, we explore the economic mechanism of a government subsidy for the secondary airport. For these analyses, we specifically examine the economic incentives of players, i.e., passengers, the (dominant) airline, airports, and the government.

The main result obtained from this simplest analysis is that a subsidy for the secondary airport can be valid to encourage recovery of the passenger volume which is served originally by the main airport. The subsidy can decrease the second airport's charge for the airline. Therefore, the airline has an incentive to decrease airfares on the market via the secondary airport. Moreover, the traffic flows can recover because passengers can save travel costs and inconvenience in their trips. We also show the amount of subsidy necessary to recover the original volume fully when the main airport is damaged. Traditional discussions have held that subsidy input can be an effective policy by a government experiencing a disaster. As described herein, we explore this mechanism by particularly addressing typical route networks and interaction among passengers, an airline, and the government.

The remainder of this paper is configured into three sections. In Section 2, we select some earlier studies related to our work. Analysis using an economic model is presented in Section 3. We conclude with a report of our achievements from this study and an explanation of some future tasks of this research in Section 4.

2. Literature Review

Much of the literature particularly addressing air transportation explores the airline network using theoretical models.

For instance, Zhang (1996) applies an economic model approach and points out the “fortress hub” phenomenon, by which major airlines impose local monopolies in spoke markets from their respective hubs by operating individual hub-and-spoke networks. Many reports have investigated the effectiveness of competition and cooperation among airlines. Additionally, some studies have specifically examined the relation between air transportation and high-speed rail. Recently, Tsunoda (2018) demonstrated the validity of joint investments by both government and operators of high-speed rail networks competing with airlines.

From the perspective of airport authorities, Xiao, Fu, and Zhang (2013) consider transportation demand uncertainty for optimal capacity of airports. Xiao et al. (2017) expands earlier analyses by considering a real option approach. Jiang and Zhang (2014) assume a situation under which the hub airport capacity is constrained, and in which airlines with a hub-and-spoke network cooperate with high-speed rail operators. Their findings demonstrate that when airlines compete with high-speed rail during the earlier period, such cooperation can reduce market traffic. However, they also find that traffic can increase in the market where competition between airlines and high-speed rail is weak in the earlier period, and where market welfare is improved through cooperation. By contrast, Xiao, Fu, and Zhang (2016) specifically examine arrangements between airlines and airports that choose capacity under conditions of demand uncertainty. They propose a situation by which an airline and airport jointly invest, share financial risks, and share revenues to alleviate difficulties caused by capacity shortages. These arrangements can increase airport capacity, but they do not induce certain revenue expansion. Reports of the literature described above suggest that flight services provided by airlines and airport operations are interdependent.

For network analysis, consideration of capacity constraints of airports on networks is important. Takebayashi (2011) investigates the relation between the capacity of hub airports (runway) and airline behavior, and finds that airlines' profitability is improved by runway capacity expansion. He applies a bi-level market model by which an airline chooses aircraft size and flight frequency for their services. His bi-level model design includes multi-stage decision making among players in the markets. Exogenous constraints for airport capacity are also explored as important factors affecting airport operation. Takebayashi and Onishi (2018) assume that the main gateway and the reliever airports are connected by high-speed rail. They assume that the main gateway airport became completely dysfunctional because of some catastrophe. They proceed to analyze the effectiveness of policy for providing support to high-speed railway passengers to induce them to go to the reliever airports. Their findings indicate that the validity of fare restriction for high-speed railway operators and fare support for high-speed rail passengers will recover or maintain the transport network flow.

For this study, we explore the validity of subsidy policy to recover the potential flow of air transportation in a hub-city served by multiple (main and secondary) airports. We then conduct counterfactual analysis indicating that the main airport capacity is damaged for some exogenous reason. Moreover, we refer to modeling of the airport capacity choice problem, traffic production bound by capacity, and solving the optimization problems with constraints described by Xiao, Fu, and Zhang (2013).

3. Model and Analysis

As the following diagram illustrates, we investigate the simplest case herein. Figure 1 presents the network structure assumed for analyses.

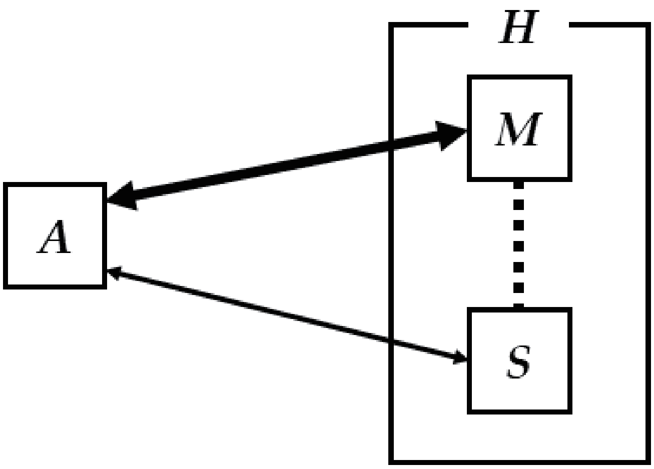

Figure 1. Network structure.

City H has a main airport M and a secondary airport S. We presume that airport M is superior to airport S in terms of infrastructure, facilities for passengers, and their amenities. Airport M, which is closer to the center of city H, is the more useful for passengers. We assume simply that a dominant monopolistic airline serves airport A (city A) and city H. In this network, the airline provides air transport services on two routes: A–M and A–S. Airport M and airport S are connected by some land transportation such as railways and shuttle-bus services. Therefore, passengers can access the center area in H also from airport S.

For this simple analysis, we assume three stages of a game. At the first stage, each airport (M and S) decides their own airport fee (including landing fee). Secondly, an airline sets the quantity, i.e., service volume including the flight frequency and the amounts of seats. Consumers who travel to city H or to A maximize their utility with consumption of air travel on the final stage. We solve this game using backward induction.

The consumers' utility function is written as

$$u(q_m, q_s) = (q_m + \alpha q_s) - \frac{1}{2}(q_m^2 + q_s^2 + 2\beta q_m q_s), \tag{1}$$

where q_i and (i=m,s) respectively represent the quantities of flight service consumed after it is provided by the airline on route A–M or A–S. In addition, α and β are parameters for which $\alpha < 1$ and $0 \leq \beta \leq 1$. They represent coefficients of benefit. When consumers visit the center of city H from airport M or S, they must pay an additional transport fee, as represented by t_i, e.g., trip costs by bus, train, and taxi. We assume that airport S is far from the center of city H. Therefore, $t_m<t_s$. Consequently, the full trip prices ρ_i for consumers are

$$\rho_m = p_m + t_m, \tag{2}$$
$$\rho_s = p_s + t_s. \tag{3}$$

In those equations, ρ_i denotes prices that passengers must pay to an airline (airfare itself). To simplify that point, we normalize $t_m = 0$ and $0 < t_s = t$. Consumers maximize their utility for travel. Their optimization problem with Equation (1) is written as

$$\max_{q_m, q_s} u\,(q_m, q_s) - p_m q_m - (p_s + t)q_s. \tag{4}$$

Equation (4) derives the inverse demand functions as

$$p_m = 1 - q_m - \beta q_s, \tag{5}$$
$$p_s = \alpha - t - q_s - \beta q_m. \tag{6}$$

By contrast, the monopolistic airline's profit function is

$$\pi = \sum_{i=\{m,s\}} (p_i - w_i)q_i\,, \tag{7}$$

where w_i presents airport i's fee charged on service volumes. We infer that w_i includes the landing fee, airport facility fee, and taxes. However, to simplify the following discussions, we do not distinguish them. This airport fee is revenue for the airport authority (airport operator). Therefore, the profits of airport i are

$$\Pi_i = w_i q_i. \tag{8}$$

As described above, we do not consider marginal and fixed costs caused by operating airports' facility. An airline sets service volume q_i to maximize profit (7). Each airport sets airport fees w_i to maximize its own profits (8).

3.1 Benchmark Case: No Constraint Situation

In this subsection, we derive equilibria for the initial case. The function of the main airport is not damaged. Therefore, the airport capacity is not constrained exogenously. We derive equilibria through backward induction with maximization of consumers' objective function (4), maximization of the dominant airline's profit (7), and maximization of airport profits (8).

Based on the given inverse demand functions (5) and (6), the dominant airline maximizes the profit (7) by setting q_i. This optimization derives functions of the service quantity as presented below:

$$q_m(w_m, w_s) = \frac{1 - w_m - \beta(\alpha - t - w_s)}{2(1-\beta^2)}, \tag{9}$$

$$q_s(w_m, w_s) = \frac{\alpha - t - w_s - \beta(1 - w_m)}{2(1-\beta^2)}. \tag{10}$$

Given equation (9) and (10), we solve airports' optimizations. With this problem, the first-order condition is $\partial\pi_i / \partial w_i = 0$. We obtain airport charges for the equilibria as shown below. Therein, *NC* denotes that they are not constrained.

$$w_m^{NC} = \frac{2 - \beta^2 - \beta(\alpha - t)}{4 - \beta^2}, \tag{11}$$

$$w_s^{NC} = \frac{(2 - \beta^2)(\alpha - t) - \beta}{4 - \beta^2}. \tag{12}$$

Therefore, transport quantities and service prices on equilibria are calculated by substituting (11) and (12) for (5), (6), (9), and (10). Transportation flows operated by airports *m* and *s* for the equilibria are

$$q_m^{NC} = \frac{2 - \beta^2 - \beta(\alpha - t)}{(1-\beta^2)(4 - \beta^2)}, \tag{13}$$

$$q_s^{NC} = \frac{(2 - \beta^2)(\alpha - t) - \beta}{(1-\beta^2)(4 - \beta^2)}. \tag{14}$$

The dominant airline sets airfares for the equilibria according to the following.

$$p_m^{NC} = \frac{2(3-\beta^2) - \beta(\alpha - t)}{2(4-\beta^2)}, \tag{15}$$

$$p_s^{NC} = \frac{2(3-\beta^2)(\alpha - t) - \beta}{2(4-\beta^2)}, \tag{16}$$

Additionally, we obtain the total amount of transportation between cities as,

$$\begin{aligned} Q^{NC} &= q_m^{NC} + q_s^{NC} \\ &= \frac{1+\alpha-t}{2(1+\beta)(2-\beta)}. \end{aligned} \tag{17}$$

These equilibrium values are benchmarks compared to counterfactual analysis, as described in the following subsections.

3.2 Scenario 1: Airport *M* Damaged

We conduct counterfactual analysis. We presume that airport M is damaged because of some exogenous factors such as a typhoon or earthquake. However, the damage characteristics need not be identified here. This scenario relies on an assumption that airport M is to be closed partially. This situation is equivalent as an example in which one runway in Airport M is closed, but other runways are available.

Let $0 < \delta < 1$ represent the degree of damage to the airport capacity. The following constraint is derived with (13) as

$$q_m \leq K_m = (1-\delta) q_m^{NC}. \tag{18}$$

Equation (18) can be interpreted as described below. The function of airport M closes and eventually becomes a complete loss of potential ability if parameter δ approaches 1. However, if parameter δ approaches 0, then airport M can accommodate more of the initial traffic flows q_m^{NC}. We recalculate the equilibrium with consideration of Equation (18). Similarly to the process described in Subsection 3.1, maximizations of consumers' utility, profits of the dominant airline, and airports derive new equilibria of quantities. The dominant airline decides the service quantities with constraint (18), as shown below.

$$\max_{q_m, q_s} \pi \qquad \text{s.t.}\ q_m \leq K_m \tag{19}$$

When $w_m \leq 1-\beta(\alpha-t-w_s)-2(1-\beta^2)K_m$, we obtain functions of service quantity as

$$q_m(w_m, w_s) = K_m, \tag{20}$$

$$q_s(w_m, w_s) = \frac{1}{2}(\alpha - t - w_s - 2\beta K_m). \tag{21}$$

Otherwise, these functions are the same as non-constrained cases (9) and (10). With those given, airports maximize their profits. Charges of Airport M, w_m, are resolved at the upper limit of constraint (18) because $\partial\Pi_m / \partial w_m = 0$. Additionally, the first-order condition of profit maximization by Airport S is $\partial\pi_s / \partial w_s = 0$. Therefore, we can derive airport charges in equilibria as the following. Superscript D signifies that airport M is damaged.

$$w_m^D = \frac{1}{2}[2 - \beta(\alpha - t) - 2(2 - \beta^2)K_m], \tag{22}$$

$$w_s^D = \frac{1}{2}(\alpha - t - 2\beta K_m). \tag{23}$$

Service quantities and airfares on the equilibria are obtained by substituting (22) and (23) to (5), (6), (20), and (21) as

$$q_m^D = K_m = (1-\delta)q_m^{NC}, \tag{24}$$

$$q_s^D = \frac{1}{4}(\alpha - t - 2\beta K_m). \tag{25}$$

$$p_m^D = \frac{1}{4}[4 - \beta(\alpha - t) - 2(2 - \beta^2)K_m], \tag{26}$$

$$p_s^D = \frac{1}{4}[3(\alpha - t) - 2\beta K_m]. \tag{27}$$

The total quantity in the network is calculated using Equations (24) and (25):

$$\begin{aligned} Q^D &= q_m^D + q_s^D \\ &= \frac{1}{4}[\alpha - t + 2(2-\beta)K_m]. \end{aligned} \tag{28}$$

These equilibria indicate that the loss of function of airport M can affect transportation flow, airfares, and charges of airport S by market mechanisms. One can calculate the differences between original quantities served for non-damaged airport M and counterfactual quantities if airport M is damaged to a degree of δ as

$$Q^{NC} - Q^D = \frac{\beta^2[(2-\beta^2)(\alpha-t)-\beta] + \delta(2-\beta)[2-\beta(\alpha-t)-\beta^2]}{4(1-\beta^2)(4-\beta^2)}. \tag{29}$$

As the next steps, we explore the validity of subsidy by a government to recover the loss of airport function above.

3.3 Scenario 2: Subsidy Input to Airport S

Next we discuss effects of subsidies for airport S when main airport M is affected by some disaster. Letting the capacity constraint $q_m \leq K_m = (1-\delta)\, q_m^{NC}$ be maintained in this case, we further assume that the government gives a subsidy for airport S based on the amounts of quantities which the airport accepts from airport M to recover the loss of transportation flows. Therefore, the profit of airport S in this scenario is written as

$$\Pi_s = (w_s + \nu)q_s. \tag{30}$$

In that equation, ν represents the marginal subsidy per quantity. Similarly to Subsection 3.2, the optimization problem for the dominant airline is (19).

When $w_m \leq 1 - \beta(\alpha - t - w_s) - 2(1-\beta^2)K_m$, we obtain functions of service quantity as (20) and (21). Otherwise, these functions are the same as non-constrained cases (9) and (10). Airport M maximizes its own profit Π_m under the capacity constraint. As presented in Subsection 3.2, the charge of Airport M, w_m, is solved at the upper limit of constraint (18) because $\partial \Pi_m / \partial w_m > 0$. However, Airport S, which receives subsidies from the government maximizes own profit (30) that includes ν. The first-order condition is $\partial \pi_s / \partial w_s = 0$. These derive airport charges on new equilibria as

$$w_m^S = \frac{1}{2}[2 - \beta(\alpha + \nu - t) - 2(2 - \beta^2)K_m], \tag{31}$$

$$w_s^S = \frac{1}{2}(\alpha - \nu - t - 2\beta K_m). \tag{32}$$

Superscript S denotes the case in which the government provides a subsidy. We obtain passenger flows on new equilibria by substituting (31) and (32) for (20) and (21).

$$q_m^S = K_m, \tag{33}$$

$$q_s^S = \frac{1}{4}(\alpha + \nu - t - 2\beta K_m), \tag{34}$$

Additionally, airfares for the new equilibria are

$$p_m^S = \frac{1}{4}[4 - \beta(\alpha + \nu - t) - 2(2 - \beta^2)K_m], \tag{35}$$

$$p_s^S = \frac{1}{4}[3(\alpha - t) - \nu - 2\beta K_m]. \tag{36}$$

The total quantity is calculated as

$$\begin{aligned} Q^S &= q_m^S + q_s^S \\ &= \frac{1}{4}[\alpha + \nu - t + 2(2 - \beta)K_m]. \end{aligned} \tag{37}$$

The new equilibria, as expressed in Equations (31)–(37), depend on K_m and ν, the loss of airports M and subsidy. The subsidy can decrease airfare and airport charges for airport S. These can save passengers' trip costs on route A–S. Therefore, transportation flows can be handled partially by secondary airports in disaster situations.

Equation (37) presents passenger flows for the network in which the main airport is partially closed and the government inputs a subsidy. The difference between potential (initial) passenger flows in the network, Q^{NC}, and Equation (37) is calculable as

$$Q^{NC} - Q^{s} = \frac{\beta^2[(2-\beta^2)(\alpha - t) - \beta] + \delta(2-\beta)[2 - \beta(\alpha - t) - \beta^2]}{4(1-\beta^2)(4-\beta^2)} - \frac{\nu}{4}. \quad (38)$$

From comparison of (28) and (38), one can infer that the subsidy for secondary airport S decreases the loss of quantity in a disaster situation. A subsidy received from the government can be an economic incentive for a secondary airport to recover the main airport's function. We can also calculate the amount of subsidy for secondary airport S to recover the entire transportation loss as

$$\begin{aligned} &Q^{NC} - Q^{S} = 0 \\ &\quad \Leftrightarrow \nu = \frac{\beta^2[(2-\beta^2)(\alpha - t) - \beta] + \delta(2-\beta)[2 - \beta(\alpha - t) - \beta^2]}{(1-\beta^2)(4-\beta^2)}. \end{aligned} \quad (39)$$

3.4 Discussion

As presented in the subsections above, we developed simple models to explore subsidy mechanisms for the secondary airport. We presume three cases: (i) original situation (main airport works completely; with superscript *NC)*, (ii) disaster situation (main airport partially loses the potential function; with superscript *D)*, and (iii) subsidy support situation (government inputs a subsidy for the secondary airport; with superscript *S)*. By comparing equilibria found in these cases, one recognizes that passengers flow between cities when the main airport function is partially constrained. The main airport is assumed to be convenient for passengers in our model. In practice, for instance in the Kansai area, we consider that Itami Airport can be equivalent to this assumption because it is closer to the center of Osaka than the other second airports: Kansai Airport (as domestic) or Kobe Airport. Similarly, Haneda Airport can be the main airport in the Tokyo area. Our analysis indicates that passenger flows between cities or metropolitan areas will decrease when these main airports are affected by some disaster and their functionality is impaired. Some potential passengers will decide not to take a trip because the secondary airport is assumed to be inconvenient for passengers in terms of its location or facilities. Therefore, the traffic volumes among cities are expected to decrease.

For the analysis described above, we defined passenger flows. However, discussion and implications can also be put forth for cargo and logistics. Particularly, if such traffic diminishes over a long period of time, even economical connections among cities can stagnate. We are concerned that these negative effects might spread to other cities and other activities. The results presented above imply that a subsidy for a second airport from the government can serve as an economical incentive for the market to recover transportation flows. A subsidy for a second airport can reduce airport charges. In fact, decreasing the airport charges saves airline costs. As a result, this benefit will be passed on to passengers. Passengers have some incentive to choose a route via a secondary airport instead of the main airport because travel costs are decreased, even if the location or facility is inferior to that of the main airport. Potential transportation flows can be maintained partially through the use of secondary airports.

The amount of subsidy depends on the degree of damage to the main airport, δ, and on the additional costs for passengers to substitute the secondary airport (the degree of inconvenience for passengers), t. Enhancement of the connection between two airports using railways and shuttle bus services is necessary for smooth transfer.

Our model does not consider the capacity constraints of secondary airports. In practice, secondary airports can accept additional passengers from the main airport only within this capacity. Not only a direct subsidy but also technical investment for the facility is necessary to operate flexibly in emergency situations.

4. Conclusion

As described above, we developed simple theoretical models to demonstrate the validity of a subsidy for a secondary airport in a city when the main airport has been affected by a disaster, i.e., when the potential function of the main airport is damaged because of exogenous phenomenon, such as a natural disaster. Our models include utility maximization by passengers in addition to profit maximization by the dominant airline and by airports. First, we obtain equilibria for the original situation, whereby the function of the main airport is fully workable. We treat this case as a benchmark. Secondly, we presume that the main airport has been affected by the disaster and that its operation capabilities have been impaired. We presume that the main airport's capacity is constrained by the degree of δ in our economic model. This assumption expresses that the main airport function is partially unavailable. The constrained operations of the main airport can induce a loss of passenger flows in the network. The first non-constrained case and the second damage situation can then be compared.

When the government awards a subsidy for the secondary airport, the passenger flow can be partially recovered. The subsidy for the secondary airport operator is converted to passengers through player interaction. It leads to profit maximization by airport operators and airlines, and affects route choice by passengers based on maximization of their utility. The subsidy can decrease the second airport's charge for the airline. Therefore, the airline has an incentive to cut market prices for tickets that include travel via the second airport. In our analysis, the second airport is assumed to be far from the center of the city. The subsidy can compensate passengers' inconvenience incurred by using the secondary airport. The results presented above, obtained using our simple model, contribute to support of a political discussion theoretically. Maintaining passenger flows and logistics among cities helps to retain economic activity.

It is noteworthy that social welfare is not addressed in these analyses. Future research will examine relations between a subsidy and social welfare for irregular scenarios. Additionally, we assume only the simplest network and economic model for these analyses. We consider a more flexible model from the perspectives of a competitive market environment, hub network effects, connections among airports via outside options, and so on. Practically, we must consider that even secondary airports have some operating constraints, for instance, runway length, limitations of aircraft parking aprons, and the capacity of terminal building capacities. Comparative statics with numerical examples are also valuable to support additional discussion.

Authors' contributions

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Ryohei Yamamoto contributed to research design, interpretation of results, writing (mainly Section 1, Subsection 3.4, and Section 4). Yushi Tsunoda contributed to research design, modeling, calculations, and writing (mainly Section 2, and Section 3). All authors approved the final manuscript.

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