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Joint Provision of International Transport Infrastructure

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Abstract

This paper considers the following scheme for the joint provision of an international transport infrastructure: two countries jointly establish an operator for the infrastructure who is then responsible for collecting the user charges. The costs of the infrastructure investment are covered by financial contributions from the two countries, and the revenue from the user charges is distributed according to the share of contribution. The governments of the two countries choose the contribution that maximizes their national welfare. Assuming that the infrastructure use is non-rival, we show that financing the infrastructure with revenue from user charges is better than financing with tax revenue. We extend the analysis by incorporating congestion in infrastructure use. It is shown that independent decisions on contributions by two governments attain the first-best optimum when the operator sets the user charge such that the toll revenue just covers the cost of the investment. We further examine the conditions under which joint provision is realized at Nash equilibrium.

Keywords: international transport infrastructure, joint provision, congestion, self-financing

JEL Classification: H54, L91, R41, R48

1 Introduction

Around the world, there are many bridges and tunnels crossing borders between two countries. These facilities touch the territories of both countries; therefore, decisions to construct them should be jointly made by the governments on both sides of the border. This paper considers the scheme for joint provision of international transport infrastructure as follows: two countries jointly establish an operator for the infrastructure who is then responsible for collecting the user charge. The two countries make financial contributions to cover the costs of the infrastructure investment, and the revenue is shared according to the contributions made. Similar practices can be found in the real world. For example, the United States and Canada jointly established the Niagara Falls Bridge Commission to finance, construct, and operate the Rainbow Bridge.

We examine the performance of joint provision using a simple two-country model in which the transportation cost between countries depends on the capacity and the user charge (e.g., road toll) of the infrastructure. The governments of the two countries choose the amount of contribution that maximizes their national welfare. The sum of the contributions is spent for investment, thereby determining the capacity of the infrastructure. We consider two cases: first, the infrastructure use is non-rival; second, the infrastructure is congestible. In the non-rival case, the optimal user charge should be zero. However, setting a positive level of user charge improves welfare since it encourages contributions from the two governments. We further show that joint provision leads to under- or over-investment in capacity if the revenue is smaller (or greater) than the cost of investment. In the case of congestible infrastructure, joint provision attains the first-best optimum when the operator sets the user charge such that the toll revenue just covers the cost of investment. This is an extension of the well-known self-financing theorem by Mohring-Harwitz (1962). Unlike the original setting where a single government chooses the capacity based on a benefit-cost criterion, we obtain the result when the capacity is determined by non-cooperative contributions from multiple governments.

There is a large body of literature on the pricing and capacity choice of transport infrastructure in the system of multiple governments (e.g., the review by De Borger and Proost [2012]). Mun and Nakagawa (2010) consider the cross-border transport infrastructure that consists of two links, each of which is constructed and operated by the government of its territory. They evaluate the effects of alternative pricing and investment policies for the infrastructure on the economic welfare of the two countries. Brueckner (2014) investigates the pricing and capacity choice of a congestible bridge between jurisdictions in a monocentric metropolitan area. He assumes that the capacity of a bridge is determined solely by the government with jurisdiction on the other side. This assumption is reasonable in the context of a monocentric metropolitan area since a bridge is used only by the residents in outer locations. In this setting, Brueckner shows that a decentralized capacity choice with budget-balancing user charge attains an efficient allocation. This paper can be regarded as an extension of Brueckner's analysis in the sense that there are users on both sides of the bridge with multiple governments sharing the cost of capacity investment. Verhoef (2012) also obtains a self-financing result under the condition that users of the infrastructure facility with market power can invest in capacity. His result is strong in that self-financing holds true in broader situations where capacity cost does not exhibit constant returns. Note that government subsidy is required to attain efficiency and self-financing in Verhoef's model. In contrast, the scheme proposed in this paper attains efficiency through voluntary contributions from two governments imposing cost recovery on the operator.

This paper is also related to the literature on voluntary provision of public goods (Bergstrom, Blume, and Varian [1986]); Cornes and Sandler [1996]; Andreoni [1998]; and Batina and Ihori [2005]). If a user fee is not charged for the use of infrastructure, our formula for determining the capacity of the infrastructure is equivalent to the formula for voluntary provision of public good, leading to under-provision. There have been several proposals to induce efficient voluntary provision of public goods (e.g., Falkinger [1996], Morgan [2000], and Zubrickas [2014]). Our paper introduces charging the users and using the revenue to reward the contribution of each country[1]. We show that this mechanism gives an incentive to increase the amount of voluntary contribution and results in greater welfare in the case of non-rivalry. Furthermore, if the infrastructure is congestible, joint provision can attain the optimal level of capacity through voluntary contributions.

This paper is organized as follows. In section 2, we examine the outcome of joint provision with the assumption of non-rival infrastructure use (i.e., no congestion). Section 3 extends the analysis to a scenario in which congestion exists on the bridge or tunnel. In section 4, we examine whether two governments would choose to participate in joint provision. Section 5 concludes the paper.

2 User charge and Capacity Investment for Non-rival Infrastructure

2.1 Setting

Consider an economy with two countries, indexed by i ($i = 1, 2$). In each country, there is deamnd for transport to another country, which crosses the border using the international transport infrastructure. The transportation cost depends on the capacity and user charge (such as road toll) of the infrastructure. The demand function is given by $D_i(f + t(k))$, where f is the infrastructure charge, and $t(k)$ is the user cost that depends on the capacity of the infrastructure, k. $f + t(k)$ is the full price of transportation per trip[2]. The demand function is strictly decreasing and differentiable. We assume that an investment in transport

[1] In the absence of congestion, the service provided by the infrastructure is considered excludable but non-rival. Excludable public goods can be provided by private firms. For example, Oakland (1974) and Brito and Oakland (1980) consider this problem in cases of perfectly competitive and also monopolistic markets. They suggest that the market provision of excludable public goods does not attain an efficient allocation, and under-provision is likely.

[2] Measuring by the number of trips is naturally applicable to passenger transportation, such as in tourism and shopping. In the case of freight transportation, the quantity (e.g., weight of goods) is the usual unit of measurement; however, hereafter, we use trips as the unit of measurement.

infrastructure increases capacity, thereby saving the user cost. The investment exhibits decreasing returns to scale: $t' \equiv dt/dk < 0, t'' \equiv d^2t/dk^2 > 0$. We also assume that the cost of infrastructure investment is linearly increasing in capacity.

Two countries jointly establish an operator of the infrastructure, which constructs the facility and collects the user charge. The cost of infrastructure investment are covered by financial contributions from the two countries. We assume that the revenue from the infrastructure charge is shared according to the contribution made. The national welfare in country i is defined as the sum of users' welfare and the dividend of the revenue minus the expenditure for financial contribution, as follows

$$W_i = \int_{f+t(k)}^{\infty} D_i\left(p\right) dp + \frac{k_i}{k} f\left(x_1 + x_2\right) - p^k k_i \tag{1}$$

where k_i is the amount of financial contribution from Country i. $k_1 + k_2 = k$ should hold; $x_i = D_i(f+t(k))$ is the number of trips from Country i and p^k is the unit cost of infrastructure investment. It is convenient to rewrite national welfare as follows

$$W_i = \int_{f+t(k)}^{\infty} D_i\left(p\right) dp + \frac{k_i}{k}\Pi$$

where Π is the profit of the infrastructure project, $\Pi = f\left(x_1 + x_2\right) - p^k k$. The second term on the right hand side, $\frac{k_i}{k}\Pi$ is the dividend of the profit.

2.2 Social Optimum

In this paper, the social optimum is characterized as the solution to a global welfare maximization problem. Global welfare is defined as the sum of the national welfare of each of the two countries', as follows:

$$W(f,k) = \int_{f+t(k)}^{\infty} D_1\left(p\right) dp + \int_{f+t(k)}^{\infty} D_2\left(p\right) dp + \Pi \tag{2}$$

Let us suppose that the infrastructure charge, f, is fixed. The optimality condition with respect to the capacity is

$$-\left(x_1 + x_2\right) t' + f(x_{1k} + x_{2k}) = p^k \tag{3}$$

where $x_{ik} \equiv \frac{\partial D_i}{\partial k} > 0$. Let the solution of (3) be $K^O(f)$. Differentiating the global welfare function with respect to f at $k = K^O(f)$, we have the following:

$$\frac{dW(f, K^O(f))}{df} = f(x_{1f} + x_{2f}) < 0 \tag{4}$$

where $x_{if} \equiv \frac{\partial D_i}{\partial f} < 0$. The above inequality implies that global welfare is maximized at $f = 0$ while the capacity is determined by (3). In other words, the optimal pricing policy is that the infrastructure use should be free of charge. This is natural since the marginal cost of usage is zero for the non-rival infrastructure. Under this optimal pricing, (3) is reduced to

$$-\left(x_1+x_2\right)t'=p^k \tag{5}$$

We see that $f=0$ together with (5) is the condition for the first-best optimum. The left hand side of (5) is the number of users, (x_1+x_2) multiplied by the marginal benefit of a user (i.e., saving of the transport cost) by increasing the capacity, $-t'$. The right hand side is the marginal cost of increasing the capacity. (5) is the social benefit-cost rule for the transport project. It also has the same formal structure as the Samuelson's condition for optimal public goods provision.

2.3 Capacity investment under joint provision

The government of each country takes the infrastructure charge as given, and chooses the amount of financial contribution k_i so as to maximize national welfare defined by (1). The optimality condition for the government of country i is

$$-x_i t'+\frac{k_j}{k^2}f\left(x_1+x_2\right)+\frac{k_i}{k}f(x_{1k}+x_{2k})=p^k, \qquad j\neq i \tag{6}$$

The first term on the left hand side of (6) is the users' marginal benefit in the home country, the second and third terms are the effects on the dividend through changes in the share of contribution and in capacity, respectively. For the special case, $f=0$, (6) is reduced to

$$-x_i t'=p^k \tag{7}$$

Comparing (7) with (5), we see that the national government ignores the benefit of the users in the other country, which leads to too small capacity. This discrepancy is essentially the same as that between voluntary provision and optimal provision of public good (Cornes and Sandler (1996), Batina and Ihori (2005)).

Recall that $f=0$ is the optimal pricing policy. This implies that the first-best optimum is never achieved under the decisions by the national government.

Let us examine the effects of increasing the level of infrastructure charge on the contribution and the level of economic welfare. Summing up the investment rule (6) for two countries yields

$$-(x_1+x_2)t'+\frac{1}{k}f\left(x_1+x_2\right)+f(x_{1k}+x_{2k})=2p^k \tag{8}$$

Let the solution of (8) be $K^J(f)$. Totally differentiating (8) with respect to k and f , evaluated at $f=0$, we have the following:

$$\left.\frac{dk}{df}\right|_{f=0}=\frac{dK^J(0)}{df}=\frac{\frac{1}{k}\left(x_1+x_2\right)}{(x_1+x_2)t''+(x_{1k}+x_{2k})t'} \tag{9}$$

The denominator of the RHS of (9) is positive from the second-order condition for (6). Thus we have $\frac{dK^J(0)}{df} > 0$: k is increased by increasing f from zero. Differentiating the global welfare function with respect to f while k is determined by the national governments: $k = K^J(f)$, we have the following:

$$\frac{dW(0, K^J(0))}{df} = p^k \frac{dK^J(0)}{df} > 0$$

The above analysis is summarized as follows.

Proposition 1 *Increasing the infrastructure charge from zero improves global welfare through expanding the capacity of the infrastructure.*

If the infrastructure charge is zero, the national government should use tax revenue to finance the contribution to the infrastructure project. Also note that the optimal infrastructure charge is zero in the non-rival case, so increasing the infratructure charge from zero means a deviation from optimal pricing. The above proposition implies that shifting the revenue source from taxes to user charges, in other words, a deviation from optimal pricing, improves welfare.

We address the next question: what does the efficient infrastructure charge look like under joint provision based on voluntary contributions by the national governments? We assume that the operation of the infrastructure is profitable[3].

Proposition 2 *Assume that there exists a profit maximizing user charge, $\overline{f}$, $\overline{f} > 0$, and $\Pi > 0$ at $\overline{f}$.*

(i) Let $\widehat{f}$, be the break-even user charge, at which $\Pi = 0$. Capacity determined by contributions from two national governments is equal to the optimal capacity at $\widehat{f}$, i.e., $K^J(\widehat{f}) = K^O(\widehat{f})$; thereby $W(\widehat{f}, K^J(\widehat{f})) = W(\widehat{f}, K^O(\widehat{f}))$;

(ii) $K^J(f) < K^O(f)$, if $f < \widehat{f}$ and vice versa;

(iii) There exists an infrastructure charge f^* at which global welfare is maximized under joint provision, i.e., $f^* = \arg\max_f W(f, K^J(f))$;

(iv) f^* is smaller than $\widehat{f}$.

Proof. (i) First, there exists $\widehat{f}$ in $(0, \overline{f})$, since $\Pi < 0$ at $f = 0$, and $\Pi > 0$ at $\overline{f}$. (8) is rewritten as follows:

$$-(x_1 + x_2)t' + \frac{1}{k}\Pi + f(x_{1k} + x_{2k}) = p^k \tag{10}$$

The above equation is reduced to (3) at $f = \widehat{f}$ where $\Pi = 0$.

(ii) Based on the assumption, Π is increasing with f in $[0, \overline{f})$. And $0 < \widehat{f} < \overline{f}$ from (i). It follows that $\Pi \lesseqqgtr 0 \iff f \lesseqqgtr \widehat{f}$. If $\Pi > 0$, the LHS of (10) is larger than the LHS of (3) thereby $K^J(f) < K^O(f)$ and vice versa.

[3] In other words, the profit is positive when the operator sets the level of user charge to maximize the revenue by exercising market power.

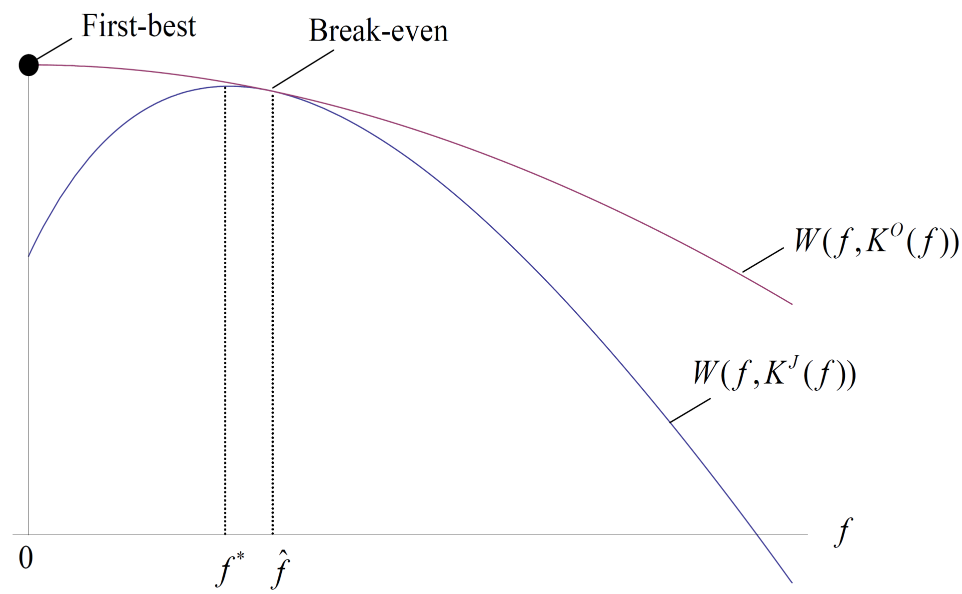

Figure 1　Infrastructure charge and global welfare

(iii)(iv) We know $\frac{dW(0,K^J(0))}{df} > 0$ from Proposition 1, and $\frac{dW(\widehat{f},K^J(\widehat{f}))}{df} = \frac{dW(\widehat{f},K^O(\widehat{f}))}{df} < 0$ from (4). Thus there must be $f^*, 0 < f^* < \widehat{f}$, where $\frac{dW(f^*,K^J(f^*))}{df} = 0$. ■

Figure 1 is drawn based on the propositions 1 and 2. $W(f, K^O(f))$ and $W(f, K^J(f))$ are loci of global welfare when capacity is determined optimally and by joint provision, respectively. As Proposition 1 states, global welfare is increased by increasing f from zero. From (4), the optimal value function $W(f, K^O(f))$ decreases with f, so the first-best optimum is attained at $f = 0$. These two curves touch at $f = \widehat{f}$ where the revenue just covers the cost of investment. We also see that there exists a point f^* where global welfare under joint provision is maximized ((iii) of Proposition 2). This point can be regarded as the second-best[4].

[4] f^* maximizes $W(f, K^J(f))$. The optimality condition, $\frac{dW(f,K^J(f))}{df} = 0$, is written as

$$f(x_{1f} + x_{2f}) + \left[-(x_1 + x_2)\, t' + f(x_{1k} + x_{2k}) - p^k\right] \frac{dK^J}{df} = 0$$

The first term is the direct effect of the user charge that reduce the transport demand. The second term is the indirect effect through encouraging capacity investment. The second-best is characterized by the trade off of these negative and positive effects on global welfare. This point can be also interpreted as the bargaining solution, as discussed by De Borger and Proost (2013).

From (iv) of Proposition 2, the revenue from the infrastructure charge at f^* is not sufficient to cover the cost of investment. Thus (i) together with (4) implies that break-even pricing is the most efficient among the schemes in which capacity investment is financed solely by the revenue from the infrastructure. Part (ii) states that over-investment of capacity could arise if the infrastructure charge is larger than $\widehat{f}$. This result never arises in earlier studies, such as Mun and Nakagawa (2010), who examine a number of alternative pricing schemes for the cross-border transport infrastructure consisting of two links, but they all result in under-investment.

2.4 Equilibrium with break-even pricing

Equilibrium is described as a game with three players, which, in this case, are two governments and the operator. The two governments choose the investment level, as described in the previous section. The operator sets the level of infrastructure charge according to the pricing policy. Recall that the operator is established by the two governments. So the pricing policy is determined by the agreement of two governments. Once the pricing policy is fixed, the operator behaves as an independent player of the game. We assume that the two governments agree to adopt break-even pricing. We focus on this case because this pricing rule is commonly adopted in regulation. It is also a good case because break-even pricing leads to an efficient outcome, as shown in Proposition 2[5].

The operator sets the level of infrastructure charge such that the revenue equals the cost of investment, taking the contributions from two governments as a given. Let us denote by $F^b(k)$ the response function of the operator, which is obtained by solving the following equation for f

$$f\left(x_1 + x_2\right) - p^k k = 0$$

The response of the governments is described by $K^J(f)$, as discussed earlier. Nash equilibrium is characterized by the solution (f^b, k^b) of the following system of equations.

$$\begin{aligned} f^b &= F^b(k^b) \\ k^b &= K^J(f^b) \end{aligned}$$

Equilibrium is stable when the response functions are positioned as in Figure 2, where the curve of $K^J(f)$ crosses $F^b(k)$ from above. Other than the break-even policy, we can also consider various pricing policies for which the position of the operator's response function is changed.

[5] Note that Proposition 2 shows that the break-even pricing is the third-best: there is the second-best infrastructure charge, f^*. However the profit of the infrastructure project is negative under the second-best pricing. It is also the advantage of break-even pricing that implementation is much easier. On the other hand, finding the second-best charge would be difficult in practice.

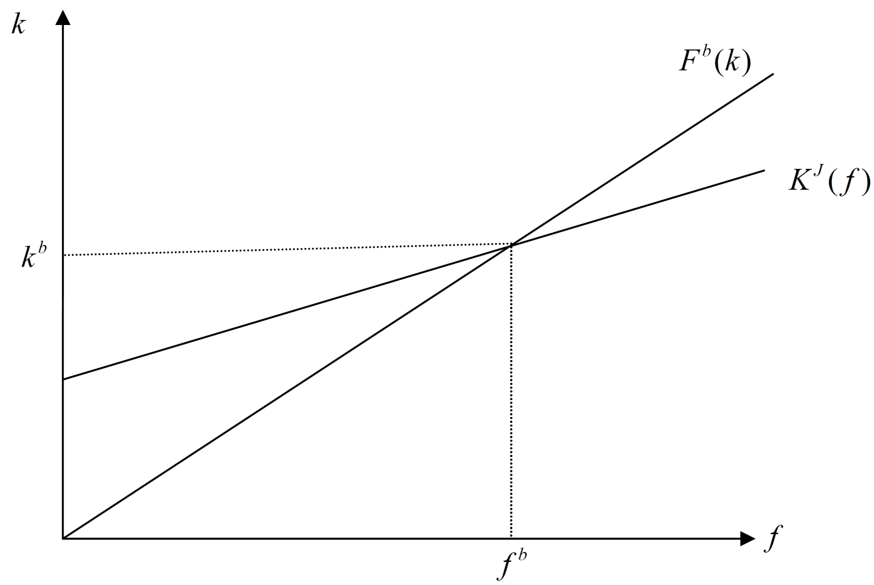

Figure 2 Response functions of governments and operator

3 Congestible Infrastructure

We extend the analysis to the case that the infrastructure is congestible. Congestion is described by the user cost function $c\left(\frac{x_1+x_2}{k}\right)$, where we assume $c' > 0$ [6]. Accordingly, national welfare is written as $W_i = \int_{f+c\left(\frac{x_1+x_2}{k}\right)}^{\infty} D_i(p)\,dp + \frac{k_i}{k} f(x_1+x_2) - p^k k_i$, and global welfare is the sum of national welfare of each of two countries, $W(f,k) = W_1 + W_2$.

The conditions for global welfare maximization (first-best) are as follows:

$$f = (x_1+x_2)\frac{c'}{k} \tag{11}$$

$$\left(\frac{x_1+x_2}{k}\right)^2 c' = p^k \tag{12}$$

These two conditions are standard formulas for the congestion problem: (11) states that the infrastructure charge should be equal to the congestion externality; (12) states that the social marginal benefit (the reduction of congestion) from capacity expansion should be equalized to the marginal cost of investment.

[6] This specifications implies that the user cost function is homogeneous of degree zero in volume and capacity.

Under the scheme of joint provision by two governments, each government chooses the amount of contribution to maximize national welfare. The optimality condition for the government of country i is as follows:

$$x_i\left[\frac{(x_{1k}+x_{2k})}{k}-\frac{(x_1+x_2)}{k^2}\right]c'+\frac{k_j}{k^2}f\left(x_1+x_2\right)+\frac{k_i}{k}f(x_{1k}+x_{2k})=p^k,\qquad j\neq i \tag{13}$$

Summing up the investment rule (13) for two countries and rearranging, we have the following:

$$\left(\frac{x_1+x_2}{k}\right)^2c'+\left[f-\frac{(x_1+x_2)}{k}c'\right](x_{1k}+x_{2k})+\frac{f}{k}\left(x_1+x_2\right)=2p^k \tag{14}$$

As in the case of non-rivalry, we examine the consequence of break-even pricing. Substituting the zero-profit condition, $f\left(x_1+x_2\right)-p^kk=0$ into the above equation, we have the following:

$$\left(1-\frac{k(x_{1k}+x_{2k})}{x_1+x_2}\right)\left[\left(\frac{x_1+x_2}{k}\right)^2c'-p^k\right]=0$$

The above equality holds when the condition for optimal capacity, (12) holds. And zero profit together with optimal capacity leads to (11), the optimal pricing rule. Thus, we have the following proposition:

Proposition 3 *Under break-even pricing, the first-best charge and capacity are attained by contributions from two governments, each of which seeks to maximize its national welfare.*

The above proposition shows that the self-financing theorem by Mohring-Harwits (1962) can be extended to the case that capacity is determined in a decentralized way. It is known that the first-best optimum is attained under the zero profit and optimal capacity rules. A new finding here is that the optimal capacity rule is derived from non-cooperative choices of contribution by the two governments.

4 Joint Provision vs Single Provision

Until now, we have not discussed whether joint provision is actually realized. This section examines the incentives for two governments to join the infrastructure project. There are several alternative ways to provide international infrastructure. One common alternative to joint provision is for only one of the two countries build and operate the transport infrastructure[7]. Hereafter, we call this case "single provision." Brueckner (2015) considers exactly this situation: the bridge between jurisdictions of a mid-city area and a suburb is built by the government of the suburb.

[7] Even in this case, two governments should agree on the infrastructure project, since it touches the territories of both countries.

This section examines whether joint provision is realized by the decisions of two governments seeking to maximize national welfare. Each government chooses whether to participate in joint provision by comparing national welfare with alternative choices[8]. There are four possible combinations of choices by two national governments: case YY (joint provision) in which both countries participate in joint provision; case NN in which no country commits to the infrastructure; case YN (single provision by country 1) in which country 1 builds the infrastructure individually; and case NY in which country 2 builds the infrastructure individually. Let us denote the national welfare of country i for the four cases by $W_i^{YY}, W_i^{NN}, W_i^{YN}, W_i^{NY}$, respectively.

The conditions under which joint provision is Nash equilibrium are written as follows

$$W_1^{YY} > W_1^{NY} \text{ and } W_2^{YY} > W_2^{YN}$$

4.1 Non-rival case

When the infrastructure use is non-rival, W_i^{YY} is obtained by substituting to (1) the capacity obtained in Section 2. In cases YN or NY, the infrastructure charge and capacity are determined by the decision of the government that implements the infrastructure project. Without loss of generality, we consider the case YN in which country 1 builds and operates the infrastructure. The problem to be solved by the government of country 1 is[9]

$$\max_{f,k} \int_{f+t(k)}^{\infty} D_1(p)\,dp + f(x_1 + x_2) - p^k k \tag{15}$$

The optimality conditions with respect to the user charge and the capacity of the infrastructure, respectively, are:

$$\begin{aligned} x_2 + f(x_{1f} + x_{2f}) &= 0 \quad (16)\\ -x_1 t' + f(x_{1k} + x_{2k}) &= p^k \quad (17) \end{aligned}$$

Let us denote the solution of the above equation by (f^{YN}, k^{YN}). From (16) and (17), we have $f^{YN} > 0$ and $-(x_1 + x_2)t' = p^k$. In words, the user charge in single provision is higher than the efficient level (i.e., zero), and the investment rule is consistent with the benefit-cost rule. Substituting $(f^{YN}, k^{YN})$to the objective function in (15), we have W_1^{YN}. And we obtain $W_2^{YN} = \int_{f^{YN}+t(k^{YN})}^{\infty} D_2(p)\,dp$. In case NY(single provision by country 2), W_1^{NY} and W_2^{NY} are obtained likewise.

[8]The problem discussed in this section is similar to the voluntary participation of public goods provision (Saijo and Yamato [1999] and Furusawa and Konishi [2011]). The difference is that the infrastructure use is excludable.

[9]In the case of single provision, the national government can control the operation of the infrastructure. So, we assume that the government determines the user charge and the capacity of the infrastructure. On the other hand, in the case of joint provision, no single government can choose the level of infrastructure charge by itself. There are various alternative ways to determine the pricing policy, so we allow flexibility in pricing under joint provision.

In the non-rival case, either joint provision or single provision can be realized in equilibrium. To see this, we provide the following example:

Example 1 *Suppose that break-even pricing is adopted in the case of joint provision. Let us specify the forms of the demand function and user cost function as follows:*

$$x_i = A_i \exp\left[-\alpha(f + t(k))\right] \tag{18}$$

$$t(k) = -\beta \ln k, \tag{19}$$

where A_i, α, β are parameters[10]*. Under the above specifications, joint provision is Nash equilibrium if the following inequality holds true (see Appendix A for the details of derivation),*

$$\frac{\alpha\beta}{1-\alpha\beta} + \alpha\beta \ln(1-\alpha\beta) < s \tag{20}$$

where $s \equiv \min\{\frac{A_1}{A_1+A_2}, \frac{A_2}{A_1+A_2}\}$, i.e., the share of demand from the smaller country.

The condition for joint provision, (20), depends on s and $\alpha\beta$.Note that $\alpha\beta$ is equal to the demand elasticity with respect to capacity, k. Figure 3 illustrates the condition on $s-\alpha\beta$ plane. We see that joint provision is more likely when the demand sizes of the two countries are symmetric and the transport demand is less sensitive to the capacity of the infrastructure. In the special case that two countries are symmetric, $s = 0.5$, the inequality (20) is approximately equivalent to $\alpha\beta < 0.4227$. Joint provision is unlikely when two countries are asymmetric. In the very asymmetric case, $s = 0.1$, joint provision is realized if $\alpha\beta < 0.0994$. According to the calibration by Mun and Nakagawa (2010), $\alpha\beta = 0.0499$. In other words, joint provision is realized even in this very asymmetric case[11].

From the above discussion, we have the following proposition.

Proposition 4 *If the infrastructure is non-rival, either joint provision or single provision may be realized in equilibrium.*

4.2 Congestible Case

We follow the formulation in Section 3, to describe the capacity choice in joint provision, case YY. For case YN (single provision by country 1), the national government solves the following problem:

[10] A_i represents the demand size of the country i.

[11] The details of the calibration are provided in the working paper version that is downloadable at http://www.econ.kyoto-u.ac.jp/~mun/papers/Pricing_and_investment091006.pdf

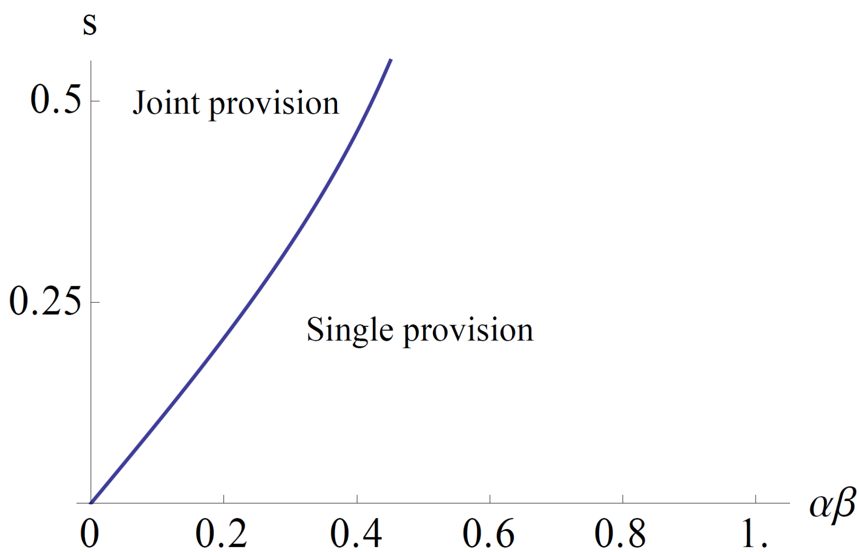

Figure 3 Parameter region of joint provision

$$\max_{f,k} \int_{f+c\left(\frac{x_1+x_2}{k}\right)}^{\infty} D_1(p)\, dp + f(x_1+x_2) - p^k k \tag{21}$$

The optimality conditions with respect to the user charge and the capacity of the infrastructure are respectively

$$-x_1\left(1 + c'\frac{(x_{1f}+x_{2f})}{k}\right) + (x_1+x_2) + f(x_{1f}+x_{2f}) = 0 \tag{22}$$

$$-x_1 c'\left(-\frac{(x_1+x_2)}{k^2} + \frac{(x_{1k}+x_{2k})}{k}\right) + f(x_{1k}+x_{2k}) = p^k \tag{23}$$

(22) is rewritten as follows

$$f = (x_1+x_2)\frac{c'}{k} - \frac{x_2}{(x_{1f}+x_{2f})} \tag{24}$$

The first term on the RHS of (24) is the congestion externality, and the second term is the mark-up, so the user charge in single provision is higher than the optimal level[12]. The investment rule (23) is reduced to the same as in the social optimum, (12). However, due to

[12] As shown by Proposition 3, joint provision with break-even pricing attains the first-best, in which infrastructure charge is equal to the congestion externality.

the excessively high user charge, the capacity under single provision is smaller than that in social optimum.

We then have the following result.

Proposition 5 *Joint provision with break-even pricing is Nash equilibrium.*

Proof. See Appendix B. ■

Consider the choice of country 1 between cases YY and NY. In both cases, the national welfare of country 1 is equal to the users' benefit, so it depends solely on the full price of transportation, $f + c\left(\frac{x_1+x_2}{k}\right)$. In case NY, users in country 1 incur a higher full price than case YY since the user charge is higher and the capacity is smaller. So the country is better off by choosing joint provision.

So far, we have assumed that under single provision, the national government providing the infrastructure rationally maximizes national welfare by choosing higher user charge and smaller capacity. However, as discussed in Section 2.4, break-even pricing is widely adopted in practice since it is simple to implement and easily obtains public acceptance. So, we examine single provision with break-even pricing and obtain the following result:

Proposition 6 *If break-even pricing is adopted in both joint provision and single provision of a congestible infrastructure, the two cases yield the same outcome, and they attain the first-best optimum.*

Proof. See Appendix C. ■

The optimality of single provision with break-even pricing is also shown by Brueckner (2013) based on the model of locational equilibrium in a monocentric city with multiple jurisdictions. Proposition 6 is obtained by combining this result with Proposition 3. Now we know that joint provision is indifferent to single provision. This result suggests that the countries might not undertake joint provision. Even if two cases attain the same outcome by adopting break-even pricing, joint provision would require the transaction cost in the process of reaching agreement on the design of the facility, pricing policy, organization of the operator, and other such concerns.

5 Conclusion

This paper investigates the performance of the scheme for joint provision of an international transport infrastructure facility. We find that decentralized contributions by two countries might lead to an efficient level of transport infrastructure. The dividend of revenue from infrastructure charge plays an essential role in inducing the governments to provide efficient levels of contributions. In particular, joint provision with break-even pricing attains the first-best optimum in the case of congestible infrastructure. This is an extension of the self-financing theorem by Mohring and Harwitz in which capacity is determined by non-cooperative decisions of multiple governments. By looking at the choice between joint provision and single provision, we further examine whether the governments would participate in joint provision. In a non-rival case, either joint provision or single provision can be realized in equilibrium. On the other hand, joint provision with break-even pricing is always Nash equilibrium when the infrastructure is congestible.

There are suggestions for future research. First, in the non-rival case, joint provision does not attain the first-best outcome although it improves efficiency. This is because joint provision requires positive user charge, which implies a deviation from the first-best policy, i.e., the policy of free-of-charge use of non-rival infrastructure. Also, note that the first-best result in the congestible case crucially depends on the assumption of constant returns to scale of the transport cost. We should consider additional instruments or alternative designs of schemes for international transport infrastructure to attain the first-best optimum in broader classes of transport costs[13]. Second, we see that private involvement in infrastructure provision, such as a public-private partnership, is increasingly common worldwide. In our setting, a private firm can be the operator of the infrastructure. There are several issues in this regard, such as the design of an auction to select the operator and the forms of regulation on the behavior of the private operator, among other issues.

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Appendix A: Derivation of (20)

For the specified functions (18) and (19), the equation to determine the contribution from country i in the case of joint provision (case YY), (6), is written as follows

$$\alpha \exp[-\alpha f] k^{\alpha\beta-2} \{f k_j (A_1 + A_2) + \beta k A_1 + \alpha\beta f k_i (A_1 + A_2)\} = p^k, \qquad j \neq i \tag{A.1}$$

The second order condition is

$$1 - \alpha\beta > 0$$

Aggregating (A.1) for two countries and solving the resulting equation for k, we have

$$K^J(f) = \left(\frac{\exp[-\alpha f](A_1 + A_2)(f + \beta + \alpha\beta f)}{2p^k} \right)^{\frac{1}{1-\alpha\beta}}$$

[13] Verhoef (2012) provides useful insights regarding this issue.

The operator's response under break-even pricing, $F^b(k)$, is derived from $f(x_1+x_2) - p^k k = 0$. Then we have the solution for the system of equations, $f^{YY} = F^b(k^{YY})$ and $k^{YY} = K^J(f^{YY})$, as follows,

$$
\begin{aligned}
f^{YY} &= \frac{\beta}{1-\alpha\beta} \\
k^{YY} &= \left(\frac{\exp[-\frac{\alpha\beta}{1-\alpha\beta}](A_1+A_2)\beta}{p^k(1-\alpha\beta)} \right)^{\frac{1}{1-\alpha\beta}}
\end{aligned}
$$

The formula to calculate national welfare (1) becomes $\frac{x_i}{\alpha} + \frac{k_i}{k}\Pi$. Using the above solution, we have the following:

$$
W_i^{YY} = \frac{A_1}{\alpha} \left(\frac{(A_1+A_2)\beta}{p^k(1-\alpha\beta)} \right)^{\frac{\alpha\beta}{1-\alpha\beta}} \exp\left[-\frac{\alpha\beta}{(1-\alpha\beta)^2} \right]
$$

In single provision, the user charge and the capacity of the infrastructure are determined by (16) and (17). In case NY where country 2 provides the infrastructure, the solution is

$$
\begin{aligned}
f^{NY} &= \frac{A_1}{\alpha(A_1+A_2)} \\
k^{NY} &= \left(\frac{(A_1+A_2)\beta}{p^k} \right)^{\frac{1}{1-\alpha\beta}} \exp\left[-\frac{A_1}{(A_1+A_2)(1-\alpha\beta)} \right] \\
W_1^{NY} &= \frac{A_1}{\alpha} \left(\frac{(A_1+A_2)\beta}{p^k} \right)^{\frac{\alpha\beta}{1-\alpha\beta}} \exp\left[-\frac{A_1}{(A_1+A_2)(1-\alpha\beta)} \right]
\end{aligned}
$$

The expressions for case YN are obtained likewise.

Substituting the above results to the conditions for joint provision to be Nash equilibrium, $W_1^{YY} > W_1^{NY}$ and $W_2^{YY} > W_2^{YN}$, we have

$$
\begin{aligned}
\frac{\alpha\beta}{1-\alpha\beta} + \alpha\beta\ln(1-\alpha\beta) &< \frac{A_1}{(A_1+A_2)} \\
\frac{\alpha\beta}{1-\alpha\beta} + \alpha\beta\ln(1-\alpha\beta) &< \frac{A_2}{(A_1+A_2)}
\end{aligned}
$$

It is seen that the inequality for the smaller country is critical. Thus the condition is reduced to

$$
\frac{\alpha\beta}{1-\alpha\beta} + \alpha\beta\ln(1-\alpha\beta) < s
$$

where $s \equiv \min\{\frac{A_1}{A_1+A_2}, \frac{A_2}{A_1+A_2}\}$, i.e., the share of demand from the smaller country. Thus (20) is the condition for Nash equilibrium.

Appendix B: Proof of Proposition 5

The conditions for joint provision to be Nash equilibrium are $W_1^{YY} > W_1^{NY}$ and $W_2^{YY} > W_2^{YN}$.

We examine $W_1^{YY} > W_1^{NY}$ first. Let us simplify the notation as $x \equiv x_1 + x_2$, $x_f \equiv x_{1f} + x_{2f}$, $x_k \equiv x_{1k} + x_{2k}$. The national welfare of country 1 in two cases are

$$\begin{aligned} W_1^{YY} &= \int_{f^{YY}+c(\frac{x}{k^{YY}})}^{\infty} D_1(p)\,dp \\ W_1^{NY} &= \int_{f^{NY}+c(\frac{x}{k^{NY}})}^{\infty} D_1(p)\,dp \end{aligned}$$

Note that the profit from the infrastructure project disappears in case YY, since break-even pricing is adopted. Therefore, $W_1^{YY} > W_1^{NY}$ is equivalent to $f^{YY} + c(\frac{x}{k^{YY}}) < f^{NY} + c(\frac{x}{k^{NY}})$. As shown in the Section 3, under joint provision with break-even pricing, the infrastructure charge is equal to the congestion externality, i.e., $f^{YY} = x\frac{c'}{k}$. On the other hand, the infrastructure charge under single provision (case NY) is $f^{NY} = x\frac{c'}{k} - \frac{x_1}{x_f}$ from (24). Thus for the given k, $f^{YY} < f^{NY}$.

The investment rule in both cases is (12). Totally differentiating (12) yields the following.

$$\left[c'\left(-\frac{2x^2}{k^3} + \frac{2x \cdot x_k}{k^2}\right) + c''\left(\frac{x^2}{k^2}\right)\left(-\frac{x}{k^2} + \frac{x_k}{k}\right)\right] dk + \left[c'\left(\frac{2x \cdot x_f}{k^2}\right) + c''\left(\frac{x^2}{k^2}\right)\left(\frac{x_f}{k}\right)\right] df = 0$$

The first bracket is negative from the second-order condition for optimality. And the second bracket is negative since $x_f < 0$. Thus $\frac{dk}{df} < 0$ should hold on the locus of (12). Synthesizing the above results, we have $f^{YY} < f^{NY}$ and $k^{YY} > k^{NY}$. Thus $f^{YY} + c(\frac{x}{k^{YY}}) < f^{NY} + c(\frac{x}{k^{NY}})$. In words, in case NY, users in country 1 incur the higher full price than in case YY since the user charge is higher and the capacity is smaller. So country 1 is better off by choosing the joint provision. $W_2^{YY} > W_2^{YN}$ is shown in a similar manner.

Appendix C: Proof of Proposition 6

Under single provision, the government providing the infrastructure chooses the user charge and capacity, subject to the break-even condition. The problem to be solved is

$$\max_{f,k} \int_{f+c(\frac{x_1+x_2}{k})}^{\infty} D_1(p)\,dp + f(x_1+x_2) - p^k k$$

$$\text{s.t.} \quad f(x_1+x_2) - p^k k = 0$$

The optimality conditions with respect to f and k are respectively

$$\begin{aligned} -x_1\left(1 + c'\frac{(x_{1f}+x_{2f})}{k}\right) + (1+\lambda)\left[(x_1+x_2) + f(x_{1f}+x_{2f})\right] &= 0 \\ -x_1 c'\left(-\frac{(x_1+x_2)}{k^2} + \frac{(x_{1k}+x_{2k})}{k}\right) + (1+\lambda)\left[f(x_{1k}+x_{2k}) - p^k\right] &= 0 \end{aligned}$$

where λ is the Lagrange multiplier of the break-even constraint. Combining the two optimality conditions to eliminate the Lagrange multiplier yields the following

$$\left(1 - \frac{(x_{1k} + x_{2k})}{(x_1 + x_2)}k\right)\left(c' \frac{(x_1 + x_2)^2}{k^2} - p^k\right) = 0$$

The above equality holds when the condition for optimal capacity, (12) holds. And this optimal capacity together with break-even condition leads to (11), the optimal pricing rule.

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