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Transportation policy for high-speed rail competing with airlines

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Abstract

This study investigates the desirable transportation policy for a government seeking to regulate the competition between high-speed rail (HSR) and air transportation. To address this issue, we construct a game-theoretic model. A basic assumption underlying the model is that the airline maximizes its own profit whereas the HSR operator maximizes a weighted sum of profit and social welfare due to the government regulation. We assume a two-stage game in which the government sets the weight to maximize social welfare in the first stage and the HSR operator and the airline maximize their respective objective functions in the second stage. The central result from our model is that partial public regulation arises as a subgame perfect equilibrium unless the benefits to consumers from using the HSR are sufficiently large or sufficiently small compared to the benefits to consumers from using air transportation. The result provides a theoretical foundation for the public policies of joint investments by both governments and HSR operators in HSR networks in European and Asian countries. In addition, our results suggest that the optimal regulation by the government depends on the benefits for consumers using each mode of transport and the difference between the levels of benefits.

Key words: Air transportation, High-speed rail, Regulation, Bertrand competition

1. Introduction

Since the first modern high-speed rail (HSR) started to run between Tokyo and Osaka; in Japan in 1964, HSR networks have been constructed mainly in European and Asian countries. For a variety of reasons, such as substantial capital requirements or political circumstances, most HSR operators are owned by governments. Even in countries where HSR operators are owned by private companies, such as some European and Asian countries, the governments have often co-invested in the networks with these companies. In Japan, the central government, local governments, and private companies have co-invested in high-speed rail networks (i.e., the Shinkansen networks). In China, the government has planned the construction of an HSR network that is over 12,000 km is planed by the government in China, and the investment in this construction is about USD 300 billion.

Numerous previous studies have examined the economic consequences of HSR's entry into transportation markets. In particular, the effects of competition between HSR and air transportation on economic outcomes have commanded significant attention as an important issue in the transport literature from both theoretical and empirical viewpoints. Most previous theoretical studies that construct analytical models assume that both HSR operators and airlines maximize their own profits because they are private companies. However, some analytical studies (D'Alfonso et al., 2015; Yang and Zhang, 2012) focus on the fact that HSR operators are regulated by the government because of government ownership and co-investment. Hence, these studies assume that HSR operators maximize a weighted sum of their own profit and social welfare due to this regulation by the government. This assumption has been conventionally used in previous studies that discuss the welfare consequences of the partial privatization of a public firm in a mixed oligopoly market (Matsumura, 1998).

An important finding in Yang and Zhang (2012) is that both HSR fares and airfares decrease as the weight on social welfare in the HSR operator's objective function increases. In addition, the authors show that HSR fares and airfares depend on the airport access time and the HSR's speed by analyzing a model that considers business and leisure passengers, price discrimination, and the flight schedule frequency decision. However, Yang and Zhang (2012) assume that the degree of the strictness of the government regulation, which is represented by the weight on social welfare in the HSR operator's objective function, is given exogenously.

This study investigates the optimal level of regulation determined by the government endogenously in an economic model. To address this issue, we construct a game-theoretic model. We assume a two-stage game, in which the government sets the weight to maximize social welfare in the first stage, and the HSR operator and the airline subsequently maximize their respective objective functions in the second stage. An important assumption underlying this model is that the airline maximizes its own profit whereas the HSR operator maximizes a weighted sum of profit and social welfare due to the government regulation. This assumption is consistent with both Yang and Zhang (2012) and D'Alfonso et al. (2015). Although this analysis is closely related to the analysis of Yang and Zhang (2012), the degree of the strictness of the regulation by the government is endogenously determined within the model constructed in this study. In this respect, this study clearly differs from Yang and Zhang (2012) and thus makes a significant contribution to the existing literature on transportation research.

The central result from our model is that a partial regulation by the government arises in a subgame perfect equilibrium unless the benefits for consumers using the HSR are sufficiently large or sufficiently small compared to the benefits for consumers using air transportation. The result provides a theoretical foundation for the public transportation policies of HSRs owned by governments and of joint investments by both governments and private companies in the HSR networks in European and Asian countries. The intuition behind this result is laid out as follows. The government strengthening the regulation on the HSR causes both airfares and HSR fares to decline. Because the decline in HSR fares is larger than the decline in airfares, the number of consumers using the HSR increases. Since each consumer has his own preferences over transport modes, it is undesirable for social welfare that all consumers who prefer air transportation use the HSR. Therefore, the government sets a partial regulation so that consumers continue to use air transportation. In addition, our results suggest that the optimal level of the government regulation depends on benefits for consumers using each transport mode and the difference between the levels of benefits. Specifically, when the difference between the benefits provided by each transport mode is small, the regulation is strengthened by the government as the consumers' benefits from the HSR increase, and the regulation is relaxed as the consumers' benefits from air transportation increase. On the other hand, when the difference between the benefits of the two transport modes is large, the regulation is strengthened as the benefits of air transportation increase, and the regulation is relaxed as the benefits of HSR increase. The intuition behind this results is laid out as follows. An increase in the benefits to consumers from using a specific transport mode makes the use of the transport mode more desirable for social welfare. Intuitively, it is desirable for the government to coordinate the regulation on the HSR in order to help the transport mode whose benefits are increased. When the difference between the benefits from each transport mode is small, such regulation coordination by the government occurs. On the other hand, when the difference between the benefits from each transport mode is large, it is socially desirable to maintain the transport mode whose benefits are not increased, rather than to help the other transport mode whose benefits are increased. This result follows because it is undesirable for the transport mode whose benefits are not increased to exit the market. Therefore, the government needs to carefully observe the benefits from each transport mode to consumers and the difference between the benefits of each transport mode to set an appropriate regulation. Furthermore, we extend the model to incorporate schedule frequency as an additional decision variable. Even in the extended model, we show that a partial regulation on the HSR by the government arises as a subgame perfect equilibrium, and that the optimal level of the regulation by the government depends on the benefits to consumers using each transport mode.

The remainder of the paper is organized as follows. Section 2 provides a review of the literature on the competition between HSR and air transportation. In Section 3, we delineate the assumptions underlying our model and solve the model to determine the transportation policy adopted by the government in the subgame perfect equilibrium. Section 4 extends the model so that schedule frequency is incorporated as an additional factor. Finally, Section 5 provides concluding remarks.

2. Literature Review

A number of previous empirical studies have investigated the economic outcomes of the competition between HSR and air transportation (Behrens and Pels, 2012; Castillo-Monzano et al., 2015; Clewlow et al., 2014; Dobruszkes, 2011; Fu et al., 2011; González-Savignat, 2004; Park and Ha, 2006; Román et al., 2007, 2010). González-Savinat (2004) analyzes model choices between the HSR and the airline using stated-preference methods. The study shows that HSR has a significant impact on the airline market and that this impact mainly depends on total travel time. Specifically, she shows that HSR's share decreases as HSR's travel time increases. By the using stated-preference method, Park and Ha (2006) point out that the opening of South Korea's HSR line significantly influenced the domestic airline market. Behrens and Pels (2012) estimate multinomial and mixed logit models with the use of revealed preference methods to examine the competition between HSR and air transportation in the London-Paris passenger market. Their result explains that travel time and frequency are the main determinants of travel behavior. Clewlow et al. (2014) analyze the impacts of HSR and low-cost carriers on European air transportation with the use of origin-destination (O-D) passenger traffic data. They show that reductions in HSRs' travel times have resulted in reductions in short-haul air travel, and the expansion of the low-cost carrier supply has led to a significant increase in total air traffic. Castillo-Monzano et al. (2015) show that the substitution rate between HSR and air transportation has changed dynamically using dynamic linear regression models. Fu et al. (2011) show that services between HSR and air transportation are significantly differentiated and that travel time and frequency affect the shares of each transport mode by estimating a travel demand model in Japan's intercity market with aggregate O-D data. Román et al. (2007, 2010) estimate disaggregated mode choice models using mixed revealed and stated preference data collected from consumers. Their unique contribution is that they measure consumers' willingness to pay to use transport modes and show that consumers' willingness to pay differs based on the level of service quality. Dobruszkes (2011) investigates the competition between HSR and air transportation in Western Europe from a supply-oriented perspective, showing empirically that not only the travel time but also the frequencies of each transport mode affect the competition.

In addition to these empirical studies, some analytical studies (Adler et al, 2010; D'Alfonso et al., 2015; Takebayashi, 2015; Yang and Zhang, 2012) use a game theoretic approach to investigate the competition between HSR and air transportation. Adler et al. (2010) assume that operators, including HSR, legacy airlines, and low-cost carriers, maximize their own respective profits by choosing prices, frequencies, and train or plane sizes as control variables. They conclude that the European Union should encourage the development of an HSR network across Europe. Takebayashi (2015) examines the relationship between the role of inter-intra transit airport and the connectivity between HSR and air transportation. His result suggests that although international consumers increase as the connectivity between HSR and air transport increases, this effect depends on the demand of the area where the airport is located.

Although Adler et al. (2010) and Takebayashi (2015) assume that the HSR operator and the airline maximize their respective profits, Yang and

Zhang (2012) and D'Alfonso et al. (2015) assume that the HSR operator takes a weighted sum of profit and social welfare as its objective function due to regulations imposed on the HSR by the government. Yang and Zhang (2012) use Hotelling model framework to capture the product-differentiation aspect of the two transport modes. Based on this framework, they show that both HSR fares and airfares decrease as the weight on social welfare in the HSR's objective function increases. In addition, they show that although airfares decrease as the access time to the airport increases, HSR fares increase as this access time increases. Finally, they provide the result that whether HSR fares increase as rail speed increases depends not only on the HSR's marginal cost but also on the weight placed on welfare. D'Alfonso et al. (2015) investigate the impact of the competition between HSR and air transportation on the environment as well as that on social welfare. Their result suggests that competition between HSR and air transportation may have a net negative effect on the environment and social welfare compared to a monopoly by the airline because demand is higher under competition than under a monopoly.

3. Model

We consider a model that involves competition between high-speed rail and air transportation over a single origin-destination link. The Hotelling model is adapted to capture the product-differentiation of the two transport modes. Following Yang and Zhang (2012), we assume an infinite linear city where one unit of a consumer is distributed uniformly with a density of one unit per unit of length. This model specification can capture not only the competition between transport modes but also outside options for consumers besides the use of the transport modes (i.e., the choice of travel by transport modes other than HSR and air and that of not traveling at all). Specifically, we assume that air transportation is located at 0 on the line and that HSR is located at the position of 1. Consumers located at x that satisfies the following equation are indifferent between using HSR and air transportation:

$$b - p_a - v \cdot t_a - \tau \cdot x = b - p_r - v \cdot t_r - \tau \cdot (1 - x) \geq 0,$$

where b is the gross benefit of travel; p_i is the price of transport mode i; v is the value of time; t_i is the travel time of transport mode i, which consists of the access time to the airport or the station, the travel time, and the expected

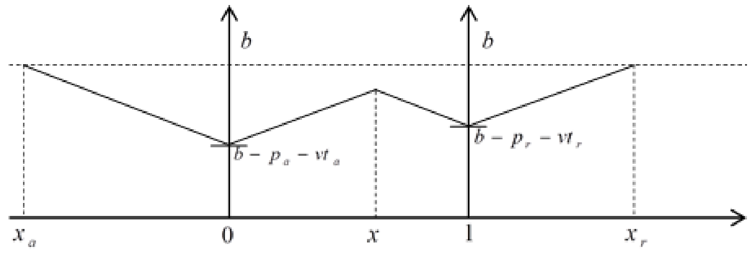

Figure 1: Distribution of consumers and the air transportation and HSR covering areas

schedule delay; and the parameter τ represents the disutility caused by factors other than the value of time (e.g., comfort and safety). The subscript i represents transport mode i, with $i = r$ (HSR) or $i = a$ (air transportation). Given that air transportation also captures consumers at immediate left side of the city, we define x_a as the location of the last consumers located on the left side of the city who uses air transportation. Similarly, we define x_r as the location of the last consumer on the right side of the city who takes HSR. Note that all consumers whose locations are less than x_a or greater than x_r will choose either not to travel or to use an alternative transport mode such as consumer cars. It follows that

$$b - p_a - v \cdot t_a - \tau \cdot |x_a| = 0,$$
$$b - p_r - v \cdot t_r - \tau \cdot (x_r - 1) = 0.$$

The market area that air transportation and HSR cover is shown in Fig. 1, and the transport demands are stated as $q_a = x + |x_a|$ and $q_r = x_r - x$.

The surpluses for consumers who use air transportation and HSR are respectively given by

$$CS_a = \int_0^x (b - p_a - vt_a - \tau y)dy + \int_0^{|x_a|} (b - p_a - vt_a - \tau y)dy,$$
$$CS_r = \int_x^1 (b - p_r - vt_r - \tau(1 - y))dy + \int_1^{x_r} (b - p_r - vt_r - \tau(y - 1))dy.$$

Following Flores-Fillol (2009), we assume that the operating cost of a flight (HSR ride) is given by $K_i f_i + c_i \xi_i$ where K_i is the marginal cost per departure, c_i is the marginal cost per seat, and ξ_i is the number of seats on that flight (HSR ride). By assuming a 100% load factor, we have $q_i = f_i \xi_i$, where f_i is the number of flights (HSR rides). Consequently, the profit is

$$\pi_i = p_i q_i - f_i(K_i f_i + c_i \xi_i) = (p_i - c_i)q_i - K_i f_i^2.$$

The social welfare in the market from HSR and air transportation is defined as $W_i = CS_i + \pi_i$. Whereas the airline maximizes its own profit, the HSR operator maximizes the following weighted sum of welfare and profit:

$$\max_{p_r} \quad \theta W_r + (1-\theta)\pi_r = \pi_r + \theta CS_r,$$

where $0 \leq \theta \leq 1$ is interpreted as the degree of the government's regulation. Specifically, $\theta = 0$ means the HSR is a private firm, and $\theta = 1$ means the HSR is a public firm. Table 1 lists the variables used in our model.

Following the literature on "linear city" models (e.g., Mas-Colell et al. 1995), we assume that the gross benefit is sufficiently high so that the following inequality holds[1].

$$b \geq \max\{c_a + vt_a, c_r + vt_r\} + \frac{3}{2}\tau \tag{1}$$

This inequality guarantees that the HSR and the air transportation compete to capture consumers.

We construct a two-stage game, in which the government sets the weight θ to maximize social welfare in the first stage and the HSR operator and the airline maximize their respective objective functions. Using backward induction, we obtain the equilibrium solutions in the second stage as follows.

$$p_r^* = \frac{34R - 6A + 14\tau + 2c_r - \theta\left(38b + 7\tau + 3c_a + v\left(3t_a - 41t_r\right)\right)}{70 - 41\theta} \tag{2}$$

$$p_a^* = \frac{34A - 6R + 14\tau + 2c_a - \theta\left(20b + 8\tau + 21c_a - 20vt_a\right)}{70 - 41\theta} \tag{3}$$

$$x^* = \frac{15A - 15R + 35\tau - \theta\left(9A + 20\tau\right)}{\left(70 - 41\theta\right)\tau} \tag{4}$$

[1] In this study, we focus on operating costs and consumer's time costs for the simplicity of discussion. A number of previous studies focus on social costs, including emission/pollution costs. See De Rus and Nombela (2007) for the HSR costs, and Fu et al. (2014) for the air transportation costs.

Table 1: Variables list

Notations	
b	Gross benefit of travel
p_i	Price
v	Value of time
t_i	Total travel time (e.g., access time, travel time, and expected schedule delay)
τ	Disutilities other than the value of time (e.g., comfort and safety)
c_i	Marginal cost per seat
K_i	Marginal cost per departure
ξ_i	Number of seats
f_i	Number of flights (HSR rides)
α_i	Marginal benefit per flight (HSR ride)
θ	Level of government's regulation
A	Benefits for consumers using air transportation ($= b - c_a - vt_a$)
R	Benefits for consumers using HSR ($= b - c_r - vt_r$)
i	Subscript that indexes the transport mode with $i = r$ (HSR) or a (air transportation)
π	Profit
CS	Consumer surplus
W	Social welfare

where $A = b - c_a - vt_a$ and $R = b - c_r - vt_r$. Because of Inequality (1), we need to assume the following two inequalities.

$$0 \leq x^* \leq 1 \tag{5}$$

$$b - p_a^* - vt_a - \tau x^* \geq 0 \tag{6}$$

Inequality (5) requires the following inequalities.

$$\theta \leq \frac{5(3A - 3R + 7\tau)}{9A + 20\tau} \qquad \left(\frac{3}{2}\tau \leq A < \frac{7}{3}\tau\right) \tag{7}$$

$$\frac{5(3A - 3R - 7\tau)}{3(3A - 7\tau)} \leq \theta \leq \frac{5(3A - 3R + 7\tau)}{9A + 20\tau} \qquad \left(A \geq \frac{7}{3}\tau\right) \tag{8}$$

Inequality (6) requires the following inequalities.

$$\theta > \frac{7\,(7\tau - 3A - 3R)}{4\,(7\tau - 3A)} \qquad \left(\frac{3}{2}\tau \leq A < \frac{7}{3}\tau\right) \tag{9}$$

$$\theta \leq \frac{7\,(3A + 3R - 7\tau)}{4\,(3A - 7\tau)} \qquad \left(A \geq \frac{7}{3}\tau\right) \tag{10}$$

Substituting Equations (2) and (3) into π_i and CS_i, we have $W(= CS_r + CS_a + \pi_r + \pi_a)$. In the first stage, the government sets the weight θ to maximize social welfare W:

$$\begin{array}{ll} \max\limits_{\theta} & W \\ \text{subject to} & (7),\ (8),\ (9),\ (10) \end{array}$$

Solving the first stage game provides the following proposition.

Proposition 1
When the benefits for consumers using HSR exist in the following range,

$$\frac{57A - 113\tau}{85} \leq R \leq \frac{57A + 85\tau}{85}, \tag{11}$$

then there exists the following optimal weight:

$$\theta^* = \frac{596R - 204A + 196\tau}{697R - 111A + 95\tau},$$

where $0 \leq \theta^* \leq 1$ is met.

Proof
We derive the first-order condition of the government's optimization as follows.

$$\frac{\partial W}{\partial \theta} = -\frac{(123R + 3A - 7\tau)\left\{596R - 204A + 196\tau - \theta\,(697R - 111A + 95\tau)\right\}}{\tau(70 - 41\theta)^3}$$

From Assumption (1), we have the following inequalities.

$$A \geq 3\tau/2 \tag{12}$$

$$R \geq 3\tau/2 \tag{13}$$

From Inequalities (11) and (13), we have the following inequalities.

$$R \geq \frac{3}{2}\tau \qquad \left(A \leq \frac{481}{114}\tau\right) \tag{14}$$

$$R > \frac{57A - 113\tau}{85} \qquad \left(A > \frac{481}{114}\tau\right) \tag{15}$$

From Inequalities (12) and (13), we have the following inequalities.

$$123R + 3A - 7\tau \geq 123 \cdot \frac{3}{2}\tau + 3 \cdot \frac{3}{2}\tau - 7\tau = 182\tau > 0 \tag{16}$$

From Inequality (14), we have the following inequalities when $A \leq 481\tau/114$.

$$\begin{aligned} &596R - 204A + 196\tau = 4(149R - 51A + 49\tau) \\ \geq &4\left(149 \cdot \frac{3}{2}\tau - 51 \cdot \frac{481}{114}\tau + 49\tau\right) = \frac{4356}{19}\tau > 0 \end{aligned} \tag{17}$$

From Inequality (15), we have the following inequality when $A > 481\tau/114$.

$$\begin{aligned} &596R - 204A + 196\tau = 4(149R - 51A + 49\tau) \\ > &4\left(149 \cdot \frac{57A - 113\tau}{85} - 51A + 49\tau\right) = \frac{792\,(21A - 64\tau)}{85} \\ > &\frac{792\,\{21 \cdot (481\tau/114) - 64\tau\}}{85} = \frac{4356}{19}\tau > 0 \end{aligned} \tag{18}$$

From Inequalities (12) and (13) we have the following inequality.

$$\begin{aligned} &(697R - 111A + 95\tau) - (596R - 204A + 196\tau) \\ = &101R + 93A - 101\tau \\ \geq &101 \cdot \frac{3}{2}\tau + 93 \cdot \frac{3}{2}\tau - 101\tau = 190\tau > 0 \end{aligned} \tag{19}$$

Inequalities (17), (18) and (19) provide the next inequality.

$$697R - 111A + 95\tau \geq 596R - 204A + 196\tau > 0 \tag{20}$$

Inequalitiy (20) provides the next inequality.

$$0 \leq \theta^* \leq 1 \tag{21}$$

We derive the second-order condition of the government's optimization as follows.

$$\frac{\partial^2 W}{\partial \theta^2} = \frac{2\,(123R + 3A - 7\tau)\,\{12259R - 8661A + 8729\tau - \theta(28577R - 4551A + 3895\tau)\}}{\tau(70 - 41\theta)^4}$$

From inequality (16), the next inequalities hold.

$$\frac{\partial^2 W}{\partial \theta^2} \begin{cases} > 0 & (0 \leq \theta < \bar{\theta}) \\ < 0 & (\bar{\theta} < \theta \leq 1) \end{cases},$$

where

$$\hat{\theta} = \frac{12259R - 8661A + 8729\tau}{28577R - 4551A + 3895\tau}.$$

We calculate the difference between θ^* and $\hat{\theta}$,

$$\theta^* - \hat{\theta} = \frac{99(123R + 3A - 7\tau)}{41(697R - 111A + 95\tau)} > 0.$$

From Inequalities (16) and (20), the following inequality is satisfied.

$$\theta^* \geq \hat{\theta} \tag{22}$$

In conclusion, Inequalities (21) and (22) indicate that θ^* maximizes social welfare. □

Inequality (11) means that there is no significant difference in benefits for consumers to the HSR and air transportation. The intuition of Proposition 1 is as follows. In our model, consumers between [0, 1] judge which transport mode to use based on their prices and other conditions. The location x^* where consumers are indifferent between using HSR and air transportation is important for the intuition of this result. Yang and Zhang (2012) not only show that both the HSR fare and the airfare decrease as θ increases, but they also show that the HSR fare decreases more than the airfare does for a given increase in θ. This findings means that the consumer's location x^* at which consumers are indifferent between using HSR and air transportation approaches the air transportation side (i.e., 0) by the increase in θ. In other words, consumers between [0, 1] using the HSR as θ increases. In terms of the overall social surplus, it is undesirable for all consumers between [0, 1] to use the HSR because the difference in benefits is small. Therefore, a partial regulation arises as a subgame perfect equilibrium.

We investigate how the optimal level of regulation by the government θ^* depends on the benefits to consumers from each transport mode. The results are summarized as the following corollary.

Corollary 1
The optimal level of regulation by the government θ^* in Proposition 1 increases as the HSR's benefit to consumers (i.e., R) increases, whereas θ^* decreases as air transportation's benefit to consumers (i.e., A) increases.

Proof
We derive the following inequalities by using Inequalities (12) and (13).

$$\begin{aligned}\frac{\partial\theta^*}{\partial R} &= \frac{792\,(96A-101\tau)}{(697R-111A+95\tau)^2}\\ &\geq \frac{792\,\{96\cdot(3\tau/2)-101\tau\}}{(697R-111A+95\tau)^2}\\ &= \frac{34056\tau}{(697R-111A+95\tau)^2} > 0\end{aligned}$$

$$\begin{aligned}\frac{\partial\theta^*}{\partial A} &= -\frac{2376\,(32R-\tau)}{(697R-111A+95\tau)^2}\\ &\leq -\frac{2376\,\{32\,(3\tau/2)-\tau\}}{(697R-111A+95\tau)^2}\\ &= -\frac{111672\tau}{(697R-111A+95\tau)^2} < 0\end{aligned}$$

□

The intuition of Corollary 1 is as follows. An increase in the benefits of consumers makes the use of a transport mode more desirable for social welfare. The government induces consumers to use a relatively desirable mode to increase the total benefits from using transportation. Hence, as HSR's benefits to consumers increase, the government strengthens the regulation pertaining to the HSR to make the HSR operator public and to induce consumers to use the HSR, whereas as the benefits of air transportation to consumers increase, the government relaxes the regulation to make the HSR operator competitive and to induce consumers to use air transportation.

When benefits to consumers from using the HSR fall outside the range of Proposition 1, the first-stage game provides the following propositions.

Proposition 2
When the benefits to consumers using HSR exist in the range of

$$\frac{6A - 14\tau}{15} \leq R < \frac{57A - 113\tau}{85}, \tag{23}$$

then there exists the following optimal weight:

$$\underline{\theta}^* = \frac{5\,(3A - 3R - 7\tau)}{3\,(3A - 7\tau)},$$

where $0 \leq \underline{\theta}^* \leq 1$ is met.

Proof
We derive the first order condition of the government's optimization as follows.

$$\frac{\partial W}{\partial \theta} = -\frac{(123R + 3A - 7\tau)\,\{596R - 204A + 196\tau - \theta\,(697R - 111A + 95\tau)\}}{\tau(70 - 41\theta)^3}$$

From Assumption (1), Inequalities (12), (13), and (16) hold. From Inequality (16), the next inequalities hold.

$$\frac{\partial W}{\partial \theta} \begin{cases} > 0 & (0 \leq \theta < \theta^*) \\ < 0 & (\theta^* < \theta \leq 1) \end{cases},$$

where $\theta^* = (596R - 204A + 196\tau)\,/\,(697R - 111A + 95\tau)$. We derive the second-order condition of the government's optimization as follows.

$$\frac{\partial^2 W}{\partial \theta^2} = \frac{2\,(123R + 3A - 7\tau)\,\{12259R - 8661A + 8729\tau - \theta(28577R - 4551A + 3895\tau)\}}{\tau(70 - 41\theta)^4}$$

From inequality (16), the next inequalities hold.

$$\frac{\partial^2 W}{\partial \theta^2}\begin{cases} > 0 & (0 \leq \theta < \bar{\theta}) \\ < 0 & (\bar{\theta} < \theta \leq 1) \end{cases},$$

where $\hat{\theta} = (12259R - 8661A + 8729\tau)\,(28577R - 4551A + 3895\tau)$. From Inequalities (13) and (23), we have the following inequality.

$$\begin{aligned} &\frac{57A - 113\tau}{85} > \frac{3}{2}\tau \\ \Leftrightarrow &A > \frac{481}{114}\tau \end{aligned} \tag{24}$$

From Inequalities (16), (23), and (24), we have the following inequalities.

$$\begin{aligned} &697R - 111A + 95\tau \\ > &697 \cdot (6A - 14\tau)/15 - 111A + 95\tau = (2517A - 8333\tau)/15 \\ > &(2517 \cdot 481\tau/114 - 8333\tau)/15 = 17381\tau/114 > 0 \end{aligned} \tag{25}$$

$$\theta^* - \hat{\theta} = \frac{99(123R + 3A - 7\tau)}{41(697R - 111A + 95\tau)} > 0.$$

From Inequality (24), Inequality (8) is applied to the constraint of the government's optimization. From Inequalities (16), (23), (24), and (25), we have the following inequality.

$$\begin{aligned} &\frac{5(3A - 3R - 7\tau)}{3(3A - 7\tau)} - \theta^* \\ = &-\frac{(85R - 57A + 113\tau)(123R + 3A - 7\tau)}{3(3A - 7\tau)(697R - 111A + 95\tau)} > 0 \end{aligned}$$

Therefore, $\underline{\theta}^*$ maximizes social welfare. From Inequalities (23) and (24), the following inequality holds.

$$\begin{aligned} &3A - 3R - 7\tau \\ > &3A - 3 \cdot (57A - 113\tau)/85 - 7\tau = (84A - 256\tau)/85 \\ > &(84 \cdot 481/114\tau - 256\tau)/85 = 22\tau/19 > 0 \end{aligned}$$

$$3(3A - 7\tau) - 5(3A - 3R - 7\tau) = 15R - 6A + 14\tau > 0$$

Consequently, $0 \leq \underline{\theta}^* \leq 1$ holds. □

Proposition 3
When the benefits for consumers using HSR exist in the range of

$$\frac{57A + 85\tau}{85} < R < \frac{3A + 7\tau}{3}, \tag{26}$$

then, there exists the following optimal weight:

$$\overline{\theta}^* = \frac{5\,(3A - 3R + 7\tau)}{9A + 20\tau},$$

where $0 \leq \overline{\theta}^* \leq 1$ is met.

Proof
We derive the first-order condition of the government's optimization as follows.

$$\frac{\partial W}{\partial \theta} = -\frac{(123R + 3A - 7\tau)\,\{596R - 204A + 196\tau - \theta\,(697R - 111A + 95\tau)\}}{\tau(70 - 41\theta)^3}$$

From assumption (1), inequalities (12), (13), and (16) hold. From inequality (16), the next inequalities hold.

$$\frac{\partial W}{\partial \theta} \begin{cases} > 0 & (0 \leq \theta < \theta^*) \\ < 0 & (\theta^* < \theta \leq 1) \end{cases},$$

where $\theta^* = (596R - 204A + 196\tau)\,/\,(697R - 111A + 95\tau)$. We derive the second-order condition of the government's optimization as follows.

$$\frac{\partial^2 W}{\partial \theta^2} = \frac{2\,(123R + 3A - 7\tau)\,\{12259R - 8661A + 8729\tau - \theta(28577R - 4551A + 3895\tau)\}}{\tau(70 - 41\theta)^4}$$

From inequality (16), the next inequalities hold.

$$\frac{\partial^2 W}{\partial \theta^2} \begin{cases} > 0 & (0 \leq \theta < \bar{\theta}) \\ < 0 & (\bar{\theta} < \theta \leq 1) \end{cases},$$

where $\hat{\theta} = (12259R - 8661A + 8729\tau)\,(28577R - 4551A + 3895\tau)$. From inequalities (12), (16), and (26), we have the following inequalities.

$$\begin{aligned} &697R - 111A + 95\tau \\ >&697 \cdot (57A + 85\tau)/85 - 111A + 95\tau = 198\,(9A + 20\tau)/5 > 0 \end{aligned} \tag{27}$$

$$\theta^* - \hat{\theta} = \frac{99(123R + 3A - 7\tau)}{41(697R - 111A + 95\tau)} > 0.$$

From inequalities (16), (26), and (27), we have the following inequality.

$$\begin{aligned} &\theta^* - \frac{5\,(3A - 3R + 7\tau)}{9A + 20\tau} \\ =&\frac{(85R - 57A - 85\tau)\,(123R + 3A - 7\tau)}{(9A + 20\tau)\,(697R - 111A + 95\tau)} > 0 \end{aligned}$$

Therefore, $\overline{\theta}^*$ maximizes social welfare. From inequality (26), $0 \leq \overline{\theta}^* \leq 1$ holds. □

Under the cases assumed by Propositions 2 and 3, the location x^* of the consumer who is indifferent between using HSR and air transportation is not an interior solution between [0, 1] but an endpoint solution of 0 or 1. Specifically, the location $x^* = 0$ appears when the benefits to consumers from using the HSR is sufficiently large (i.e., Inequality (26) holds) and the location $x^* = 1$ appears when the benefits to consumers from using the HSR is sufficiently small (i.e., Inequality (23) holds). When the benefits of the HSR are sufficiently large, many consumers between [0, 1] use the HSR without regulation. However, with the decrease in the HSR fare and the airfare due to the government's regulation, all consumers between [0, 1] use the HSR, and more consumers located outside 0 use air transportation. This outcome is desirable for social welfare because of the large benefits from HSR to consumers. When the benefits to consumers from using the HSR are sufficiently small, the intuition is explained by switching the transport mode. In addition, if the benefits of the HSR are so large that it does not satisfy Inequality (26), no regulation (i.e., $\theta = 0$) is desirable for social welfare. If the benefits of the HSR are so small that it does not satisfy Inequality (23), full regulation (i.e., $\theta = 1$) is desirable for social welfare.

We investigate how the optimal level of regulation by the government $\underline{\theta}^*$ and $\overline{\theta}^*$ depends on the benefits to consumers of each transport mode. The results are summarized as the following corollary.

Corollary 2

The optimal levels of regulation by the government $\underline{\theta}^*$ and $\overline{\theta}^*$ in Propositions 2 and 3 decreases as the benefits from HSR to consumers (i.e., R) increase, whereas θ^* increases as the benefits from air transportation to consumers (i.e., A) increase.

Proof

We derive the following inequalities by using inequalities (13) and (24).

$$\frac{\partial \underline{\theta}^*}{\partial R} = -\frac{15}{3\left(3A - 7\tau\right)} < 0$$
$$\frac{\partial \underline{\theta}^*}{\partial A} = \frac{15R}{\left(3A - 7\tau\right)^2} > 0$$
$$\frac{\partial \overline{\theta}^*}{\partial R} = -\frac{15}{\left(9A + 20\tau\right)} < 0$$
$$\frac{\partial \overline{\theta}^*}{\partial A} = \frac{\left(9R - \tau\right)}{\left(9A + 20\tau\right)^2} > 0$$

□

Corollary 2 shows the opposite result of Corollary 1. The intuitions behind Corollary 2 is as follows. In the cases of Propositions 2 and 3, it is desirable for social welfare that the location x^* of the consumer who is indifferent between using HSR and air transportation maintains an endpoint solution (i.e., 0 or 1). In other words, the government regulation is adjusted so that all consumers between [0, 1] use the transport mode with sufficiently large benefits. Therefore, the movement of the location x^* in the "0" direction due to the increase in the benefits of HSR is controlled by the relaxation of regulation by the government. The movement of the location x^* in the "1" direction due to the increase in the benefits of air transportation is controlled by the strengthening of the government regulation.

The discussion on the economic benefits of investment in HSR has received great attention and has been analyzed using various methods, such as cost-benefit analysis. Our results provide a meaningful contribution to this discussion by using a mathematical microeconomic approach. In particular, Propositions 1, 2, and 3 provide a theoretical foundation for the justifying the public policies of joint investments by both governments and HSR operators in HSR networks in European and Asian countries. In addition, Corollaries 1 and 2 suggest that the optimal degree of regulation of the HSR by the government does not simply depend on the change in the benefits of the transport mode. Specifically, when the difference in the benefits of competing transport modes is small, the regulation should be adjusted to support the transport mode with increased benefits. On the other hand, when the difference in the benefits is large, the regulation should be adjusted to support the transport mode with no increase in benefits. Therefore, the government needs to carefully observe the benefits of each transport mode to consumers and the difference between the benefits of each transport mode to set an appropriate regulation.

4. Extensions

In this section, we extend the model to treat flight (HSR ride) frequency as a decision variable in addition to prices. There are a number of previous studies that treat flight (HSR ride) frequency as a decision variable (Brueckner, 2004; Brueckner and Flores-Fillol, 2007; Flores-Fillol, 2009; Richard, 2003; Wei and Hansen 2007; Yang and Zhang 2012). As mentioned in the previous studies, schedule frequency is closely related to the quality of transportation services and is an important dimension in competition between HSR and airlines. Hence, we extend the model so that the airline and HSR operator determine not only their prices p_a and p_r but also their flight (HSR ride) frequencies f_a and f_r. We reconstruct the model as follows.

According to Flores-Fillol (2009), consumers located at x, x_a, and x_r satisfy the following equation:

$$b - p_a - v \cdot (t_a - \alpha_a f_a) - \tau \cdot x = b - p_r - v \cdot (t_r - \alpha_r f_r) - \tau \cdot (1 - x),$$
$$b - p_a - v \cdot (t_a - \alpha_a f_a) - \tau \cdot |x_a| = 0,$$
$$b - p_r - v \cdot (t_r - \alpha_r f_r) - \tau \cdot (x_r - 1) = 0,$$

where f_i is number of flights (HSR rides), and α_i is marginal benefit to consumers per flight (HSR ride) frequency. Transport demands are stated as $q_a = x + |x_a|$ and $q_r = x_r - x$. Similarly, the consumer surpluses CS_a and CS_r and profits π_a and π_r include the effect of flight (HSR ride) frequency.

Unfortunately, since this model is too complicated to solve analytically, the results of a numerical study are provided below. The parameter values used in the numerical study are shown in Table 2. Based on the analytical results in Section 3, the reference parameter values are given symmetrically for HSR and air transportation.

Table 2: Parameter values for numerical analysis

	Reference value
Gross benefit of travel	$b = 100$
Disutilities other than the value of time	$\tau = 50$
Value of time	$v = 5$
Total travel time	$t = 5$
Marginal cost per seat	$c = 5$
Marginal cost per departure	$K = 3$
Marginal benefit per frequency	$\alpha = 1$

Table 3: Numerical results on air transportation

Parameter	value	θ^*	p_a^*	p_r^*	f_a^*	f_r^*	x^*	W^*
	4	0.793	40.983	11.747	0.900	1.869	0.209	167.095
t_a	5	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	6	0.808	35.393	10.700	0.760	1.948	0.144	152.548
	4	0.803	37.747	11.328	0.844	1.900	0.183	160.956
c_a	5	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	6	0.808	38.629	11.118	0.816	1.916	0.170	158.046
	2	0.797	39.434	11.665	1.291	1.886	0.193	162.633
K_a	3	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	4	0.809	37.599	11.018	0.611	1.919	0.169	158.041
	0.5	0.816	36.483	10.639	0.394	1.939	0.154	156.551
α_a	1	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	1.5	0.784	41.497	12.423	1.369	1.847	0.220	166.719

We have solved the game in 17 scenarios by choosing a value that differ from the reference value for the eight variables, that is total travel time (t_a, t_r), marginal benefit per flight (HSR ride) (α_a, α_r), marginal cost per seat (c_a, c_r), and marginal cost per departure (K_a, K_r). The results for air transportation are shown in Table 3, and the results for HSR are shown in Table 4. We obtain the following observations.

- In all scenarios, θ^* exists between [0, 1] since the benefits of the transport modes are not sufficiently different, as shown in Proposition 1.
- θ^* decreases with an increase in the benefits to consumers from air transportation, or, in other words, decreases in t_a and c_a, which has been shown in Corollary 1.

Table 4: Numerical results on HSR

Parameter value		θ^*	p_a^*	p_r^*	f_a^*	f_r^*	x^*	W^*
t_r	4	0.809	37.140	11.026	0.803	2.048	0.127	172.546
	5	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	6	0.801	39.236	11.419	0.856	1.769	0.226	147.389
c_r	4	0.806	37.978	10.183	0.824	1.936	0.166	162.023
	5	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	6	0.805	38.397	12.262	0.835	1.880	0.186	156.991
K_r	2	0.809	37.113	11.021	0.803	3.077	0.125	172.896
	3	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	4	0.803	38.671	11.313	0.842	1.383	0.199	153.791
α_r	0.5	0.799	39.545	11.478	0.864	0.864	0.241	146.589
	1	0.805	38.188	11.223	0.830	1.908	0.176	159.488
	1.5	0.815	35.159	10.655	0.754	3.468	0.033	196.383

- θ^* increases with an increase in the benefits to consumers from the HSR, or, in other words, decreases in t_r and c_r, which has been shown in Corollary 1.
- θ^* increases with an increase in the marginal cost per departure of the airline, K_a, and it decreases with an increase in the marginal cost per departure of the HSR, K_r.
- θ^* decreases with an increase in the marginal benefit per flight of the airline, α_a, and it increases with an increase in the marginal benefit per HSR ride of the HSR, α_r.

5. Concluding remarks

This study investigates the desirable transportation policy for a government concerning how to regulate the competition between HSR and air transportation. To discuss this issue, we construct a two-stage game in which the government sets the regulation to maximize social welfare in the first stage and the HSR operator and the airline maximize their respective objective function in the second stage. A basic assumption underlying our model is that the HSR operator and the airline have different objective functions. Specifically, the airline maximizes its own profit, whereas the HSR operator maximizes a weighted sum of profit and social welfare due to the regulation imposed on the HSR by the government.

Our main finding from the model is that a partial regulation by the government arises as a subgame perfect equilibrium unless the benefits to consumers from using the HSR are sufficiently large or sufficiently small compared to the benefits to consumers from using air transportation. This result provides a theoretical foundation for the public transportation policies regarding HSR lines owned by governments and on joint investments by both governments and private companies in HSR networks in European and Asian countries. Furthermore, our results suggest that the optimal level the government regulation depends on the benefits to consumers from using each transport mode and the difference between the benefits. Specifically, when the difference in the benefits from the transport modes is small, the government should strengthen the regulation on the HSR as HSR's benefits to consumers increase, whereas it should relax the regulation as air transportation's benefits to consumers increase. On the other hand, when the difference in the benefits from the transport modes is large, the government should relax the regulation as HSR's benefits to consumers increase, and it should strengthen the regulation as air transportation's benefits to consumers increase.

In addition, we extend a model in which the airline and the HSR operator determine not only their prices but also their frequencies. Even in the extended model that incorporates flight (HSR ride) frequency as an additional factor, we show that a partial regulation on the HSR by the government arises as a subgame perfect equilibrium through a numerical analysis, and we show that the optimal level of the regulation by the government depends on the benefits to consumers using each transport mode.

This study has raised some issues for future research. Our model focuses on the competition between an airline and an HSR. As a more general setting, however, there is a market in which two or more transport modes exist. In particular, because low-cost carriers have become a major presence in the air transport market, a number of previous studies focus on product differentiation between full service airlines and low cost carriers (Clewlow et al., 2014; Fu et al., 2011; Fu et al., 2012; Hofer et al., 2008; Windle and Dresner, 1999). An analysis on the regulation of HSR in such a general market can have a great practical contribution. Since our model uses the Hotelling model to capture horizontal product differentiation between HSR and air transportation according to Yang and Zhang (2012), it is difficult to analyze such a general market in this context due to the model constraints.

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