Joint Provision of International Transport Infrastructure*

Se-il Mun
Graduate School of Economics, Kyoto University,
Yoshida Hon-machi, Sakyo-ku, Kyoto 606-8501, Japan
mun@econ.kyoto-u.ac.jp
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Abstract

We consider the following scheme for the development of cross-border transport infrastructure: two countries jointly establish an operator of the infrastructure that are responsible of collecting the user charge, maintenance, etc.; the costs for infrastructure investment are covered by financial contributions from two countries; and the revenue from infrastructure charge is distributed according to the share of contributions. The governments of two countries choose the amount of contribution so as to maximize the national welfare. Assuming that the infrastructure use is non-rival, we show that financing infrastructure by the revenue from user charges is better than financing by tax revenue. We extend the analysis by incorporating congestion in infrastructure use. It is shown that independent decisions on contributions by two governments attains the first-best optimum when the operator sets the user charge so that the toll revenue just covers the cost for the investment. We further examine the condition that joint provision is realized in Nash equilibrium.

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

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1 Introduction

There are many places in the world where bridges or tunnels cross the border between two countries. These facilities are indivisible and thereby decisions to construct them should be jointly made by the governments on both sides of the border. This paper deals with the problem concerning the joint provision of cross-border transport infrastructure. We consider the following scheme for the infrastructure development: two countries jointly establish an operator of the infrastructure that are responsible of collecting the user charge, maintenance, etc.; the costs for infrastructure investment are covered by financial contributions from two countries, and the revenue from infrastructure charge is distributed according to the share of contributions. Similar cases can be found in the real world. For example, United States and Canada jointly established the Niagara Falls Bridge Commission to finance, construct and operate the Rainbow Bridge.

We develop a simple two-country model in which the transportation cost between countries depends on the capacity and user charge (e.g., road toll) of infrastructure. The governments of two countries choose the amount of contribution so as to maximize the national welfare. The sum of contributions is spent for investment, and thereby determines the capacity of the infrastructure. We consider two cases: the infrastructure use is non-rival; and congestible. In the non-rival case, financing the cost for infrastructure investment by revenue from user charges encourages the contributions from two governments, and thereby attains the higher welfare than financing by tax revenue. We next compare the following two situations: (i) optimal capacity choice for the two countries as a whole; (ii) equilibrium capacity choice by independent decisions by two governments. It turns out that capacity in equilibrium (case (ii)) is smaller than the optimum (case (i)) if user charge is low, and vice versa. In the case of congestible infrastructure, it is shown that independent decisions on contributions by two governments attains the first-best optimum when the operator sets the user charge so that the toll revenue just covers the cost for the investment. This is a variant of the well-known self-financing theorem by Mohring-Harwitz (1962). Unlike the original setting where a single government chooses the capacity based on benefit-cost criterion, we obtained the result in the situation that the capacity is determined by contributions by multiple governments.

There is a large body of literature on pricing and capacity choice of transport infrastructure in the system of multiple governments (see e.g. 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 economic welfare of two countries. Recently, Brueckner (2014) investigates pricing and capacity choice of a congestible bridge between jurisdictions in a monocentric metropolitan area. He assumes that the capacity of the bridge is determined solely by the government of the jurisdiction on the outer side. This assumption is reasonable in the context of a monocentric metropolitan area since bridge is used only by the residents in outer locations. In this setting, Brueckner shows that decentralized capacity choice with budget-balancing user fee attains the efficient allocation. This paper can be regarded as an extension of Brueckner’s
analysis to the case that there are users on both side of the bridge and multiple governments share the cost for capacity investment. Verhoef (2012) also obtains the self-financing result in the setting that users of the infrastructure have market powers. His result is strong in that self-financing holds in broader situations where capacity cost does not exhibit constant returns. Note that the subsidy from the government is required to attain the efficiency and self-financing in Verhoef’s model. In contrast, the scheme proposed in this paper attains the efficiency through voluntary contributions from two governments imposing cost recovery to the operator.

This paper is also related to the literature on voluntary provision of public good (Bergstrom, Blume and Varian, 1986). In the absence of congestion, the service provided by the infrastructure we consider is excludable but non-rival. In this case, optimal infrastructure charge should be zero, and thereby the formula to determine the capacity of the infrastructure is reduced to that corresponding to the voluntary provision of public good, leading to under provision. In other words, optimal pricing (or financing by taxation) suffers from too small capacity. There have been several proposals to induce the efficient voluntary provision of public good (e.g., Falkinger (1996)). We show that imposing user charge gives an incentive to increase the amount of voluntary contribution and larger welfare in the case of non-rivalry (i.e., without congestion). Furthermore, if the infrastructure is congestible, pricing attain the optimal level of capacity by voluntary contributions.

This paper is organized as follows. In Section 2, we examine the outcome of the proposed scheme assuming that infrastructure use is non-rival (i.e., no congestion). Section 3 extends the analysis to the case allowing congestion. Section 4 considers the possibility of single provision where one of two countries builds and operates the infrastructure. We investigate the condition that joint provision is realized in Nash equilibrium. Section 5 concludes the paper.

2 Infrastructure Charge and Capacity Investment with Non-rivalry

2.1 Setting

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

$^1$Measuring by the number of trips is naturally applicable to passenger transportation, such as Tourism, shopping. In the case of freight transportation, the quantity (e.g., weight of goods) is the unit of measurement, but hereafter we use trips as the unit of measurement.
infrastructure increases capacity, thereby saves the user cost and that the investment is decreasing return to scale:

\[ \frac{dt}{dk} < 0, \quad \frac{d^2t}{dk^2} > 0. \]

We also assume that the transport infrastructure is produced with constant returns to scale technology.

There is an operator of the infrastructure jointly established by two countries, which constructs the facility and collects the user charge. The costs for infrastructure investment are covered by financial contributions from two countries. We assume that the revenue from the infrastructure charge is distributed according to the share of contributions. 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

\[
W_i = \int_{f+t(k)}^{\infty} D_i(p) \, dp + \frac{k_i}{k} f(x_1 + x_2) - p^k k_i
\]

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 unit cost of infrastructure investment. It is convenient to rewrite the national welfare as

\[
W_i = \int_{f+t(k)}^{\infty} D_i(p) \, dp + \frac{k_i}{k} \Pi
\]

where \( \Pi \) is the profit of the infrastructure project, \( \Pi = f(x_1 + x_2) - p^k k \). The second term on the RHS, \( \frac{k_i}{k} \Pi \) can be interpreted as the dividend of profit.

### 2.2 Social Optimum

In this paper, the social optimum is characterized as the solution to a global welfare maximization problem. The global welfare is defined as the sum of the two countries’ national welfares, as follows

\[
W(f, k) = \int_{f+t(k)}^{\infty} D_1(p) \, dp + \int_{f+t(k)}^{\infty} D_2(p) \, dp + \Pi
\]

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

\[
-(x_1 + x_2) t' + f(x_{1k} + x_{2k}) = p^k
\]

where \( x_{ik} = \frac{\partial D_i}{\partial k} \). 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

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

where \( x_{if} = \frac{\partial D_i}{\partial f} \). The above inequality implies that infrastructure use should be free of charge. This is natural since marginal cost of usage is zero when the infrastructure is non-rival. Under this optimal pricing, (3) is reduced to

\[
-(x_1 + x_2) t' = p^k
\]
The optimality condition for the government of country \(i\) is
\[ -x_i t' + \frac{k_j}{k^2} f(x_1 + x_2) + \frac{k}{k} f(x_{1k} + x_{2k}) = p^k, \quad j \neq i \quad (5) \]

The first term on the LHS of (5) 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. For the special case, \(f = 0\), (5) is reduced to
\[ -x_i t' = p^k \quad (6) \]

Comparing (6) with (4), we see that the national government ignores the benefit of users in 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 (Bergstrom, Blume and Varian, 1986).

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 amount of contributions and the level of economic welfare. Summing up the investment rule (5) for two countries yields
\[ -(x_1 + x_2)t' + \frac{1}{k} f(x_1 + x_2) + f(x_{1k} + x_{2k}) = 2p^k \quad (7) \]

Let the solution of (7) be \(K^e(f)\). Totally differentiating (7) with respect to \(k\) and \(f\), evaluated at \(f = 0\), we have
\[ \left. \frac{dk}{df} \right|_{f=0} = \frac{dK^e(0)}{df} = \frac{1}{k} (x_1 + x_2) \quad (8) \]

The denominator of the RHS of (8) is positive from the second-order condition for (5). Thus we have \(\frac{dK^e(0)}{df} > 0\): \(k\) is increased by increasing \(f\) from zero. Differentiating the global welfare function with respect to \(f\) while \(k\) is determined by the national governments: \(k = K^e(f)\), we have
\[ \frac{dW(0, K^e(0))}{df} = p^k \frac{dK^e(0)}{df} > 0 \]

The above analysis is summarized as follows.
**Proposition 1** Increasing the infrastructure charge from zero improves the global welfare through expanding the capacity of infrastructure.

If the infrastructure charge is zero, the national government should use the tax revenue to finance the contribution to the infrastructure project. Also note that optimal infrastructure charge is zero, so the shift from taxes to user charging means deviation from optimal pricing. The above proposition implies that shifting the revenue source from taxes to user charging, i.e., deviation from optimal pricing, is welfare-improving.

We address the next question: what the efficient infrastructure charge looks like under the joint provision based on the voluntary contributions by the national governments.

**Proposition 2** Let \( \hat{f} \) be the infrastructure charge at which the revenue equal to the cost for capacity investment, i.e., \( \Pi = \hat{f} (x_1 + x_2) - p^k K^e(\hat{f}) = 0 \), where \( x_i = D_i \left( \hat{f} + t \left( K^e(\hat{f}) \right) \right) \), \( i = 1, 2 \).

(i) Capacity determined by contributions by two national governments is equal to the optimal capacity at \( \hat{f} \), i.e., \( K^e(\hat{f}) = K^O(\hat{f}) \), and thereby \( W(\hat{f}, K^e(\hat{f})) = W(\hat{f}, K^O(\hat{f})) \);

(ii) \( K^e(f) < K^O(f) \), if \( f < \hat{f} \) and vice versa;

(iii) There exists an infrastructure charge \( f^* \) maximizing the global welfare while the capacity is determined by the contribution from the national governments, i.e., \( f^* = \arg \max f W(f, K^e(f)) \);

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

(iii) and (iv) suggest that, at \( f^* \), the revenue from the infrastructure charge is not sufficient to cover the cost for investment. Thus (i) implies that the break-even pricing is most efficient among the schemes in which capacity investment is financed solely by the revenue from the infrastructure. (ii) states that over investment of capacity may arise. This result never arises in Mun and Nakagawa (2010), which examines a number of alternative pricing schemes for the cross-border transport infrastructure consisting of two links, but they all result in under investment. Figure 1 is drawn based on the Proposition 2.

### 2.4 Equilibrium with break-even pricing

Equilibrium is described as a game by three players, i.e., two governments and the operator. 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 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 two governments agree to adopt break-even pricing. We focus on this case because this pricing rule is commonly adopted in practice of
regulation. It is also a good reason that break-even pricing leads to efficient outcome, as shown in the Proposition 2\(^2\).

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

\[
f(x_1 + x_2) - p^k k = 0
\]

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

\[
\begin{align*}
f^b &= F^b(k^b) \\
k^b &= K^e(f^b)
\end{align*}
\]

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

### 3 Congestible Infrastructure

We extend the analysis to the case that the infrastructure is congestible. Congestion is described by the user cost function \(c(x_1 + x_2)\), where we assume \(c' > 0\) \(^3\). Accordingly the national welfare is written as \(W_i = \int_{f+c(x_1+x_2)}^{\infty} D_i(p) \, dp + \frac{k_i}{k} f(x_1 + x_2) - p^k k_i\), and the global welfare is the sum of the two countries' national welfares, \(W(f, k) = W_1 + W_2\).

The conditions for the global welfare maximization (first-best) are

\[
\begin{align*}
f &= (x_1 + x_2) \frac{c'}{k} \quad (9) \\
\left(\frac{x_1 + x_2}{k}\right)^2 c' &= p^k \quad (10)
\end{align*}
\]

These two conditions are standard formulas for congestion problem: \((9)\) states that the infrastructure charge is equal to the congestion externality; \((10)\) states that the social marginal benefit (reduction of congestion) from capacity expansion should be equalized to marginal cost of investment.

\(^2\)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 could be difficult in practice.

\(^3\)This specification implies that the user cost function is homogeneity 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 the national welfare. The optimality condition for the government of country \( i \) is

\[
x_i \left( \frac{(x_{1k} + x_{2k})}{k} - \frac{(x_1 + x_2)}{k^2} \right) c' + \frac{k_i}{k^2} f(x_1 + x_2) + \frac{k_i}{k} f(x_{1k} + x_{2k}) = p^k, \quad j \neq i \tag{11}
\]

Summing up the investment rule (11) for two countries and rearranging, we have

\[
\left( \frac{x_1 + x_2}{k} \right)^2 c' + \left[ f - \left( \frac{x_1 + x_2}{k} \right) c' \right] (x_{1k} + x_{2k}) + \frac{f}{k} (x_1 + x_2) = 2p^k \tag{12}
\]

As in the case of non-rivalry, we examine the consequence of break-even pricing. Let us substitute the zero-profit condition, \( f(x_1 + x_2) - p^k k = 0 \) into the above equation, we have the following

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

The above equality holds when the condition for optimal capacity, (10) holds. And zero profit together with optimal capacity leads to (9), the optimal pricing rule. Thus we have

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

The above proposition is a variant of self-financing theorem by Mohring-Harwits (1962). It is obvious that the first-best is attained under the zero profit and optimal capacity rule. New finding here is that the national governments respond to break-even pricing by choosing the amount of contribution that leads to the optimal capacity.

### 4 Joint Provision vs Single Provision

We have not discussed whether the joint provision is actually realized. There are alternative ways to provide international infrastructure. One common practice is that one of two countries builds and operates the transport infrastructure crossing the border. We call this case as "single provision" hereafter. Brueckner (2013) considers exactly this situation: the bridge between jurisdictions of mid city and suburb is controlled by the government of suburb. Brueckner shows that, when the bridge capacity cost is financed by budget-balancing tolls, decentralized capacity choices by local government generate the social optimum.

This section examines whether joint provision is realized by the decisions of two governments seeking to maximize the national welfare. Each government chooses whether to join the infrastructure project by providing the contribution or not. If one government makes a positive amount of contribution while another does not, the outcome is the single provision. There are four possible combinations of choices by two national governments: case YY
(joint provision) in which both countries provide positive amount of contribution; case \(NN\) in which no country provides contribution; case \(YN\) (single provision by country 1) in which country 1 provides a contribution while country 2 does not; and vice versa for the case \(NY\). Let us denote the national welfare of country \(i\) for the four cases by \(W_{YY}^i, W_{NN}^i, W_{YN}^i, W_{NY}^i\), respectively.

The conditions under which each of the four cases, \(YY, YN, NY, NN\) is realized in Nash equilibrium are written as follows

- **Case YY**: \(W_{YY}^1 > W_{NY}^1\) and \(W_{YY}^2 > W_{YN}^2\)
- **Case YN**: \(W_{YN}^1 > W_{NN}^1\) and \(W_{YN}^2 > W_{YN}^2\)
- **Case NY**: \(W_{NY}^1 > W_{YY}^1\) and \(W_{NY}^2 > W_{NN}^2\)
- **Case NN**: \(W_{NN}^1 > W_{YN}^1\) and \(W_{NN}^2 > W_{NY}^2\)

### 4.1 Non-rival case

When the infrastructure use is non-rival, \(W_{YY}^i\) are obtained by substituting to (1) the capacity obtained in Section 2. In case \(NN\), \(W_{NN}^i\) depend on the existing transport route without the infrastructure project, so they are given exogenously as parameters. In cases \(YN\) or \(NY\), the infrastructure charge and capacity is determined by the decision of the government implementing 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\(^4\)

\[
\begin{align*}
\max_{f,k} \ & \int_{f+t(k)}^{\infty} D_1 (p) \, dp + f(x_1 + x_2) - p^k k \\
\end{align*}
\]  

(13)

The optimality condition with respect to the capacity of infrastructure is

\[
\begin{align*}
x_2 + f(x_{1f} + x_{2f}) &= 0 \\
-x_1 t' + f(x_{1k} + x_{2k}) &= p^k 
\end{align*}
\]

Let us denote the solution of the above equation by \((f^{YN}, k^{YN})\). Substituting \((f^{YN}, k^{YN})\) to the objective function in (13), we have \(W_{YN}^1\). And we obtain \(W_{YN}^2 = \int_{f+t(k^{YN})}^{\infty} D_2 (p) \, dp\). In the case \(NY\) (single provision by country 2), \(W_{YN}^1\) and \(W_{NY}^2\) are obtained likewise.

We investigate the Nash equilibrium based on the specific forms of the demand function and user cost function as

\[
\begin{align*}
x_i &= A_i \exp \left[ -\alpha (f + t(k)) \right] \\
t(k) &= -\beta \ln k, 
\end{align*}
\]  

\(4\)In the case of single provision, the government can control the operation of the infrastructure. So we assume that the government chooses the user charge and the capacity of the infrastructure. On the other hand, in the case of joint provision, a single government cannot choose the level of infrastructure charge by oneself. There are various alternative ways to determine the pricing policy, so this section keeps flexibility in pricing under joint provision.
where $A_i, \alpha, \beta$ are parameters.

We first look at the special case that two countries are symmetric, i.e., $A_1 = A_2$, and break-even pricing is adopted in joint provision.

**Proposition 4** Suppose that (i) two countries are symmetric; (ii) in the case of joint provision, two governments agree on break-even pricing; (iii) in the case of single provision, the government providing the infrastructure chooses the user charge and the capacity of the infrastructure so as to maximize the national welfare. Then, under the specification (14) and (15), joint provision is Nash equilibrium if the following holds

$$\left(1 - \alpha \beta \right)^{\frac{\alpha \beta}{1 - \alpha \beta}} e^{\frac{3 \alpha \beta - 1}{2(1 - \alpha \beta)^2}} < 1 \tag{16}$$

The inequality (16) is approximately equivalent to $\alpha \beta < 0.4227$. Calibrated values in Mun and Nakagawa (2010) satisfy the above inequality. Numerical results will be presented for more general cases that two countries are asymmetric, or other pricing policies are adopted in joint provision.

### 4.2 Congestible infrastructure

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

$$\max_{f,k} \int_{f+c(\frac{x_1+x_2}{k})}^{\infty} D_1(p) \, dp + f(x_1 + x_2) - pk \tag{17}$$

It turns out that the optimality conditions are equivalent to the first-best rule, as in (9) and (10). The self-financing also follows. This result is essentially the same as in Brueckner (2014) in the setting of a monocentric city with multiple jurisdictions.

Considering the Proposition 3, the above results implies the following.

**Proposition 5** When the infrastructure is congestible, joint provision with break-even pricing yields the same outcome as in single provision. Both cases attains the first-best allocation.

### 5 Conclusion

This paper examines the scheme for joint provision of international transport infrastructure, in which two countries jointly establish an operator of the infrastructure that are responsible of collecting the user charge, maintenance, etc.; the costs for infrastructure investment are covered by financial contributions from two countries; and the revenue from infrastructure charge is distributed according to the share of contributions. Assuming that the infrastructure use is non-rival, we show that financing infrastructure by the revenue from user charges is better than financing by tax revenue. We extend the analysis by incorporating congestion
in infrastructure use. It is shown that independent decisions on contributions by two governments attains the first-best optimum when the operator sets the user charge so that the toll revenue just covers the cost for the investment. We further investigate the governments’ choice between joint provision and single provision. For reasonable values of parameters, joint provision is realized in Nash equilibrium.

References


Figure 1  Infrastructure charge and global welfare

Figure 2  Response functions of governments and operator