Population Size and Cooperation between Airlines and Railways

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Abstract: We analyze the route structure of an intercity transportation network from the perspective of population size. First, we develop a simple theoretical model of heterogeneous passengers' route choice behaviors. We then consider a differentiated duopoly model involving an airline and railway that compete on fare setting in an intercity transportation market. The airline can choose one of three strategies to maximize profit: a) competition with the railway, b) cooperation with the railway to serve intermodal routes, and c) exiting the market. Our analysis shows that the airline chooses the social welfare maximizing cooperation strategy in cases involving large population size, low transit cost or where direct flights are inconvenient for passengers. We also show that route length and transit cost are important determinants of the effect of cooperation on social welfare.

Keywords: Intercity transportation, Cooperation, Competition, High speed rail, Air transport

1. INTRODUCTION

Intercity transportation networks have developed with population growth in Japan. Competition between airlines and railway (specifically high speed rail, or HSR) can contribute to improved intercity transportation services. However, Japan is becoming an ageing society with a falling birthrate and shrinking population. In this situation, competition does not necessarily improve user convenience and the service level of intercity transportation may deteriorate, especially in rural areas. For example, Murakami et al.(2006) point out that the competition between railway and airline operator in the major market, between Tokyo and Hakata (Kitakyushu), became intense, the frequency of railways in some local areas decreased simultaneously.

An efficient contraction policy is needed in Japan to avoid population decline negatively impacting service levels. Negative impacts are reduction of frequency, exit of service provider and so on. Cooperation between airlines and railways is considered an efficient way to improve service level given a small population. For example, Murakami et al.(2006) analyze socially optimal route structure while including intermodal routes. Givoni and Banister (2006) also points out the potential benefits from cooperation and integration between the modes (operators). However, do cooperation incentives exist for railway and airline under conditions of competition? Takebayashi (2014) points out that while the railway lacks incentives to cooperate, for the airline such incentives do exist.

Research on competition and cooperation between railways and airlines is a rapidly growing field. Jiang and Zhang (2014) examines the impact of cooperation between a hub-and-spoke airline and a HSR operator and finds that such cooperation improves social welfare if the capacity of hub airport is constrained. Clark (2014) analyzes the changes in price mark-up over marginal cost for changes in service distance for the different types of competition. Socorro and Viecens (2013) examines the effects of airline and HSR integration on the environment and

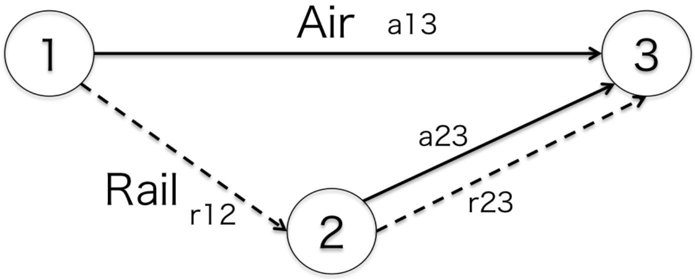

Figure 1. Network structure (nodes are cities, links *r12* and *r23* are served by the railway and links *a13* and *a23* can be served by the airline.)

social welfare at airports with capacity constraints. These theoretical studies focus on the air and HSR cooperation as one effective policy to reduce the negative impact of the capacity constraint at hub airport. Our study focus on the travel convenience of the intercity passengers who travel from local city (spoke city) to other local city (spoke city). The decrease of service level in such local cities are severe in Japan.

Many existing theoretical studies assume passengers' route choice of airline and railway as horizontally differentiated. Xia and Zhang (2016) points out that it seems better to regard the route choice as vertically differentiated from some empirical evidence, such as Behrens and Pels (2012) and Fu et. al.(2014). Xia and Zhang (2016) provides airlines and railway competition and cooperation model with vertically differentiated route choice. We also regard passengers' route choice as vertically differentiated, because if there are several different routes and all passengers would prefer the fastest route to the other if all of the routes can be used at the same fare. We also develop an airline and railway competition and cooperation model with vertical differentiation. Furthermore, we also consider the strategy choice of airline and population size to explicitly analyze the exit behavior of airline. We examine the cooperation incentives for the railway and airline and their consequences for social welfare when population size is considered.

2. MODEL

We consider a network structure that comprises three cities, as shown in Figure 1.There exists one origin-destination pair, with *N* passengers traveling from city 1 to city 3.Links r12 and r23 are served by the railway. Thus passengers choosing to travel between cities 1 and 3 by rail do so via city 2. Conversely, links a13 and a23 can be served by an airline, directly flying from the origin city to the destination airport. On link a23 passengers can choose either the rail or air travel modes at city 2. In this model, we consider three possible strategies for the airline: 1) competition, 2) cooperation, and 3) exit. In the first strategy, the airline enjoys a monopoly on link a13 and competes with the railway from city 2. In the second strategy, the airline only operates link a23 and offers an intermodal route for passengers who come from city 1. Finally, the exit strategy means the airline services none of the links, because providing service is not profitable. We further assume that the airline chooses one among these three strategies to maximize profit. Simultaneously, we assume the railway has no choices about which links to operate, based on high railway construction cost implying high abandonment cost. Consequently, three routes are available to passengers, travel by railway only (*rr*), travel by air only (*a*), and intermodal travel (*ra*).

2. 1 Passenger Utility

We assume a population of size *N* planning to travel from city 1 to city 3. The population is heterogeneous in terms of the value individuals assign to their time (θ). Some individuals will travel by any available route, while others with a higher value of time will not travel if the associated time cost is too high. In the model, we assume θ to be uniformly distributed between 0 and 1, $\theta \in [0,1]$).

The generalized cost ($C^s(\theta)$) of travel via route s comprises the time cost plus the fare cost for travel between cities *i* and *j*. It can be written as,

$$C^s(\theta) = \theta t_{13}^s + p_{13}^s \tag{1}$$

where t_{ij}^s is travel time via route s. The available routes and route sets of passengers are determined by the behavior of the airline and railway. When the airline chooses to operate link *a13*, the path set is $s \in \{rr, a\}$. Meanwhile, when the airline chooses to operate link *a23*, the path set is $s \in \{rr, ra\}$.

Passengers choose the utility maximizing routes. The utility function of passengers who travel via route *s* can be defined as

$$U^s(\theta) = u - C^s(\theta) \tag{2}$$

where u is constant utility. The generalized cost $C^s(\theta)$ is an increasing function of θ, and we then assume that when the value of time is sufficiently large to become the utility less than zero, the passenger does not travel. This assumption enables us to make the number of passengers endogenous.

2.2. Equilibrium under the competition strategy

The railway company operates transportation services on links *r12* and *r23* and sets profit maximizing fares for each link. However, airlines can choose one among the following three strategies: (1) operate services on link *r13* (competition strategy), (2) operate services on link *r23* (cooperation strategy) and (3) do not operate services on any link (exit).

In our model we assume the railway and airline control unit time fares p^r and p^a, respectively. Furthermore, the airline chooses to operate either link *a13* or link *a23*, or to operate no link, according to profit maximization.

Under the airline's competition strategy, passengers can choose either railway or airline to travel from city 1 to city 3. The profit maximization problems for the railway and airline are

$$\max_{p^r} \pi^r = p^r t_{13}^{rr} q^{rr} - f_{13}^{rr} \tag{3}$$

$$\max_{p^a} \pi^a = p^a t_{13}^{a} q^{a} - f_{13}^{a} \tag{4}$$

where q^{rr} and q^a denote the number of passengers who travel through paths *rr* and *a*, f_{13}^{rr} denotes the fixed cost to operate services on links *r12* and *r23*. Route *rr* is the pure rail link, namely *r12* and *r23*, and has travel time of t_{13}^{rr}. Route *a* comprises only a single air link, namely *a13*, and has travel time of t_{13}^a.

From equations (3) and (4), the first order condition for profit maximization of the railway and airline can be described in matrix form,

$$\boldsymbol{F_0 q} + \boldsymbol{F_1 p} = \boldsymbol{0} \tag{5a}$$

where,

$$p = \begin{bmatrix} p^r \\ p^a \end{bmatrix}, q = \begin{bmatrix} q^{rr} \\ q^a \end{bmatrix}, F_0 = \begin{bmatrix} t_{13}^{rr} & 0 \\ 0 & t_{13}^a \end{bmatrix}, F_1 = \begin{bmatrix} t_{13}^{rr} \dfrac{\partial q^{rr}}{\partial p^r} & 0 \\ 0 & t_{13}^a \dfrac{\partial q^a}{\partial p^a} \end{bmatrix} \tag{5b}$$

When the airline operates link *a13*, passengers can choose between two routes. The generalized costs of each route are

$$C^{rr}(\theta) = \theta t_{13}^{rr} + p^r t_{13}^{rr}, \tag{6}$$

$$C^a(\theta) = \theta t_{13}^a + p^a t_{13}^a \tag{7}$$

In the model, the value of time θ differs among individual passengers.

Assumption 1
Travel time by air is shorter than by rail; that is, $t_{13}^a < t_{13}^{rr}$.

From Assumption 1, passengers with high time value prefer travel by air because of the shorter travel time; that is, $U^{rr}(\theta) < U^a(\theta)$. Therefore, we can express the threshold value of time θ_1^*, which make travelers indifferent between travel by air and rail, as follows,

$$\theta_1^* = \frac{p^a t_{13}^a - p^r t_{13}^{rr}}{t_{13}^{rr} - t_{13}^a}. \tag{8}$$

Then, the demand function for railway satisfies $q^{rr} = N\theta_1^*$ and can be expressed as

$$q^{rr} = \frac{p^a t_{13}^a - p^r t_{13}^{rr}}{t_{13}^{rr} - t_{13}^a} N. \tag{9}$$

Demand for railway decreases as the fare p^r or travel time t_{13}^{rr} increase.
However, as airline service level increases (that is, lower fares or shorter travel times) demand for railway decreases.

Assumption 2
When passengers choose no travel, their utility is zero, $U^n = 0$.

The passengers with higher time value $\theta_1^* < \theta < \theta_2^*$, travel by airline.
We can also express the time value at which passengers are indifferent between travel by air and no travel.

$$\theta_2^* = \frac{u - p^a t_{13}^a}{t_{13}^a}. \tag{10}$$

The demand function for the airline satisfies $q^a = (\theta_2^* - \theta_1^*)N$. The numbers of passengers who do not travel, q^a and q^n, can be derived as,

$$q^a = \left(\frac{u-p^a t_{13}^a}{t_{13}^a} - \frac{p^a t_{13}^a - p^r t_{13}^{rr}}{t_{13}^{rr}-t_{13}^a}\right)N, \quad q^n = \left(1 - \frac{u-p^a t_{13}^a}{t_{13}^a}\right)N \tag{11}$$

Equation (11) can be derived by introducing the flow conservation law of the total number of passengers, as follows

$$q^{rr} + q^a + q^n = N. \tag{12}$$

Passengers' demand function can also be written in matrix form,

$$\boldsymbol{q} = (\boldsymbol{D_0 p} + \boldsymbol{d_1})N, \tag{13a}$$

where,

$$\boldsymbol{D}_0 = \frac{1}{t_{13}^{rr}-t_{13}^a}\begin{bmatrix} -t_{13}^{rr} & t_{13}^a \\ t_{13}^{rr} & -t_{13}^{rr} \end{bmatrix}, \boldsymbol{d}_1 = \begin{bmatrix} 0 \\ u/t_{13}^a \end{bmatrix} \tag{13b}$$

From the equation (5b), (13a) and (13bb), q^{rr} decreases as railway fare p^r increases, or airline fare p^a decreases. On the other hand, q^a decreases as railway fare p^r decreases, or airline fare p^a increases. These relationship shows the standard competition relation between railway and airline.

Then, we can derive the optimal airline and railway fares, which can be written as follows,

$$\boldsymbol{p}^* = -\left(\boldsymbol{F}_0\boldsymbol{D}_0 + \widetilde{\boldsymbol{F}_1}\right)^{-1}\boldsymbol{u} \tag{14a}$$

where,

$$\boldsymbol{F}_1 = -\frac{t_{13}^{rr}}{t_{13}^{rr} - t_{13}^a}\begin{bmatrix} t_{13}^{rr} & 0 \\ 0 & t_{13}^a \end{bmatrix} N \equiv \widetilde{\boldsymbol{F_1}} N \tag{14b}$$

$$\boldsymbol{u} = \boldsymbol{F}_0\boldsymbol{d}_1 = \begin{bmatrix} 0 \\ u \end{bmatrix} \tag{14c}$$

$\boldsymbol{F}_1$ can be divided into travel distance $\widetilde{\boldsymbol{F_1}}$ and population size *N* as in equation (14b). By using the expression (14b), the airline and railway fare is expressed as equation (14a). And the airline and railway fares are independent from population size *N*, they are determined by travel distances(t_{13}^{rr}, t_{13}^a) and the utility from travel (u).

Social Welfare Function

We define the social welfare function as follows,

$$W = \pi^r + \pi^a + N\int_0^{\theta_1^*} U^{rr}(\theta)f(\theta)d\theta + N\int_{\theta_1^*}^{\theta_2^*} U^a(\theta)f(\theta)d\theta \tag{15}$$

Social welfare function can also be rewritten as,

$$W = \frac{N}{2}\{2u\theta_2^* - (t_{13}^{rr} - t_{13}^a)\theta_1^{*2} - t_{13}^a\theta_2^{*2}\} - f_{13}^{rr} - f_{13}^a \tag{16}$$

If the constant utility *u* is sufficiently large for all the passengers to prefer travel in case of zero airline fare, that is to say $u - t_{13}^{a} > 0$, W is a monotonic increasing function of θ_2^* in $[0,1]$. θ_2^* represents the fraction of the total number of passengers, $\theta_2^* = (q^a + q^{rr})/N$. Therefore, social welfare W increases according to the number of passengers who travel. The optimal fares are already determined by equation (14), then we can calculate the value of social welfare by using equation (8) and (10).

2.3. Equilibrium under the Cooperation strategy

In case of the cooperation strategy, passengers cannot choose a mode at city 1, and all passengers travel by link *r12*. From city 2, passengers can choose either the air or rail travel mode according to their utility. We denote the number of passengers, who travel via rail only, route *rr,* as q_c^{rr} under the cooperation strategy. We also denote the number of passengers who travel via an intermodal route, route *ra,* as q_c^{ra} under the cooperation strategy.

The airline and railway compete in providing travel services between cities 2 and 3. The airline can only provide transportation service for passengers who change their travel mode from railway. We denote the profits and fares as $\pi_c^r, \pi_c^a, p_c^r, p_c^a$ to distinguish the results from those in the previous subsection. The profit maximization problem of railway and airlines is

$$\max_{p_c^r} \pi_c^r = p_c^r t_{13}^{rr} q_c^{rr} + p_c^r t_{12}^{r} q_c^{ra} - f_{13}^{rr}, \tag{17}$$

$$\max_{p_c^a} \pi_c^a = p_c^a t_{23}^{a} q_c^{ra} - f_{23}^{a}. \tag{18}$$

As shown in equation (17), the railway can earn revenue not only from railway passengers $p_c^r t_{13}^{rr} q_c^{rr}$ but also from intermodal passengers $p_c^r t_{12}^{ra} q_c^{ra}$. From these profit functions, the first order condition for profit maximization of the railway and airline can be described in matrix form as,

$$\boldsymbol{F_0^c q_c} + \boldsymbol{F_1^c p_c} = \boldsymbol{0}, \tag{19a}$$

where,

$$p^c = \begin{bmatrix} p_c^r \\ p_c^a \end{bmatrix}, q^c = \begin{bmatrix} q_c^{rr} \\ q_c^{ra} \end{bmatrix}, F_0^C = \begin{bmatrix} t_{13}^{rr} & t_{12}^{r} \\ 0 & t_{23}^{a} \end{bmatrix}, F_1^C = \begin{bmatrix} t_{13}^{rr} \frac{\partial q_c^{rr}}{\partial p^r} + t_{13}^{rr} \frac{\partial q_c^{ra}}{\partial p^r} & 0 \\ 0 & t_{23}^{a} \frac{\partial q_c^{ra}}{\partial p^a} \end{bmatrix} \tag{19b}$$

The generalized cost to passengers for each route can be defined as

$$C_c^{rr}(\theta) = \theta t_{13}^{rr} + p_c^r t_{13}^{rr}, \tag{20}$$

$$C_c^{ra}(\theta) = \theta t_{13}^{ra} + p_c^r t_{12}^{r} + p_c^a t_{23}^{a} + \gamma - \beta q_c^{ra}. \tag{21}$$

Equation (20) has the same composition as equation (6). In equation (21), γ denotes the transit cost between the rail and air travel modes in city 2. The last term in equation (21) shows the economies of transportation density. If the number of passengers q_c^{ra} increases, where these passengers travel through the intermodal route *ra*, the service levels of the intermodal routes improve; for example frequency is increased or discount tickets are made available.

Additionally, the threshold value of time, which is θ_1^{c*} between route *rr* and ra, and

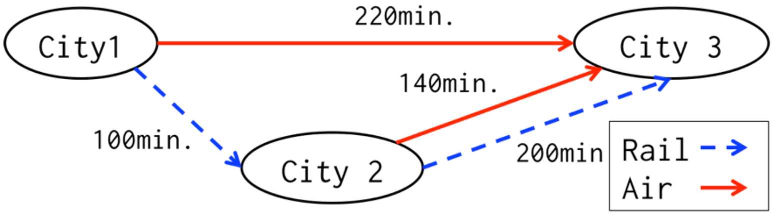

Figure 2. Basic settings of the numerical example

θ_2^{c*} between route *ra* and no travel, can be derived using the procedure from the previous section,

$$\theta_1^{c*} = \frac{p_c^r t_{12}^r + p_c^a t_{23}^a - p_c^r t_{13}^{rr} + \gamma - \beta q_c^{ra}}{t_{13}^{rr} - t_{13}^{ra}}, \theta_2^{c*} = \frac{u - p_c^r t_{12}^r - p_c^a t_{23}^a - \gamma + \beta q_c^{ra}}{t_{13}^{ra}} \tag{22}$$

Passengers' demand function can also be written in matrix form as follows,

$$\boldsymbol{q_c} = (\boldsymbol{D_0^c})^{-1}(\boldsymbol{D_1^c p^c} \ + \boldsymbol{d_2^c})N \tag{23a}$$

where,

$$D_0^c = \begin{bmatrix} t_{13}^{rr} - t_{13}^{ra} & \beta N \\ t_{13}^{ra} & t_{13}^{ra} - \beta N \end{bmatrix}, D_1^c = \begin{bmatrix} t_{12}^r - t_{13}^{rr} & t_{23}^a \\ -t_{12}^r & -t_{23}^a \end{bmatrix}, d_2^c = \begin{bmatrix} \gamma \\ u - \gamma \end{bmatrix} \tag{23b}$$

$\boldsymbol{F_1^c}$ can also be rewritten as,

$$\boldsymbol{F_1^c} = \frac{t_{13}^{rr} N}{\phi} \begin{bmatrix} t_{12}^r t_{23}^a - t_{23}^r t_{13}^{ra} + \beta N t_{13}^{rr} & 0 \\ 0 & -(t_{23}^a)^2 \end{bmatrix} \equiv \boldsymbol{\widetilde{F}_1^c N} \tag{24a}$$

where

$$\phi = t_{13}^{ra}(t_{13}^{rr} - t_{13}^{ra}) - \beta N t_{13}^{rr} \tag{24b}$$

Then, we can derive the optimal fares for the airline and railway as follows,

$$\boldsymbol{p^{c*}} = -\left(\boldsymbol{D_0^c}(\boldsymbol{F_0^c})^{-1}\boldsymbol{\widetilde{F}_1^c} + \boldsymbol{D_1^c}\right)^{-1}\boldsymbol{d_2^c} \tag{25}$$

Social Welfare Function

The Social Welfare function can be defined as,

$$W_c = \pi_c^r + \pi_c^a + N\int_0^{\theta_1^{c*}} U^{rr}(\theta)f(\theta)d\theta + N\int_{\theta_1^{c*}}^{\theta_2^{c*}} U^{ra}(\theta)f(\theta)d\theta \tag{26}$$

where, θ_1^{c*}, θ_2^{c*} are threshold values. θ_1^{c*} distinguishes routes *rr* and *ra*, and θ_2^{c*} distinguishes route *ra* and no travel.

2.4. Equilibrium when airline Exits

In the event of exit by the airline, the intercity transportation markets become the monopoly of the railway. When the railway operates as a monopolist, the profit maximization problem can be written as,

$$\max_{p_e^r} \pi_e^r = p_e^r t_{13}^{rr} q_e^{rr} - f_{13}^{rr}, \tag{27}$$

$$\pi_e^a = 0 \tag{28}$$

Here passengers can choose either travel by train or no travel. The threshold value of the value of time is

$$\theta_e^* = \frac{u - p^r t_{13}^{rr}}{t_{13}^{rr}} \tag{29}$$

Then the profit, optimal fare, threshold time value and number of passengers are

$$\pi_e^{r*} = \frac{u^2 N}{4t_{13}^{rr}} - f_{13}^{rr}, \; p_e^{r*} = \frac{u}{2t_{13}^{rr}}, \; \theta_e^* = \frac{u}{2t_{13}^{rr}}, \; q_e^{rr*} = \frac{uN}{2t_{13}^{rr}} \tag{30}$$

The profit of railway is increasing according to the increase in constant utility u and decreasing according to the increase in travel distance. If the travel distance t_{13}^{rr} become large, the railway fare become small to maintain the number of passenger as q_e^{rr*}.

Social Welfare Function

The Social Welfare Function can be explicitly written as,

$$W_e = \pi_e^r + N \int_0^{\theta_e^*} U_e^{rr}(\theta) f(\theta) d\theta = \frac{3u^2}{8t_{13}^{rr}} N - f_{13}^{rr} \tag{31}$$

3. AIRLINE'S STRATEGY AND SOCIAL WELFARE

3.1 Numerical Setting

We show the profits of each strategy and analyze airline and railway strategy choice. Figure 2 shows the parameter settings, which are based on the following assumption that airline travel time is shorter than railway travel time for the same origin-destination pair ($t_{13}^a < t_{13}^{rr}$, $t_{23}^a < t_{23}^r$). The fixed cost increases with travel time in each mode ($f_{23}^a < f_{13}^a$). The parameters for railway-airline transfer are $\beta = 0$, $\gamma = 10$. And fixed operating costs are $f_{13}^{rr} = 100, f_{13}^a = 400$, $f_{23}^a = 200$. The constant utility is 250 ($u = 250$). We change the population size N from 0 to 50 to analyze the changes in airline and railway profits and social welfare.

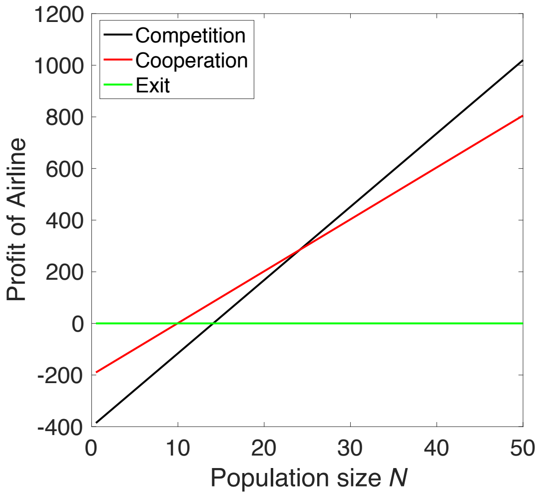

Figure 3. Airline profits for each strategy

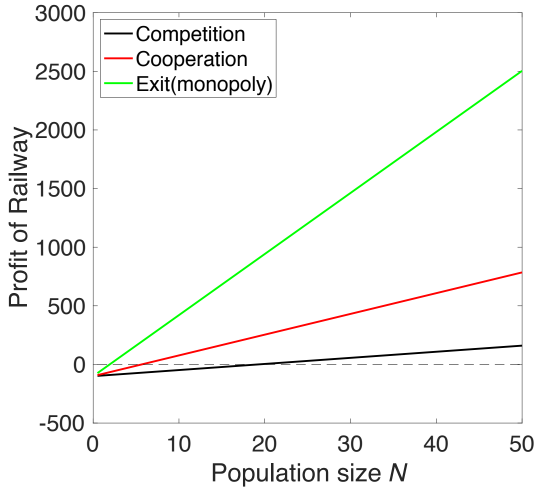

Figure 4. Railway profit under each airline strategy

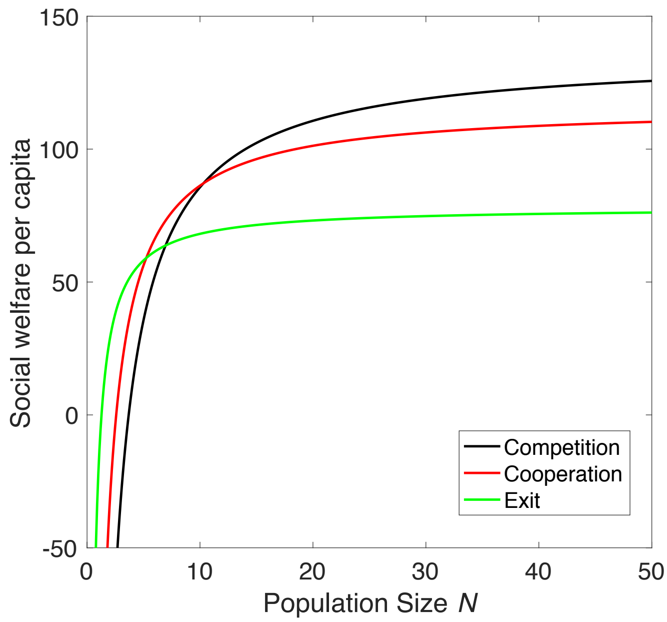

Figure 5. Social welfare per capita under each airline strategy.

3.2 Airline's strategy and social welfare

Figure 3 shows that airline profit-maximizing strategy changes with population. We assume the airline selects the profit maximizing strategy. If the population size is large, the airline chooses competition strategy to operate in link *a13* and compete with the railway from city 1. However, if the population size is small, the airline exits because the profits of the two alternative strategies are negative. For a population that lies between these two extremes, cooperation strategy maximizes airline profit in $N \in [10, 25]$. This occurs because when the population size is small, airlines shorten their operating distance to save fixed operating costs.

Figure 4 shows that railway profit changes with population size. Profit is maximized when the airline exits, because the intercity transportation market becomes a railway monopoly. The next most profitable strategy for the railway is cooperation, since railway profit is always higher under partial competition than full competition. Because the railway can get revenue

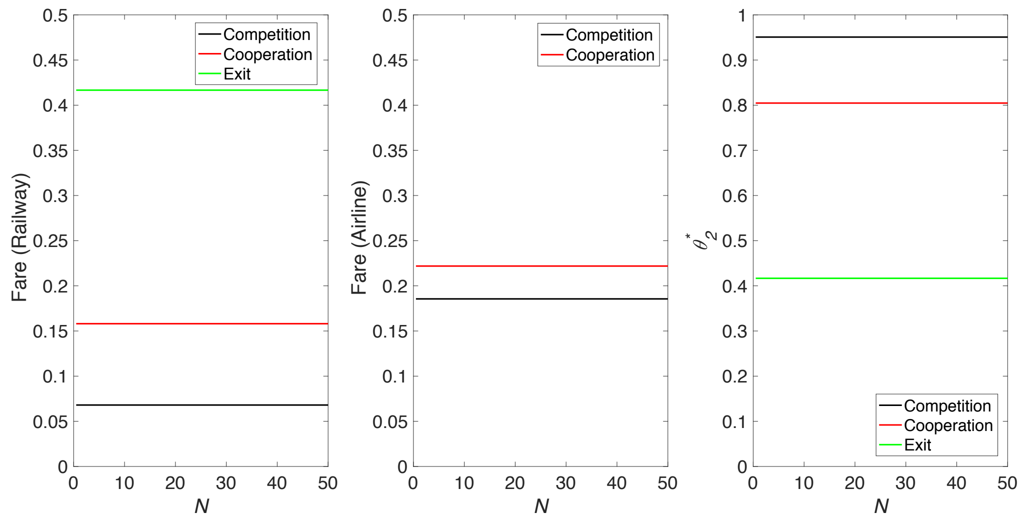

Figure 6. Railway's fare (left), Airline's fare (center), and the fraction of total passenger ($\theta_2^*, \theta_2^{c*}$, and θ_e^*, right)

from passengers on both of routes *rr* and *ra*, it has an incentive to provide a connection from the rail to air modes at city 2 and to provide intermodal routes.

Next, Figure 5 illustrates the changes in the social welfare per capita associated with population change. The ordering of the profitability of the various strategies is similar to that in Figure 3, but the timing of switches between strategies differs. Comparison of Figures 3 and 5 reveals the need for policy intervention. For example, the range of competition strategy in Figure 5 is wider than in Figure 3. This means that competition strategy is socially efficient, even if the airline chooses cooperation strategy. This is because the airline and railway fares are smaller in competition strategy than in cooperation strategy as shown in Figure 6. And it results that the fraction of total passenger θ_2^* become larger in competition strategy than in cooperation strategy.

Competition strategy is the welfare maximizing strategy because fares are lower under competition strategy than any other strategy (Fig. 6). Competition strategy also makes travel easier and so increases the number of passengers. Conversely, if the airline exits, welfare decreases because of high fares and a small number of passengers. Moreover, if the population decreases, the airline's exit strategy improves welfare by saving fixed operating costs.

Finally, cooperation strategy is effective for avoiding airline exit, even if the airline exits to maximize profit. If the airline exit from link a13, we can improve the level of service between city 1 and city 3 by appropriately choosing transit city 2.

3.3 Policy implication

First, we discuss the general characteristics of the social welfare functions. When the economies traffic density does not exist ($\beta = 0$), social welfare function under cooperation strategy can be written as follows,

$$W_c = \frac{N}{2}\{2u\theta_2^{c*} - (t_{13}^{rr} - t_{13}^{ra})\theta_1^{c*2} - t_{13}^{ra}\theta_2^{c*2} - 2\gamma(\theta_2^{c*} - \theta_1^{c*})\} - f_{13}^{rr} - f_{23}^{a} \qquad (32)$$

By comparing social welfare function under competition strategy (equation (16)) and under

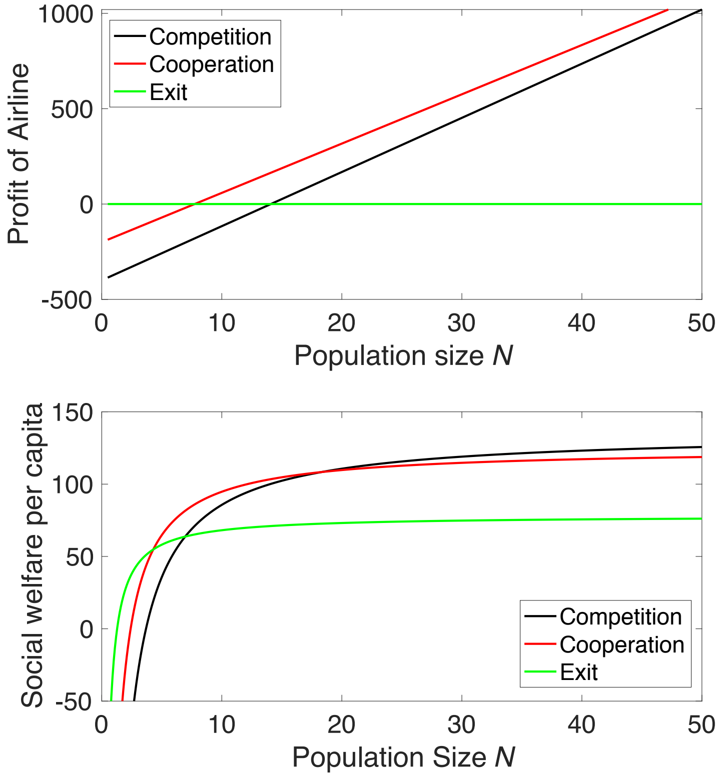

Figure 7. Airline profit (top) and social welfare (bottom), when transit cost is low ($\gamma = 0$)

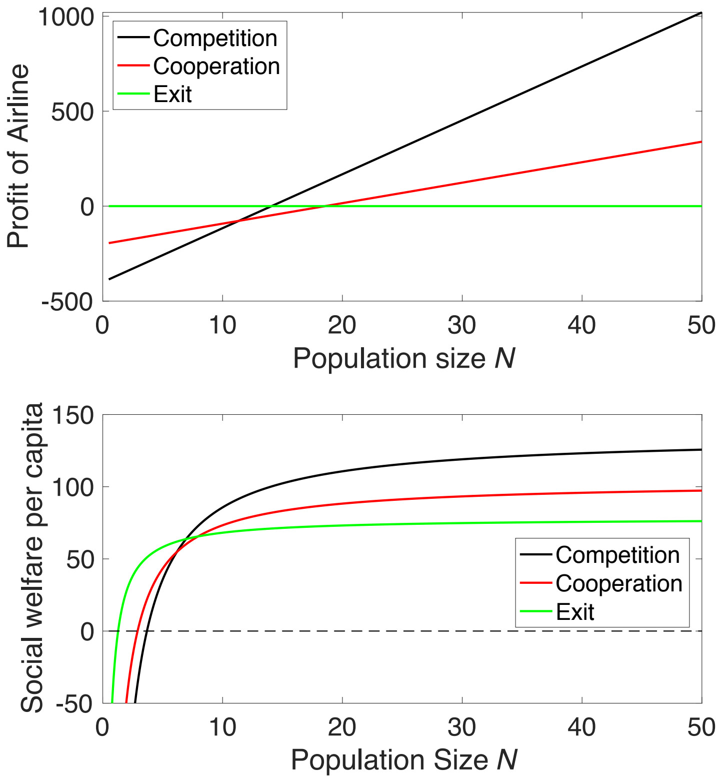

Figure 8. Airline profit (top) and social welfare (bottom), when transit cost is high ($\gamma = 30$)

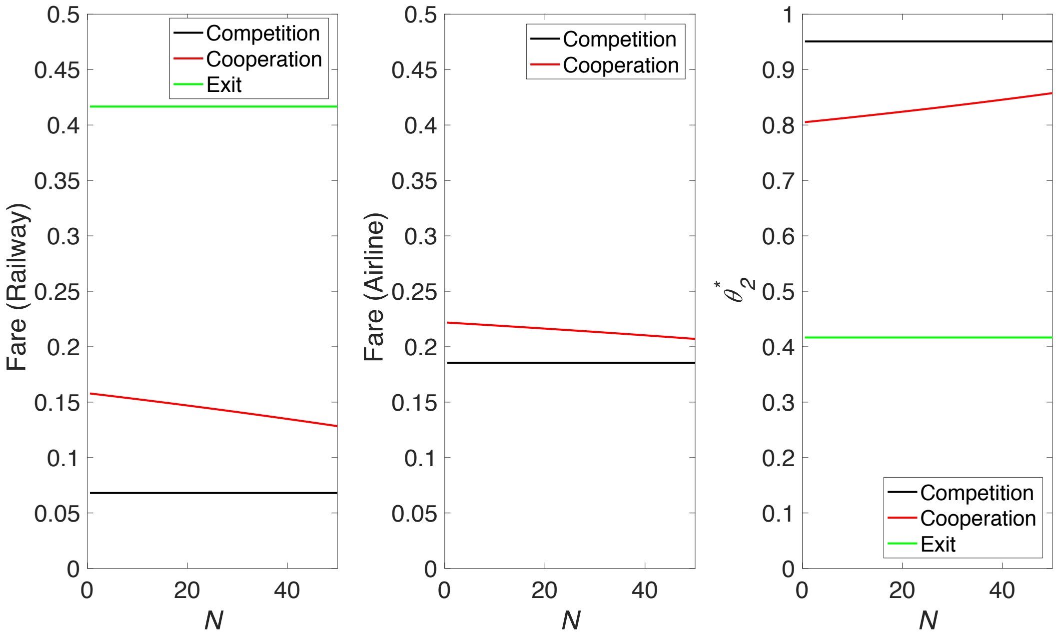

Figure 9. Railway's fare (left), Airline's fare (center), and the fraction of total passenger ($\theta_2^*, \theta_2^{c*}$, and θ_e^*, right) with economies of traffic density, ($\beta = 0.2$)

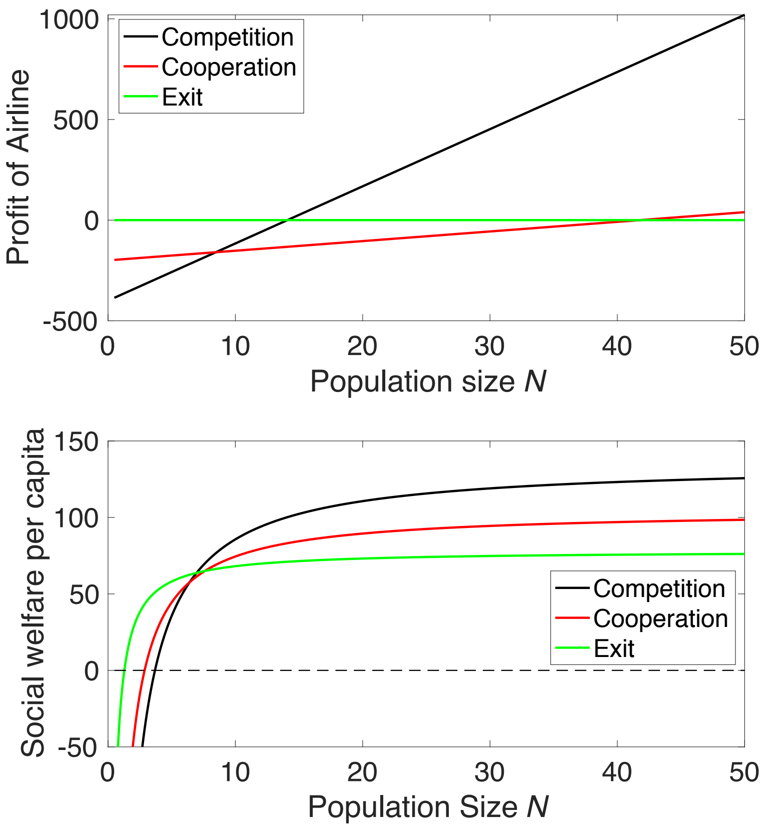

Figure 10. Airline profit (top) and social welfare (bottom) when the advantage of airline become small ($t_{23}^a = 180$)

cooperation strategy (equation (32)), they are linear function of population size N and its coefficients have similar structure. However, equation (32) contains $-2\gamma(\theta_2^{c*} - \theta_1^{c*})$. This term comes from the transit cost and decreases social welfare under cooperation strategy by increasing generalized cost. And the increase in generalized cost decrease the number of passenger smaller, $\theta_2^{c*} \leq \theta_2^{*}$. The coefficient of population size N in equation (32) tend to become smaller than in equation (16). Since these welfare functions are increasing function of population size N, we can say that the effect of welfare improvement by increasing population size is smaller under cooperation strategy than under competition strategy. On the other hand, fixed cost of equation (32) is smaller than that of equation (16). Therefore, when the population size N is large, social welfare under competition strategy tend to be larger, because of the effect of population size. When the population size N become small, social welfare under cooperation strategy tend to become larger, because the effect of fixed costs saving dominates the effect of population size. We can say that when the population decline, it may be better to examine the promotion of cooperation strategy and to choose and prepare transit city 2 for travel between city 1 and 3. Next, we discuss the conditions of transit city which enhances the social welfare improvement by cooperation strategy.

The effect of the transit cost

To study the effect of transit cost γ, for transit between the railway and airline at city 2, we set minimal transit cost ($\gamma = 0$) and made the generalized cost of the intermodal route small. As illustrated in Figure 7 (top), the airline's profit is always larger under cooperation strategy than competition strategy. Figure 7 (bottom) shows the social welfare per capita. Figure 7 suggests that if the transit cost is small, the welfare-maximizing route is achieved by the airline's choice of profit-maximizing strategy in the middle range of population size.

Next, we set larger transit cost ($\gamma = 30$) and made the generalized cost of the intermodal route large. As illustrated in Figure 8 (top), the airline's profit is always smaller under cooperation strategy than competition strategy. Figure 8 (bottom) also shows the value of the social welfare per capita. Figure 8 suggests that if the transit cost is large, the welfare-maximizing route is also achieved by the airline's choice of profit-maximizing strategy. However, airline should not exit in small population size, even if the profit become negative, to maximize social welfare.

The effect of economies of traffic density β

Next, we discuss the effect of economies of traffic density β. If there exists economies of traffic density ($\beta = 0.2$), the main difference from the previous case is the changes in airline and railway fares and the fraction of passengers. Figure 9 represents the railway fare (left), airline fare(center) and the fraction of passenger (right). The railway and airline fares under cooperation strategy are decreasing according to population size. And the fraction of passengers is increasing simultaneously.

The effect of travel time from city 2 to 3 t_{23}^{a}

we discuss the effect of travel time t_{23}^{a}. We change t_{23}^{a} from 140 minutes to 180 minutes. This change shows the reduction of time advantage of airline, since travel time between city 2 to 3 by railway is 200 minutes. As illustrated in Figure 10 (top), the airline's profit is always smaller under cooperation strategy than competition strategy. Figure 10 (bottom) also shows the value of the social welfare per capita. Figure 10 suggests that if the time advantage is small, cooperation strategy is not the profit and welfare maximizing strategy. The cooperation strategy will not be selected by airline. In other words, the welfare-maximizing competition strategy is achieved by the airline's choice of profit-maximizing strategy. However, airline should not exit in small population size, even if the profit become negative, to maximize social welfare.

Summary of policy implication
When the population size become small, airlines' cooperation strategy is one of a way to maintain the service level of travel between spoke cities (city 1 and 3). To promote the introduction of cooperation strategy, we can set or prepare appropriate transit city (city 2) to save the fixed operating cost. The condition for appropriate transit city is transit cost between railway and airline should be sufficiently small, travel time from city 2 to 3 by airline is sufficiently shorter than by railway. In our numerical study, we can observe that welfare maximizing strategy is often selected as profit maximizing strategy by airline. However, the exit of airline in profit maximizing strategy tend to become earlier than that of welfare maximizing strategy. We should carefully observe the operating fixed costs and service level between city 1 and city 3.

4. CONCLUSION

We analyze the route structure of an intercity transportation network based on population size. We first develop a simple theoretical model of heterogeneous passengers' route choice behavior. Then we consider a differentiated duopoly model whereby an airline and a railway compete on fare setting in an intercity transportation market. The airline seeks to maximize profit by selecting one among three strategies: a) compete with the railway, b) cooperate with the railway by serving intermodal routes, and c) exit the market. Our analysis shows that the airline chooses the social welfare maximizing route based on its profit maximization in cases involving large population size, low transit costs or where passengers find direct flights inconvenient. We also show that route length and transit cost are important determinants of the effect of cooperation on social welfare. When the transit cost between rail and air modes is high, the competition strategy may yield better results in terms of social welfare. The cooperation policy increases fares and decreases welfare.

Notably, cooperation strategies are not always socially optimal. However, in the present case, increased profits incentivize cooperation by railways. Moreover, we show that the introduction of a cooperative strategy effectively maintains airline services in local areas. Further study is needed that explicitly considers trip frequency.

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