Pricing and Investment of Cross-border Transport Infrastructure*

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March 24, 2010

Abstract

We develop a simple two-country model of international trade in which the transportation cost between countries is endogenously determined by pricing and invetment decisions of cross-border transport infrastructure. We evaluate alternative regimes of pricing and investment, i.e., free access (e.g., public road), pricing by two governments, and private operation. We also examine the effect of integarating operation. It is shown that investment rule in free-access regime is inefficient. On the other hand, the investment rule is efficient if infrastructure charge is levied either by the government or by the private operators. We obtain the welfare ranking of alternative regimes under specific functional form, show how the welfare results depend on pricing policies.

JEL Classification: H54, R42, R48

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*Earlier versions of this paper were presented at the Applied Regional Science Conference in Tottori University, International Conference on Funding Transport Infrastructure in Leuven, Public Economic Theory Conference in Seoul, and seminars at Berlin University of Technology, Hokkaido University, Kyoto University. We thank Achim Czerny, Robin Lindsey, Yasuhiro Sato, and the participants of conferences and seminars for valuable comments. We are most grateful to the editor and two anonymous referees for their suggestions, which were very helpful for improving the paper. This research was partially supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Grant-in-Aid for Scientic Research (No. 13851002, 17330052) and for 21st Century COE Program "Interfaces for Advanced Economic Analysis".

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1 Introduction

Cross-border transport infrastructure plays the important role of supporting trade with neighboring countries, which accounts for a significant share of total trade (Bougheas et al., 1999). The recent wave of regional integration is leading to greater needs for investment in the transport infrastructure serving the region, since a well-developed transport infrastructure is essential for successful regional integration (Fujimura, 2004). Examples of initiatives to facilitate regional integration include the Trans-European Transport Network and the Asian Land Transport Infrastructure Development (ALTID) project. At a smaller geographical scale, connection of transport links between North and South Korea is also considered as the project looking toward economic integration in the future.

Mun and Nakagawa (2008) discuss the problem of resource allocation concerning the provision of cross-border transport infrastructure connecting two neighboring countries. An investment in the infrastructure in one country decreases the transportation costs of both import and export goods, which benefits not only the home country but also the neighboring country. In this case, independent decision making leads to under-investment in infrastructure, since the investment decision of each country does not take into account the benefit to the other country. Mun and Nakagawa look at the role of foreign aid to improve the efficiency, and show that the aid may make not only the recipient but also the donor better off. The limitation of this paper is that it focuses only on investment decisions assuming that infrastructure use is free of charge.

Although free access to transport infrastructure (such as public roads) is widely applied, there exist types of transportation modes that impose user charges for infrastructure (railways, ports, airports). At the same time, there has been an increasing tendency of tolling on public roads, for several reasons such as congestion management, obtaining funds for road investments, etc. (Glaister and Graham, 2004; Lindsey, 2007). For example, a truck tolling system was recently introduced in Germany in 2005.

The present paper extends our earlier work by including pricing policies. We develop a simple two-country model of international trade where the transportation cost between two countries depends on the capacity and user charge (e.g., road toll, rail fare) of infrastructure. Once we introduce pricing desision, there are wide variety of alternative mechanisms for provision of cross-border transport infrastructure. The government of each country chooses the capacity and user charge of infrastructure within its territory so as to maximize the welfare of its citizens. The government faces the following trade-off: investment in capacity would lower the transport cost and thereby increase the gains from trade, but increase the fiscal burden; raising the user charge would increase the revenue but decrease the gains from trade.

The earlier result of under-investment in the case of free access may be modified if we incorporate pricing: the decision rule of choosing the capacity becomes efficient. Investment induces increase in the volume of traded goods, which raises not only the gains from trade but also the revenue from the user charge. The latter effect plays the role of giving the governments incentives for greater investment. However, the pricing rule may be inefficient in that each government levies an excessively high price for infrastructure use. Thus, despite the efficient investment rule, the resulting capacity does not attain the optimal level.

We examine alternative regimes with different pricing policies, and evaluate them in terms of the service levels of infrastructure, and economic welfare of the two-country economy as a whole. Considering the fact that a growing number of transport infrastructures have been constructed and operated privately or by various forms of public-private partnerships, we include the regimes with private involvement, such as profit maximization by private operators, control of investment decisions of private firms by design of bidding for franchise[1]. Furthermore, we consider the case of integrated provision in which pricing and investment decision about the infrastructure in two countries is made by a single authority or firm. This may provide useful insights about how the organization of infrastructure provider affect the outcomes.

Recently, economists have become interested in pricing and investment decisions of the transport infrastructure by multiple governments (Bond, 2006; De Borger, Dunkerley, Proost, 2007; Fukuyama, 2006; Levinson, 2000). Bond (2006) investigates the consequences of independent decision making by governments concerning infrastructure investment, and examined the effects of trade liberalization on the incentive to invest. Fukuyama (2005) also discusses a similar problem by means of numerical simulations. These papers focus only on investment decisions. Levinson (2000) looks at strategic interactions between governments on a serial network. Levinson keeps the capacity fixed, and focuses on the choice of revenue raising mechanisms (tax versus toll). He finds that larger regions are more likely to tax than smaller regions. Comprehensive review of the

[1] Roads are also operated privately (see Roth (1996)). De Palma and Lindsey (2000) analyze road pricing in the case that roads are operated privately. Yang and Meng (2000) investigate the effect of a new road project by BOT in the setting of network with route choice. Verhoef (2007) evaluates alternative highway franchise regimes for different network structure, such as parallel and serial. The primary interests of these works are the role of pricing to control traffic congestion, and they do not deal with the situation that multiple governments are involved in pricing and investment of the transport infrastructure.

literature is presented by Ubbels and Verhoef (2008).

Our paper is closely related to the recent work by De Borger, Dunkerley and Proost (2007) that deals with pricing and investment in the setting of two transport links in series, each of which is controlled by a different government. There are two types of trips in De Borger et al: local trips and transit. Transit trips are neither originated from nor destined to one of two regions, while trips between neighboring regions are assumed to be zero. In contrast, our paper considers only trips between neighboring regions. In this sense, our paper could be a complement to the work by De Borger et al. The model by De Borger et al is quite suitable for small countries in European continent (e.g., Belgium) where transit traffic have significant share. In many other contexts such as trade within Southeast Asia, North America, and Latin America, cross-border traffic is quantitatively more important than transit traffic[2]. Unlike De Borger et al, our model ignores congestion. This is a limitation, especially for application to the cases such as some transport routes in Europe or in North America, but our model would be widely applicable to other cases. In many transport routes, especially those between developing countries, low quality of infrastructure (or missing links) is a significant impediment for trade (see, e.g., Limao and Venables (2001)). Our model assumes that infrastructure investment makes better quality of pavement, wider road, less steep gradient, shortcut by tunnel, so on. These changes increase speed, or saves fuel consumption, thereby reduces resource cost for transportation. Many international programs such as ALTID in Asia aim at improving the quality of infrastructures as well as mitigating congestion. Assuming the absence

[2]As suggested by the law of gravity in international trade, trade volume significantly decline with distance. Thus it is natural to suppose that traffic between neighboring countries must be more significant than transit.

of congestion enables us to obtain a number of analytical results, which are difficult to obtain using the model with congestion. Our paper completely determines the signs of responses to pricing and investment decisions of other country. More importantly, we obtain the ranking of alternative regimes analytically, unlike numerical approach by De Borger et al[3]. We include a larger set of alternative regimes such as profit maximization, user cost minimization, and the investment with regulation on tolls. We make various comparisons to illuminate the effects of alternative financing instruments and choice of organizations, i.e., integrate or separate provision.

The rest of the paper is organized as follows. Section 2 presents the two-country model of international trade with transport infrastructure. Section 3 describes the decision making about pricing and investment of cross-border transport infrastructure under the alternative regimes: free-access, government pricing, break even pricing, profit maximization, and user cost minimization. Section 4 discusses the case of integrated provision that a single authority or firm decides on user charge and capacity of the transport infrastructure in two countries. These alternative regimes are evaluated in Section 5. Section 6 concludes the paper.

[3]There are 3 regimes considered both in our paper and De Borger et al (2007). It turns out that, for these 3 regimes, our analytical results are qualitatively the same as numerical results obtained by the model with congestion in De Borger et al. This suggests that ignoring congestion does not significantly affect the results.

2 The Model

2.1 The setting

Consider an economy with two countries, indexed by i ($i = 1, 2$). There are l_i households in Country i. All households in the same country have identical preferences and labor skills. The two countries may be different in population size, income, and preference.

This economy produces three goods, which are indexed by 1, 2, and z. The productions of Goods 1 and 2 are completely specialized, i.e., Country i produces Good i. Unlike Goods 1 and 2, Good z is produced in both countries, which is set as the numeraire. Labor is the only input for the production of the three goods. Each household in the economy consumes all three goods. Thus, Country i exports Good i and imports Good j $(j \neq i)$. Goods and factor markets are perfectly competitive.

When Goods 1 and 2 are traded, transportation costs are incurred, whereas Good z is transported without cost. The transportation costs of Goods 1 and 2 depend on the capacity and user charge (e.g., road toll, rail fare) of infrastructure. We assume that the transport infrastructure is produced from Good z with constant returns to scale technology.

2.2 Consumption

The preferences of a household in Country i are represented by the following utility function

$$u_i\left(x_i^i, x_i^j, z_i\right),$$

where x_i^i, x_i^j, and z_i are respectively the consumption of Goods i, j, and z. We assume that u_i is strictly increasing, quasi-concave, and twice continuously differentiable. Each household is endowed with one unit of labor and levied a poll tax. The household's disposable income, y_i, is defined as

$$y_i = w_i - \tau_i,$$

where w_i and τ_i are respectively the wage rate and poll tax in Country i. The budget constraint is given by

$$y_i = z_i + p_i^i x_i^i + p_i^j x_i^j,$$

where p_i^i and p_i^j represent the prices of Goods i and j in Country i. We suppose that Goods 1 and 2 are non-inferior goods.

Solving the utility maximization problem, we get the household's demand functions as

$$x_i^i\left(p_i^i, p_i^j, y_i\right), x_i^j\left(p_i^i, p_i^j, y_i\right), z_i\left(p_i^i, p_i^j, y_i\right),$$

and the indirect utility function as

$$v_i\left(p_i^i, p_i^j, y_i\right).$$

2.3 Production

Each of the three goods is produced with a linear production technology. The production of Good i in Country i requires a_i^i units of labor. It follows that

$$p_i^i = w_i a_i^i, \text{ for } i = 1, 2.$$

Since Good z is transported freely between countries, the following relation should hold

$$1 = w_i a_i^z, \text{ for } i = 1, 2,$$

where a_i^z is the amount of labor required to produce one unit of Good z in Country i. Above setting of production model implies that factor price w_i is determined by exogenously given coefficient, a_i^z , and thereby the terms of trade are constant. In this sense, our model is essentially the partial equilibrium model.

2.4 Transportation and trade

We suppose that there is a single location in each country at which all production and consumption take place. We call this location as a market. Traded goods are transported between two markets. Labor is only input for the production of the transportation service. The transport cost from the market in Country i to the border, c_i, is defined as

$$c_i = f_i + w_i t_i,$$

where f_i is the price of infrastructure use (user charge) within Country i, and t_i is the amount of labor required for transportation. We interpret t_i as the transport time from the market in Country i to the border of the two countries. t_i depends on the capacity of the transport infrastructure in Country i, namely,

$$t_i = t_i\left(k_i\right),$$

where k_i is the capacity of the transport infrastructure in Country i. We interpret the capacity of infrastructure in broad sense: larger capacity may imply milder curves and slopes, road surface or rail track with higher quality, etc. We assume that an investment in transport infrastructure increases capacity, thereby saves the labor (or time) required for transportation and that the investment is decreasing return to scale: $t_i' \equiv dt_i/dk_i < 0, t_i'' \equiv d^2t_i/dk_i^2 > 0$.

The transport cost between two countries is given by $c_1 + c_2$. We assume perfect competition among trading firms, which eliminates positive profits. The prices of the traded goods satisfy

$$p_i^j = p_j^j + c_1 + c_2, \text{ for } i, j = 1, 2, j \neq i. \tag{1}$$

3 Alternative Regimes for Pricing and Investment of Transport Infrastructure

We consider the following six regimes: (O) the first-best optimum, (F) free access regime, (G) government pricing regime, (B) break even pricing regime, (P) profit maximization regime, and (U) user cost minimization regime. Let us outline below the structures of these regimes and our plan of investigation.

Regime O, the first-best optimum, is defined as the allocation that maximizes the global welfare. This regime serves as the benchmark to evaluate the efficiency of alternative policies.

Regimes F, B, and G suppose that two governments separately decide on the policies so as to maximize the national welfare. In Regime F, the government chooses the capacity of infrastructure and collects a poll tax to finance the expenditure for this investment while the infrastructure is free access, i.e. user charge is fixed to zero. Regime B supposes that the government chooses the capacity while the infrastructure charge is set so that the revenue covers the expenditure for investment. In Regime G, the government in each country chooses the capacity and infrastructure charge without constraint. Both Regimes F and B are widely observed in the real world. For example, most public roads are free-access while fares of railways are regulated to be break-even. The comparison between Regimes F and B enable us to evaluate the relative merits between two methods for financing the infrastructure investment: lump-sum taxation and user charge. It is also possible to interpret the infrastructure charge as fuel tax that is proportional to the volume and distance of transportation. In this case, the comparison is between two types of taxations. In Regime G, there is no restriction for the government in choosing the level of infrastructure charge. It is interesting to see whether the decisions by the governments seeking to maximize the welfare of citizens leads to better outcome than the cases with restrictions such as Regimes F and B.

Regimes P and U are the cases of private involvement in the development of infrastructure. Private firm design, construct, then operate the infrastructure, is given the right to levy the infrastructure charge and finance the cost for construction and operation. We interpret that the design includes not only physical aspect such as the capacity but also the plan of operation such as the choice of the infrastructure charge. Regime P assumes pure private operation of infrastructure in that a private firm chooses user charge and capacity to maximize the profit[4]. Although it is natural to assume such behavior of the private firm, this is not compatible to the objective of the government that is to maximize the social welfare. Regime U is an alternative mechanism that induces private firms to design the infrastructure in a manner that is more compatible with the objective of the government. This regime is implemented by the auction in which the right to construct and operate the transport infrastructure is awarded to the firm proposing the plan that minimizes the user

[4] Regime P may be also implemented by an auction in which the right to construct and operate the transport infrastructure is awarded to the firm offering the highest bid.

cost[5]. Among many other alternative mechanisms, we choose the criterion of user cost minimization for the following reasons. First, this regime has an advantage in practical implementation that user cost is observable after the operation starts. So it is easier to monitor and verify whether the design of infrastructure meets the criterion of the auction. Second, earlier works (e.g., Verhoef (2007)) show that this regime yields relatively efficient outcome.

3.1 First-best optimum (Regime O)

In this paper, the first-best optimum is characterized as the solution to a global welfare maximization problem, which is called Regime O. The social planner chooses the user charge, the capacity of infrastructure and the poll tax, to maximize the global welfare. The problem to be solved is formulated as follows

$$\max_{f_1, f_2, k_1, k_2, \tau_1, \tau_2} W(v_1, v_2) \tag{2}$$

$$\text{subject to } p_1^k k_1 + p_2^k k_2 = l_1 \tau_1 + l_2 \tau_2 + (f_1 + f_2)\left(l_1 x_1^2 + l_2 x_2^1\right), \tag{3}$$

where $v_i = v_i\left(p_i^i, p_j^j + f_1 + f_2 + w_1 t_1 + w_2 t_2, w_i - \tau_i\right)$, $j \neq i$. $W(.)$ is strictly increasing and continuously differentiable in v_i and quasi-concave with respect to the policy variables, and p_i^k is the amount of Good z required to produce one unit of the transport infrastructure in Country i (or, unit cost of infrastructure). (3) is the budget constraint for the two-country economy as a whole.

[5]Verhoef (2007) examines a number of alternative types of auction including those examined in our paper. Note that trade volume must be maximized by user cost minimization. Thus User cost minimization regime in our paper is essentially equivalent to the patronage maximization in Verhoef (2007). A contribution of our paper in this regard is to present a comparison between outcomes under private involvement and government provision.

The first order conditions with respect to the capacity and the user charge are

$$-\left(l_1 x_1^2 + l_2 x_2^1\right) w_i t_i' = p_i^k \tag{4}$$

$$f_i = 0 \tag{5}$$

The LHS of (4) is the quantity of Goods 1 and 2 transported between the two countries, $(l_1 x_1^2 + l_2 x_2^1)$ multiplied by the marginal change in the transport cost by an investment in transport infrastructure in Country $i, (-w_i t_i')$. The LHS is the marginal benefit of the investment, while the RHS is the marginal cost.

Condition (5) means that infrastructure use should be free of charge. This is natural since marginal cost of usage, such as operation cost or congestion, does not exist in our model.

3.2 Free access, investment by national government (Regime F)

This regime has been discussed by Mun and Nakagawa (2008). In this regime, the government chooses the capacity of infrastructure and collects a poll tax to finance the expenditure while user charge is fixed to zero, i.e. the infrastructure is free access. The objective of the government is to maximize the welfare of its citizens

$$\max_{k_i} v_i \left(p_i^i, p_j^j + w_i t_i + w_j t_j, w_i - \tau_i\right),$$

where

$$\tau_i = \frac{p_i^k k_i}{l_i}. \tag{6}$$

The first order condition of the above problem yields the following investment rule

$$-w_i t_i' l_i x_i^j = p_i^k. \tag{7}$$

The LHS of equation (7) is marginal change in transport cost multiplied by the quantity of Good j that Country i imports from Country j. Namely, the LHS is the marginal benefit to Country i of an investment in the transport infrastructure. The RHS is the marginal cost of investment. Comparison between conditions (4) and (7) reveals that the investment rule under free access is inefficient since the marginal benefit to Country j does not appear in the optimality condition, (7). Investment for infrastructure in Country i reduces not only the price of import good of Country i but also that of Country j. The latter is a spill-over benefit to Country j , which the government of Country i does not take into account in its investment decision.

Country i's optimum level of investment is given as the solution to equation (7). Since the quantity of import good depends on the capacity of the transport infrastructure in Country j, the solution to equations (7) is written as

$$k_i = K_i^F(k_j) \text{ for } i, j = 1, 2, j \neq i. \tag{8}$$

(8) is considered as Country i's best response function. As shown in Mun and Nakagawa (2008), investment is a strategic complement, namely,

$$\frac{dK_i^F}{dk_j} > 0 \text{ for } i, j = 1, 2, j \neq i.$$

Mun and Nakagawa (2008) show that equilibrium investment level under free-access is smaller than the efficient level. This result is included in Proposition 1 in Section 5 of this paper.

3.3 Pricing and investment by national government (Regime G)

In this regime, the government in Country i chooses not only the capacity of the transport infrastructure but also the level of user charge. We call this regime the government pricing regime or Regime G. The government maximizes the welfare of its citizens subject to the budget constraint. The problem of the government is given by

$$\max_{k_i, f_i} v_i \left(p_i^i, p_j^j + c_j + f_i + w_i t_i, w_i - \tau_i \right)$$

where τ_i is obtained from the budget constraint, as follows

$$\tau_i = \frac{p_i^k k_i - f_i \left(l_i x_i^j + l_j x_j^i \right)}{l_i}. \tag{9}$$

Note that τ_i may be negative: the government may choose the infrastructure charge to earn the revenue in excess of expenditure. The first order condition with respect to the infrastructure charge f_i yields

$$l_i x_i^j = -l_i \frac{\partial \tau_i}{\partial f_i}. \tag{10}$$

The LHS of (10) is the quantity of Good j imported by Country i that is equal to the loss in consumer surplus. A rise in the user charge increases the price of the import good in Country i, which harms the welfare of the consumers. The RHS of (10) is the reduction in the tax burden caused by increase in revenue from the user charge. Note that the revenue includes those paid by consumers in other country, j. Differentiating the budget constraint, and substituting it to (10), we have the pricing rule as follows [6].

$$l_i x_i^j = \frac{l_i x_i^j + l_j x_j^i + f_i \left(l_i x_{ic}^j + l_j x_{jc}^i \right)}{1 - f_i x_{iy}^j}. \tag{11}$$

[6] Differentiating equation (9) with respect to τ_i and f_i and rearranging the resulting equation yields the effect of a rise in the infrastructure charge on the poll tax as

$$\frac{\partial \tau_i}{\partial f_i} = -\frac{l_i x_i^j + l_j x_j^i + f_i \left(l_i x_{ic}^j + l_j x_{jc}^i \right)}{l_i \left(1 - f_i x_{iy}^j \right)},$$

Substituting this equation into (10), we have the pricing rule.

where $x_{ic}^j = \partial x_i^j / \partial(c_i + c_j), x_{jc}^i = \partial x_j^i / \partial(c_i + c_j), x_{iy}^j = \partial x_i^j / \partial y_i$. The numerator on the RHS of (11) is the marginal revenue for the government. Pricing rule (11) is not efficient due to the spill-over effects as follows. A rise in the user charge in Country i harms consumers' welfare in Country j by increases in the price of import good, and reduces revenue from infrastructure charge in j. These spill-over effects are not incorporated in pricing decision by the government of Country i.

We now turn to the investment rule. From the first order condition with respect to k_i, we have

$$-w_i t_i' l_i x_i^j = l_i \frac{\partial \tau_i}{\partial k_i}. \tag{12}$$

The LHS of (12) is the increase in Country i's consumer surplus from one unit increase in the capacity of the transport infrastructure, which is the marginal benefit of the investment. The RHS is the increase in the tax burden to finance the investment, which is perceived as the marginal cost of investment for the country. Condition (12) is the cost-benefit rule for the government that is concerned only with the welfare of its citizens. This is similar to the investment rule in the Regime F, but the result is diffferent as shown below.

Differentiating equation (9) with respect to τ_i and k_i yields

$$\frac{\partial \tau_i}{\partial k_i} = \frac{p_i^k - f_i \left(l_i x_{ic}^j + l_j x_{jc}^i \right) w_i t_i'}{l_i \left(1 - f_i x_{iy}^j \right)}. \tag{13}$$

The numerator of the RHS of (13) is the net effect on the government expenditure of a one-unit investment on transport infrastructure. Note that the investment increases the trade volume and the revenue from the infrastructure. The second term of the numerator is the rise in revenue from infrastructure charge, which reduces the tax burden. Substituting (11) and (13) into (12) and rearranging the resulting equation, we have the investment rule as follows.

$$-w_i t_i' \left(l_i x_i^j + l_j x_j^i \right) = p_i^k. \tag{14}$$

This equation is identical to the first-best investment rule[7]. The government that is concerned only about the welfare of its citizens takes into account the benefit for the other country's citizens in the end. In other words, it internalizes the spill-over effect of investment decision. This is because the investment generates additional benefit as described earlier: increase the revenue induced by the expansion of trade volume. This revenue effect turns out to be equal to the benefit for the other country's citizens.

Note that import and export trips in our model have different implications for national welfare, as transit and local trips in De Borger et al. The effect of pricing and investment decisions on national welfare is decomposed into changes in consumer welfare and toll revenue. The former is related to import trip, while the latter is affected by both import and export trips. Consumers welfare depends on price of import goods while toll revenue is generated from both export and import trips. For example, higher toll reduces consumers welfare but increases toll revenue. Positions of import and export trips in our paper are respectively similar to those of local and transit trips in De Borger et al.

Country i's optimal levels of investment and infrastructure charge are the solutions to equations (11) and (14). These equations include the quantity of traded goods that depend on the capacity and user charge of the transport infrastructure not only in the home country but also in the foreign country. Thus, the solutions are given in the form of

[7]Note that the equivalence of investment rule does not lead to optimal capacity level, since pricing rule (11) is different from the first-best policy. Although (14) looks the same as (4), the transport quantities x_j^i and x_i^j in those equations are different because the quantities depend on the pricing policy. So the resulting capacity should be different.

response functions as follows

$$k_i = K_i^G (k_j, f_j), \tag{15}$$

$$f_i = F_i^G (k_j, f_j) \text{ for } i, j = 1, 2, j \neq i, \tag{16}$$

where the super script G represents this regime.

The shape of response functions against changes in the policy variables of Country j is not straightforward. When the demand for an import good does not depend on the disposable income ($x_{iy}^j = 0$ for $i, j = 1, 2, j \neq i$), we obtain the following result. The proof is given in Appendix.

Lemma 1 *Suppose that the demand for import good in country* i (i.e., *Good* j $(j = 1, 2, j \neq i)$) *is independent of disposable income. Then, Country* i*'s investment decisions in response to other country's policies are*

$$\frac{\partial K_i^G}{\partial k_j} > 0 \text{ and } \frac{\partial K_i^G}{\partial f_j} < 0.$$

Country i*'s pricing response depends on the shape of the demand function for import good.*

$$\frac{\partial F_i^G}{\partial k_j} \lesseqgtr 0 \text{ and } \frac{\partial F_i^G}{\partial f_j} \gtreqless 0$$

$$\Longleftrightarrow l_j x_{jc}^i + f_i \left(l_i x_{icc}^j + l_j x_{jcc}^i \right) \gtreqless 0, \tag{17}$$

where $x_{icc}^j = \partial^2 x_i^j / \partial (c_i + c_j)^2$ *and* $x_{jcc}^i = \partial^2 x_j^i / \partial (c_i + c_j)^2$.

This lemma implies that when the demand function for an import good is linear, the pricing decisions are strategic substitutes[8]: Country i increases its price of infrastructure

[8]If the demand is linear, $x_{icc}^j = x_{jcc}^i = 0$. Applying these relations to (17), we have $\frac{\partial F_i^P}{\partial k_j} > 0$ and $\frac{\partial F_i^P}{\partial f_j} < 0$.

use in response to an increase in Country j's capacity and to a decrease in Country j's price. When the demand is nonlinear and sufficiently convex, the pricing decisions may be strategic complements[9].

3.4 Break even pricing, investment by national government (Regime B)

Suppose that the government is constrained to set the level of infrastructure charge such that the revenue exactly covers the expenditure for investment. So the following budget constraint should hold.

$$f_i \left(l_i x_i^j + l_j x_j^i \right) = p_i^k k_i \tag{18}$$

In contrast to the free-access case (Regime F), no tax is levied to cover the cost of infrastructure investment. Each government chooses the capacity of infrastructure to maximizes the welfare of its citizens. The problem to be solved by the government is formulated as follows.

$$\max_{k_i} v_i \left(p_i^i, p_j^j + c_j + f_i + w_i t_i, w_i \right)$$

s.t. (18)

From the optimality condition, we have

$$w_i t_i' + \frac{\partial f_i}{\partial k_i} = 0 \tag{19}$$

Investment decision affects the national welfare through change in price of import good that depends on k_i and f_i. Investment in infrastructure reduces transport cost by

[9] This result is not found in De Borger et al (2007) since they assume linear demand function. In addition, we determine completely the signs of investment response, which De Borger et al do not succeed.

time saving (the first term on the LHS) while it increases the level of user charge to cover the cost for investment (the second term on the LHS). These two effects should be equalized at the optimum. Differentiating (18) with respect to k_i yields

$$\left(l_i x_i^j + l_j x_j^i\right) \frac{\partial f_i}{\partial k_i} + f_i \left(l_i x_{ic}^j + l_j x_{jc}^i\right) \left(\frac{\partial f_i}{\partial k_i} + w_i t_i'\right) = p_i^k \tag{20}$$

The LHS is the marginal effect of investment on revenue, in which the first term is the direct effect and the second term is the indirect effect through changes in volume of trade. Note that the indirect effect vanishes at optimum, so (20) becomes $\frac{\partial f_i}{\partial k_i} = \frac{p_i^k}{\left(l_i x_i^j + l_j x_j^i\right)}$. In words, marginal change in infrastructure charge is equal to the marginal cost of investment divided by trade volume. Substituting this relation into the optimality condition (19) yields $-w_i t_i' \left(l_i x_i^j + l_j x_j^i\right) = p_i^k$. The investment rule in Regime B is again the same as the first-best. It is also shown that the investment decisions of two governments are strategic complements, as in Regimes F and G.

Pricing rule is derived by substituting the investment rule into the budget constraint (18). As in Regime G, pricing decision may be either strategic complement or substitute. The government raises infrastructure charge in response to increase in infrastructure charge in other country if $f_i w_i t_i'' > (w_i t_i')^2$, and vice versa[10]. Note that the direction of the response depends on the form of the transport time function, $t_i(k_i)$, unlike the Regime G where the response depends on the form of the demand function. When the transport time function is linear, the pricing decisions are strategic substitutes. On the contrary, when the function is sufficiently curved, the pricing decisions are strategic complements.

[10]We omit the details of the condition dividing the directions of response, which is available from the authors upon request.

3.5 Profit maximization by private providers (Regime P)

Suppose an auction in which the right to build and operate the transport infrastructure is awarded to the firm offering the highest bid. We assume that this auction is competitive in that there are sufficient number of equally productive firms, that no firm has a market power in the bidding process, and that there is no collusion between firms. To win the auction, each firm should choose the plan that maximizes the profit[11]. We call this regime the profit maximization regime or Regime P. In this case, the winning firm, the provider of the infrastructure service, should solve the following problem:

$$\max_{k_i, f_i} f_i \left(l_i x_i^j + l_j x_j^i \right) - p_i^k k_i$$

The first order conditions are given by

$$f_i \left(l_i x_{ic}^j + l_j x_{jc}^i \right) w_i t_i' - p_i^k = 0, \tag{21}$$

$$l_i x_i^j + l_j x_j^i + f_i \left(l_i x_{ic}^j + l_j x_{jc}^i \right) = 0. \tag{22}$$

The pricing rule is given by (22). The LHS is the marginal revenue for the provider. Since there is no operation cost, any change in traffic does not affect the cost of the provider. Thus, (22) is the condition of revenue maximization. From equations (21) and (22), we have the investment rule as

$$-w_i t_i' \left(l_i x_i^j + l_j x_j^i \right) = p_i^k. \tag{23}$$

Profit maximizing investment rule is identical to the first-best rule as in the cases of government provision.

[11] For the winner, the profit net of the bid will be zero.

Response to policy choice of other country is similar to that in the Regime G: investment decision is strategic complement, and pricing decision may be either strategic complement or substitute depending on the shape of the demad curve[12].

3.6 User cost minimization (Regime U)

In this regime, competitive bidding is designed so that the right to construct and operate the transport infrastructure is awarded to the firm proposing the plan that minimizes the user cost. We call this regime the user cost minimization regime or Regime U. To win the bid, the firm should choose the lower user charge or larger capacity of the infrastructure, which makes its profit go down. But the plan should be designed to keep the profit non-negative. So the firm as a bidder should solve the following problem

$$\min_{f_i,k_i} f_i + w_i t_i$$

$$\text{subject to } f_i\left(l_i x_i^j + l_j x_j^i\right) - p_i^k k_i = 0$$

Note that the constraint of the problem is the same as that for the break even regime (Regime B). Although the objective functions of Regimes B and U look different, maximizing the utility (Regime B) is equivalent to minimizing the user cost (Regime U): the policy variables f_i, k_i affect only the user cost among the arguments in the utility function[13].

[12]Conditions to determine the direction of response are slightly different from those for the Regime G. We omit the details of this result, which is available from the authors upon request.

[13]In the utility function, $v_i\left(p_i^i, p_j^j + c_j + c_i, w_i - \tau_i\right)$, $\tau_i = 0$ in Regime U since cost for investment of infrastructure is covered by the revenue from user charge. In this case, the policy variables f_i, k_i affect only c_i.

Thus, we have the following result.

Lemma 2 *User cost minimization regime (Regime U) yields the same outcome as the Break-even regime (Regime B) .*

It follows from the above lemma that the investment rule under Regime U is also efficient.

The equivalence result between Regimes B and U depends on the assumptions of our model: the absence of incentive problem due to asymmetric information; no difference in productivities between public and private sectors. We point out one potential advantage of Regime U over Regime B. Under Regime U, the objective function is the user cost that is observable, and the competitive bidding process ensures that the infrastructure is designed according to the postulated pricing and investment rule. On the other hand, the objective function under Regime B, the welfare of citizen, is not directly observable, and it is difficult to verify whether infrastructure is provided in accordance with the objective of the government. Other than those above, there are a number of factors that make difference between Regimes B and U.

4 Case of Integrated Provision

Integrated provision means that a single decision maker controls pricing and investment of infrastructure across two countries. We deal with all regimes considered in the last section, which suppose separate provision. We put superscript "I" on the symbols to represent the regimes under integrated provision, such as Regime F^I, G^I, B^I, P^I and U^I. The first three regimes (F^I, G^I, B^I) suppose that two governments cooperatively establish an authority that chooses pricing and investment policy to maximize the global welfare of the two country economy as a whole[14]. On the other hand, in Regimes P^I and U^I, a single private firm is awarded the right to build and operate the infrastructure across two countries. The example is Channel Tunnel project between UK and France, in which Eurotunnel is a single concessionaire created by a group of ten construction companies and five banks.

We omit the detailed description of regimes to avoid redundant presentation, and discuss below the results of comparisons.

First, it is straightforward that Regimes F^I and G^I yield the same outcome as the first-best. In Regime F^I, user charge is free as in the first-best, and investment level is chosen so as to maximize the global welfare. In Regime G^I, the problem to be solved by the authority is identical to the first-best: maximizing global welfare, (2), subject to integrated budget constraint, (3).

The following lemma shows that integrated provision does not affect the resource allocation for the Regimes B and U. In the rest of this paper, the proofs of lemmas and propositions are given in Appendix.

Lemma 3 *Break even regime under integrated provision (Regime B^I) yields the same outcome as in the case of separate provision (Regime B). This result also holds for the user cost minimization regime (Regimes U^I and U).*

Let us look at the profit maximization regime. In this case, the integrated provision has an advantage over the separate provision in that the former avoids the double marginal-

[14]This paper focuses on the aspect of resource allocation. We do not deal with the conditions for the establishment of the cooperation on which two governments agree.

ization. The problem of profit maximization is that the private firm does not consider the welfare of users in pricing and investment decisions. On the other hand, the government pricing regime takes into account the welfare of users in the home country. Note that the double marginalization arises in the government pricing regime under separate provision. So the question here is what is the relation between these positive and negative effects: double margins or disregarding users welfare.

Lemma 4 *If the demand for import good is independent of disposable income, profit maximization regime under integrated provision (Regime* P^I*) and government pricing regime under separate provision (Regime G) yield the same outcome.*

Lemma 4 shows that, in the absence of income effect, loss of users' welfare in the Regime P^I is exactly offset by avoiding double marginalization that arises in the Regime G.

It follows from the discussion above that the results of all regimes under integrated provision are found in Section 3. It should be noted that the above results of equivalences between regimes may come from the assumptions of the model such as the absense of term of trade effects between countries.

5 Evaluation of Alternative Regimes

To obtain the explicit result, we specify the form of the utility function as

$$u_i\left(x_i^i, x_i^j, z_i\right) = z_i - \frac{x_i^i}{\alpha_{ea}}\left[\ln\left(\frac{x_i^i}{\alpha_{eb}}\right) - 1\right] - \frac{x_i^j}{\alpha_{ma}}\left[\ln\left(\frac{x_i^j}{\alpha_{mb}}\right) - 1\right]$$

$$\text{for } i, j = 1, 2, j \neq i, \tag{24}$$

where α_{ea}, α_{eb}, α_{ma}, and α_{mb} are parameters representing the preferences for consumptions of the export and import goods. Then, the demand of a household in Country i for Good j is given by

$$x_i^j = \alpha_{mb} \exp\left(-\alpha_{ma} p_i^j\right). \tag{25}$$

We also specify the function describing the transport technology as

$$t_i\left(k_i\right) = -\beta \ln \frac{k_i}{\bar{k}}, \tag{26}$$

$\bar{k}$ is the upper limit of the capacity of the transport infrastructure ($\bar{k} = 1$)[15].

We present 11 regimes in Sections 3 and 4: 6 regimes for separate provision and 5 regimes for integrated provision.

From Lemmas 2, 3, 4, we see the following relations:

Regime O = Regimes F^I, G^I,

Regime U = Regimes B, B^I and U^I.

Regime G = Regime P^I ,

The last result comes from our specific utility function (24) that implies the absence of income effect on the demand for traded goods. In the following discussion, the results for the regimes on the LHS represent those on the RHS, which are omitted hereafter. So the effective number of regimes is reduced to 5 regimes: the above 3 (O, U, G) plus regimes F, P.

[15]The utility function (24) is similar to that used by Anderson, de Palma and Thisse (1988). As demonstrated in the proof of propositions in Appendix, this specification together with (26) greatly simplifies the analysis.

5.1 Case of a symmetric economy

Suppose that the sizes and technologies (incomes) of two countries are identical. We present the ranking of the regimes for several criteria such as the capacity of infrastructure, transport cost, and global welfare.

In the following, superscripts indicate the regimes: O represents the first best optimum, F the free access regime, G the government pricing regime, P the profit maximization regime and U the user cost minimization regime. First, the capacities of infrastructure under alternative regimes are ranked as follows.

Proposition 1 *In a symmetric economy, the capacities for the alternative regimes satisfy the following relations*

$$k_i^O > k_i^U \geq k_i^F > k_i^G > k_i^P \text{ if } \alpha_{ma}\beta w_i \leq \frac{1}{2}\log 2 \cong 0.346574,$$
$$k_i^O > k_i^F > k_i^U > k_i^G > k_i^P \text{ if } \alpha_{ma}\beta w_i > \frac{1}{2}\log 2, \qquad \text{for } i = 1, 2,$$

The investment levels in Regimes G and P, in which the investment rule is efficient, are lower than that in Regime F in which the investment decision is not efficient. Note that the marginal benefit of investment (LHS of the expression for the investment rule) is proportional to the volume of trade. In Regimes G and P, the volume of trade is smaller due to the higher infrastructure charge. This effect reduces the marginal benefit, and thereby leads to a smaller level of investment. The ranking of the free access regime (F) and the user cost minimization regime (U) depends on the wage rate, the slope of demand function for import good and transport technology. If the demand is more elastic (smaller α_{ma}), transport technology is backward (smaller β), or wage rate is lower (smaller w_i), the level of investment in the user cost minimization is higher than that in the free access regime.

The transport cost represents the service level of the infrastructure, which depends not only on the capacity but also on the infrastructure charge. Thus, the ranking of transport cost is different from that of the capacity:

Proposition 2 *In a symmetric economy, the infrastructure charges for trip between two countries are ranked as follows*

$$f^P > f^G > f^U > f^F = f^O,$$

where $f^r = f_1^r + f_2^r$*, for* $r = O, F, G, P$*,and U. Combining the above result and Proposition 1, we obtain the ranking of transport costs as follows*

$$c^P > c^G > c^U > c^F > c^O,$$

where $c^r = c_1^r + c_2^r$ *for* $r = O, F, G, P$*,and U.*

Note that the above results concerning the rankings among Regimes O, G, U, P hold also in asymmetric cases. In other words, the assumption of symmetry is needed only to obtain the relation between Regime F and others. Unlike the levels of investment, the ranking is not contingent: user cost in Regime U is necessarily higher than that in Regime F. This result holds, even in the case that the level of investment is higher in Regime U. The price effect dominates the effect of larger capacity. Other relations are consistent with those in Proposition 1.

We define global welfare as the sum of utilities of all households in the economy, that is, $W = l_1 v_1 + l_2 v_2$; the utility function specified as (24) is a quasi-linear form, so the utility level is measured in monetary terms. We have the ranking of the global welfare as follows:

Proposition 3 *In a symmetric economy, the levels of the global welfare for the alternative regimes are ranked as follows*

$$W^O > W^U \geq W^F > W^G > W^P \text{ if } \alpha_{ma}\beta w_i \leq \theta \cong 0.229966,$$
$$W^O > W^F > W^U > W^G > W^P \text{ if } \alpha_{ma}\beta w_i > \theta \qquad \text{for } i = 1, 2,$$

where θ is the solution of the following equation

$$\left(\frac{2}{e}\right)^{\frac{2\theta}{1-2\theta}} - 1 + \theta = 0.$$

Proposition 3 shows that the second-best regime may be different depending on the parameters. The second-best regime in a symmetric economy is the user cost minimization (Regime U) when the value of $(\alpha_{ma}\beta w_i)$ is relatively small, in other words, the demand is more elastic, transport technology is backward, or the wage rate is lower. Otherwise, the second-best regime is the free access (Regime F). The calibration of the model based on data in Japan suggests that the value of $(\alpha_{ma}\beta w_i)$ is very small (much smaller than 0.1)[16]. Therefore, it is likely that the user cost minimization is more efficient than the free access. Recall Lemma 2 that the user cost minimization is equivalent to the break-even pricing. This implies that financing by user charge (Regimes B or U) is more efficient than by taxation (Regime F). Ohsawa (2000) obtains the similar result even though he adopts different rule of policy choice: his model supposes that the pricing and investment policies are determined by voting.

The pricing by national governments (Regime G) is less efficient than the free-access (Regime F). Recall that pricing rule is efficient but investment rule is inefficient in Regime

[16] We also use the calibrated model in the next section to see whether asymmetry between countries affects the results here. Details of the calibration and simulation results are included in working paper version, which is available from http://www.econ.kyoto-u.ac.jp/~mun/papers/Pricing_and_investment091006.pdf

Table 1: Ranking of regimes in terms of the global welfare

Regime	Separate	Integrate
F	3 (2)	1 (1)
G	4 (4)	1 (1)
B	2 (3)	2 (3)
P	5 (5)	4 (4)
U	2 (3)	2 (3)

Note: Figures in the parenthesis are ranks when $\alpha_{ma}\beta w_i > \theta$.

F. On the other hand, pricing rule is inefficient but investment rule is efficient in Regime G. The above result suggests that the distortion of pricing in Regime G dominates the loss owing to inefficient investment rule in Regime F.

Table 1 summarizes the above results to give an overview of welfare ranking among alternative regimes. This table is also useful to see the equivalences between some regimes. The regimes having the same numbers on cells attain the same results.

De Borger et al (2007) also examined Regimes F, G and O as in our paper, which are respectively termed “No tolls”, “Uniform tolls” and “Centralized differentiation”[17]. Recall that their model incorporates congestion externality. Our analytical results con-

[17]De Borger et al suppose that infrastructure charges for local and transit trips may be discriminated. We do not consider the discrimination since charging different fees for import and export (directions of transportation) is impractical in our setting. For the same reason, the regime corresponding “local toll only” in De Borger et al is also out of consideration (it is difficult to justify that only one of import or export is charged).

cerning the ranking of three regimes are the same as numerical results in De Borger et al. This suggests that ignoring congestion does not affect the qualitative results significantly. In other words, strategic interaction between governments is a more crucial factor for the welfare results than congestion externality.

5.2 The effects of asymmetry

We examine the effect of asymmetry between two countries in population size and the wage rates. We have some analytical results concerning the effect of difference in population size. Let us focus on the population distribution holding the sum of the population of the two countries constant. Let s_i be Country i's share of population such that $s_i = l_i / (l_1 + l_2)$.

Proposition 4 *Under the free-access regime, the effect of population distribution on investment levels of the two countries are*

$$\frac{\partial k_1^F}{\partial s_1} \gtreqless 0 \iff s_1 \lesseqgtr 1 - \alpha_{ma}\beta w_2,$$
$$\frac{\partial k_2^F}{\partial s_1} \gtreqless 0 \iff s_1 \lesseqgtr \alpha_{ma}\beta w_1,$$

The effect on the user cost is

$$\frac{\partial c^F}{\partial s_1} \lesseqgtr 0 \iff s_1 \lesseqgtr \frac{w_1}{w_1 + w_2}.$$

In addition, suppose that the production technology in the two countries are identical, then, $w_1 = w_2$ and $p_1^1 = p_2^2$. In this case, the global welfare in the free access regime satisfies

$$\frac{\partial W^F}{\partial s_1} \gtreqless 0 \iff s_1 \lesseqgtr \frac{1}{2}.$$

The effect of population distribution on the level of investment may be either positive or negative. Since the value of $\alpha_{ma}\beta w_i$ is small as already mentioned, $\alpha_{ma}\beta w_1 < s_1 < 1 - \alpha_{ma}\beta w_2$ unless population distribution is extremely uneven. It is likely that $\partial k_1^F / \partial s_1 > 0$ and $\partial k_2^F / \partial s_1 < 0$. In words, the level of investment is increasing with the population share of home country.

When the wage rates in two countries are identical, the transport cost, c^F, is increasing with asymmetry in population size. This is because investment in infrastructure is decreasing returns: when the population size in the larger country increases and the size of the smaller country decreases by the same units, the larger country increases its investment and the smaller country decreases. However, the transport cost reduction in the larger country is smaller than the transport cost increase in the smaller country. Consequently, increasing the asymmetry increases the transport cost and decreases the global welfare.

We turn to the other regimes.

Proposition 5 *The effects of population distribution in Regimes O, G, P and U are*

$$
\begin{aligned}
&\frac{\partial f_1^G}{\partial s_1} < 0, \frac{\partial f_2^G}{\partial s_1} > 0, \frac{\partial \left(f_1^G + f_2^G\right)}{\partial s_1} = 0, \\
&\frac{\partial f^U}{\partial s_1} = \frac{\partial f^P}{\partial s_1} = 0, \\
&\frac{\partial k_i^r}{\partial s_1} \gtreqless 0 \text{ and } \frac{\partial c^r}{\partial s_1} \lesseqgtr 0 \Longleftrightarrow p_1^1 \gtreqless p_2^2,\ i = 1, 2, r = O, G, P, U.
\end{aligned}
$$

In addition, when $w_1 = w_2$ and $p_1^1 = p_2^2$, we have

$$
\frac{\partial W^O}{\partial s_1} = \frac{\partial W^G}{\partial s_1} = \frac{\partial W^P}{\partial s_1} = \frac{\partial W^U}{\partial s_1} = 0.
$$

Proposition 5 shows that the effects of population distribution on the investment levels and transport cost depend on the difference in the FOB prices. This is explained as follows. In this model, the transport costs of Goods 1 and 2 are identical. The ratio of the transported quantity of Good 1 to that of Good 2 is determined by the ratio of the FOB prices. Suppose that the FOB price of Good 2 is lower than that of Good 1. Then, a household in Country 1 consumes more Good 2 than a household in country 2 consumes Good 1. An increase in the size of Country 1 and corresponding decrease in the size of Country 2 raises the quantity transported between the two countries. This increase in the transportation raises the investment and reduces the transport cost. These effects, however, do not affect the ranking of the regimes.

Corollary 1 *Among Regimes O, G, P, and U, the rankings of the transport cost between two countries and the global welfare levels are not affected by asymmetry in population size.*

This corollary is derived from Propositions 1, 2, and 3. What is left unknown is the relationship between Regime F and other regimes under asymmetry in country size[18]. We examine numerically the effect of asymmetry on the relative performance of Regime F and other cases. Numerical results suggest that the ranking between Regime F and others is not affected unless population distribution is extremely asymmetric[19].

[18]As Proposition 1 shows, the service levels and global welfare under Regime F are variable depending on the population distribution.

[19]Details of the numerical results are included in working paper version, which is available at http://www.econ.kyoto-u.ac.jp/~mun/papers/Pricing_and_investment091006.pdf

6 Conclusion

The primal objective of our paper is to evaluate the effects of alternative pricing and investment policies on service level of cross-border transport infrastructure and economic welfare of two neighboring countries.

If the use of infrastructure is free of charge, the national government does not take into account the benefit of investment in a neighboring country, which leads to under-investment in terms of resource allocation for the two-country economy as a whole. On the other hand, it is shown that the investment rule becomes efficient if infrastructure charge is levied. It is interesting that this result holds for all regimes with charging, regardless their differences in objective functions, financial constraints, and organization of decision units[20]. We show that the investment level under the government pricing regime (Regime G) is smaller than that under free access (Regime F). This is because the user charge would be inefficiently high, which negatively affects the level of investment despite the efficient rule. Distortion of pricing in Regime G exceeds the loss owing to lack of incentive in investment decision in Regime F. This result does not mean that pricing is necessarily harmful. We show that Regime B (U) may attain higher welfare than the free access. This result suggests that a more efficient mechanism with pricing could be

[20]This result is valid in the case that pricing and investment decisions are made simultaneously, unlike sequential decision making in De Borger et al. We also examine the case of sequential decision making, and it turns out that the investment rule may be inefficient. The results are unchanged in Regimes B and U, whereas the investment rules are generally different from the efficient ones in Regimes G and P. However, under the specific utility function in Section 5, the investment rules are efficient in all regimes with pricing. Therefore the results there are still valid for the case of sequential decision making. The details of the analysis in this case are available from the authors upon request.

designed. We need to make further efforts in the future to explore the possibility of finding better mechanisms.

We also investigate theoretically the relationship between regimes. It is shown that seemingly different regimes yield the same outcome: e.g., Regimes G and P^I, Regimes B and U, etc. As for the number of decision units (i.e., separate or integrated), integrated provision improves efficiency in most cases while there is no effect of integration in Regimes B and U.

The structure of regimes considered in our paper are purely simplified, so may be far from the real practices. But the real practices can be considered as blends of elements in some regimes examined here. Therefore our results may provide some insights for understanding the consequences of policy design.

Appendix

This appendix gives the proofs of lemmas and propositions. Throughout the appendix, we simplify the notation as follows: the quantity of Good j imported by Country i is written as $N_i = l_i x_i^j$, and $N = N_1 + N_2$. The derivatives of N_i are written as

$$N_{ic} = \frac{\partial N_i}{\partial (c_1 + c_2)}, N_{icc} = \frac{\partial^2 N_i}{\partial (c_1 + c_2)^2}, \text{for } i = 1, 2,$$

$$N_c = N_{1c} + N_{2c}, N_{cc} = N_{1cc} + N_{2cc}.$$

Proof of Lemma 1

We use the above simplified notations to rewrite the pricing and investment rules, (11) and (14), as follows

$$N_j + f_i N_c = 0, \tag{27}$$

$$-N_i w_i t_i' - p_i^k + f_i N_c w_i t_i' = 0. \tag{28}$$

Solving (27) and (28) with respect to f_i and k_i for a given c_j, we get Country i's pricing and investment decisions as functions of the transport cost in Country j, $\widetilde{F}_i^G(c_j)$ and $\widetilde{K}_i^G(c_j)$. Then, Country i's responce functions are given by

$$F_i^G(k_j, f_j) = \widetilde{F}_i^G(f_j + w_j t_j(k_j)) \text{ and } K_i^G(k_j, f_j) = \widetilde{K}_i^G(f_j + w_j t_j(k_j)). \tag{29}$$

Note that we assume no income effect on the demand for an import good. Differentiating (27) and (28) with respect to f_i, k_i, and c_j yields

$$(N_{jc} + N_c + f_i N_{cc})\, df_i + (N_{jc} + f_i N_{cc})\, w_i t_i' dk_i + (N_{jc} + f_i N_{cc})\, dc_j = 0, \tag{30}$$

$$(N_{jc} + f_i N_{cc})\, w_i t_i' df_i + \left[-(N_{ic} - f_i N_{cc})(w_i t_i')^2 - N w_i t_i''\right] dk_i$$

$$+ (-N_{ic} + f_i N_{cc})\, w_i t_i' dc_j = 0. \tag{31}$$

Solving equations (30) and (31) with respect to df_i and dk_i, we get

$$\frac{d\widetilde{F}_i^G}{dc_j} = \frac{(N_{jc} + f_i N_{cc})\, N w_i t_i''}{\Delta_G} \text{ and } \frac{d\widetilde{K}_i^G}{dc_j} = \frac{(N_c)^2\, w_i t_i'}{\Delta_G},$$

where

$$\Delta_G = \begin{vmatrix} N_{ic} + 2N_{jc} + f_i N_{cc} & (N_{jc} + f_i N_{cc})\, w_i t_i' \\ (N_{jc} + f_i N_{cc})\, w_i t_i' & -(N_{ic} - f_i N_{cc})(w_i t_i')^2 - N w_i t_i'' \end{vmatrix} > 0.$$

$\Delta_G > 0$ follows from the second order condition for the government's problem under Regime G. Thus, we get

$$\frac{d\widetilde{F}_i^G}{dc_j} \gtreqless 0 \iff N_{jc} + f_i N_{cc} = l_j x_{jc}^i + f_i \left(l_i x_{icc}^j + l_j x_{jcc}^i \right) \gtreqless 0, \tag{32}$$

$$\frac{d\widetilde{K}_i^G}{dc_j} < 0. \tag{33}$$

Differentiating (29) with respect to k_j and f_j, we get

$$\frac{\partial F_i^G}{\partial k_j} = w_j t_j' \frac{d\widetilde{F}_i^G}{dc_j}, \frac{\partial F_i^G}{\partial f_j} = \frac{d\widetilde{F}_i^G}{dc_j}, \frac{\partial K_i^G}{\partial k_j} = w_j t_j' \frac{d\widetilde{K}_i^G}{dc_j}, \text{and } \frac{\partial K_i^G}{\partial f_j} = \frac{d\widetilde{K}_i^G}{dc_j}, \tag{34}$$

where $w_j t_j' < 0$. Substituting (32) and (33) in (34), Lemma 1 is obtained.

Proof of Lemma 3

In this proof, we show that integrated provision in the break even regime (Regime B^I) yields the same outcome as in the case of separate provision (Regime B). Using the Lemma 2, equivalence of integrated and separate provision also holds for the user cost minimization regime (Regimes U^I and U).

In Regime B^I, the maximization problem is

$$\max_{f,k_1,k_2} W(v_1, v_2)$$
$$\text{subject to } fN - p_1^k k_1 - p_2^k k_2 = 0. \tag{35}$$

Solving the first order conditions of this problem, we get

$$-w_i t_i' N = p_i^k. \tag{36}$$

The optimal level of investment and the optimal infrastructure charge in Regime B^I are given as the solutions to equations (35) and (36).

In Regime B, the investment rule is identical to (36) as shown in the text. Aggregating equation (18) and using the relation, $f = f_1 + f_2$, we have

$$fN - p_1^k k_1 - p_2^k k_2 = 0,$$

which is identical to (35).

The system of equations to be solved is the same between the two cases, i.e., (35) and (36). Thus, the outcome of these two cases should be the same.

This result is guaranteed if the solution of the equation system is unique. The sufficient condition for the uniqueness is given by[21]

$$N + \left(\frac{p_1^k K_1(N) + p_2^k K_2(N)}{N}\right)\left(l_1 \frac{\partial x_1^2}{\partial p_1^2} + l_2 \frac{\partial x_2^1}{\partial p_2^1}\right) > 0,$$

where $K_i(N)$ is the solution of equation (36) with respect to k_i taking N as a given. Since this is a sufficient condition, the solution may be unique if the above inequality does not hold. Even if the solution is not unique and different results emerge, it is not owing to different regimes but to the properties of equation system, or solution algorithms.

Proof of Lemma 4

In Regime P^I, the firm's problem is given by

$$\max_{f,k_1,k_2} \pi = fN - p_1^k k_1 - p_2^k k_2$$

We assume that the demands for import goods do not depend on the disposable income. Solving the first order conditions, we obtain the pricing and investment rules as

$$fN_c + N = 0, \tag{37}$$

$$-w_i t_i' N = p_i^k. \tag{38}$$

[21] We omit the derivation of this sufficient condition, which is available from the authors upon request.

In Regime G, summing up equations (11) for two countries, we get

$$(f_1 + f_2)\, N_c + N = 0.$$

Since $f_1 + f_2 = f$, we have equation (37). The investment rule in Regime G is equal to (38). Thus, Regimes P^I and G should solve the same system of equations, (37) and (38).

We examined the uniqueness of the solution as above, but omit the details.

Proof of Propositions 1, 2, and 3

These propositions give the ranking of the regimes with respect to the investment level, the transport cost, and the global welfare. We represent the amount of import goods in terms of the infrastructure charges and the investment levels. Using (25), the amount of Good j consumed in Country i becomes

$$N_i = \alpha_{mb} X_i \exp\left(-\alpha_{ma} c\right),$$

where $X_i = l_i \exp\left(-\alpha_{ma} p_j^j\right)$. Using (26), the transport cost is written as

$$c = f - \beta w_1 \ln k_1 - \beta w_2 \ln k_2. \tag{39}$$

Thus, we can write

$$N_i = \alpha_{mb} X_i \exp\left(-\alpha_{ma} f\right) k_1^{A_1} k_2^{A_2} \text{ and } N = \alpha_{mb} X \exp\left(-\alpha_{ma} f\right) k_1^{A_1} k_2^{A_2}, \tag{40}$$

where $A_i = \alpha_{ma} \beta w_i$ and $X = X_1 + X_2$.

The indirect utility of a household in Country i is given by

$$v_i = y_i + \frac{x_i^i}{\alpha_{ea}} + \frac{x_i^j}{\alpha_{ma}}.$$

Using the budget constraints of households and governments, the global welfare is written as

$$W = \overline{W} + \left(f + \frac{1}{\alpha_{ma}} \right) N - p_1^k k_1 - p_2^k k_2, \tag{41}$$

where $\overline{W} = l_1 w_1 + l_2 w_2 + \left(l_1 x_1^1 + l_2 x_2^2 \right) / \alpha_{ea}$.

Regime r (r=O,G,P,U)

Consider Regimes O, G, P, and U. First, we derive the investment level. Using (26) and (40), the investment rule can be rewritten as

$$\alpha_{mb} \beta w_i X \exp\left(-\alpha_{ma} f \right) k_i^{A_i - 1} k_j^{A_j} = p_i^k \text{ for } i, j = 1, 2, i \neq j. \tag{42}$$

Taking logarithms of both sides of the above equation, we have

$$\left(A_i - 1 \right) \ln k_i + A_j \ln k_j = \alpha_{ma} f - \ln B_i X \text{ for } i, j = 1, 2, i \neq j, \tag{43}$$

where $B_i = \left(\alpha_{mb} \beta w_i / p_i^k \right)$. The stability condition of this system is given by

$$1 - A_1 - A_2 > 0 \tag{44}$$

Solving (43) yields the investment level in Regime r (r=O,G,P,U), k_i^r, as a function of the sum of the infrastructure charges, f^r:

$$\ln k_i^r = \frac{1}{1 - A_1 - A_2} \left[-\alpha_{ma} f^r + \left(1 - A_j \right) \ln B_i X + A_j \ln B_j X \right]. \tag{45}$$

Secondly, the transport cost in Regime r, c^r, is rewritten as a function of the infrastructure charge. Substituting (45) in (39) yields

$$c^r = \frac{f^r - \beta w_1 \ln B_1 X - \beta w_2 \ln B_2 X}{1 - A_1 - A_2}. \tag{46}$$

From (44), (45) and (46), we obtain $\partial k_i^r / \partial f^r < 0$ and $\partial c^r / \partial f^r > 0$.

Thirdly, we focus on the global welfare. Substituting (40), (42) and (45) in (41), we rewrite the global welfare as

$$W^r = \overline{W} + g\left(f^r\right) \frac{\alpha_{mb} X}{\alpha_{ma}} \left(B_1 X\right)^{\frac{A_1}{1-A_1-A_2}} \left(B_2 X\right)^{\frac{A_2}{1-A_1-A_2}}, \tag{47}$$

where

$$g\left(f^r\right) = \left(\alpha_{ma} f^r + 1 - A_1 - A_2\right) \exp\left(\frac{-\alpha_{ma} f^r}{1 - A_1 - A_2}\right).$$

Differentiating g with respect to f^r, we have

$$\frac{dg}{df^r} = \frac{-\left(\alpha_{ma}\right)^2 f^r}{1 - A_1 - A_2} \exp\left(\frac{-\alpha_{ma} f^r}{1 - A_1 - A_2}\right) < 0 \text{ for } f^r > 0,$$

which implies that $\partial W^r / \partial f^r < 0$.

Fourthly, we derive the ordering of the regimes with respect to the infrastructure charge. Using the pricing rule, the sum of the infrastructure charges is given by

$$f^O = 0, f^G = \frac{1}{\alpha_{ma}}, f^U = \left(w_1 + w_2\right)\beta, f^P = \frac{2}{\alpha_{ma}}. \tag{48}$$

Thus, the ordering with respect to the infrastructure charge is given by[22]

$$f^O < f^U < f^G < f^P. \tag{49}$$

Since $\partial k_i^r / \partial f^r < 0$, $\partial c^r / \partial f^r > 0$ and $\partial W^r / \partial f^r < 0$, we derive the ordering with respect to the investment level, the transport cost and the global welfare as follows:

$$k_i^O > k_i^U > k_i^G > k_i^P,\ c^O < c^U < c^G < c^P,\ W^O > W^U > W^G > W^P.$$

[22] In inequality (49), the ordering of f^G and f^U is derived as follows: using (44), we have

$$f^G - f^U = \left(1 - A_1 - A_2\right) / \alpha_{ma} > 0.$$

Regime F

Using (26) and (40), the investment rule in Regime F is written as

$$\alpha_{mb}\beta w_i X_i k_i^{A_i-1} k_j^{A_j} = p_i^k. \tag{50}$$

Taking logarithms of both sides of equation (50), we get

$$(A_i - 1)\ln k_i + A_j \ln k_j = -\ln(B_i X_i) \text{ for } i, j = 1, 2, i \neq j.$$

Solving the above equation yields the equilibrium levels of investment as follows:

$$\ln k_i^F = \frac{1}{1 - A_1 - A_2}\left[(1 - A_j)\ln(B_i X_i) + A_j \ln(B_j X_j)\right]. \tag{51}$$

Using (39) and (51), we obtain the transport cost as

$$c^F = \frac{-\beta w_1 \ln(B_1 X_1) - \beta w_2 \ln(B_2 X_2)}{1 - A_1 - A_2}. \tag{52}$$

Substituting (40), (50), and (51) in (41) yields

$$W^F = \overline{W} + \frac{\alpha_{mb}}{\alpha_{ma}} X\left(1 - A_1\frac{X_1}{X} - A_2\frac{X_2}{X}\right)(B_1 X_1)^{\frac{A_1}{1-A_1-A_2}}(B_2 X_2)^{\frac{A_2}{1-A_1-A_2}}. \tag{53}$$

Comparison of the regimes in a symmetric economy

In a symmetric economy, we have

$$w_1 = w_2, l_1 = l_2, a_1^1 = a_2^2, A_1 = A_2, B_1 = B_2, X_1 = X_2.$$

Substituting these equations in (51), (52), and (53), we obtain

$$\ln k_i^F = \frac{1}{1 - 2A_1}\left[\ln(B_1 X) - \ln 2\right], \tag{54}$$

$$c^F = \frac{-2\beta w_1 \ln(B_1 X) + 2\beta w_1 \ln 2}{1 - 2A_1}, \tag{55}$$

$$W^F = \overline{W} + \frac{\alpha_{mb}}{\alpha_{ma}} X(1 - A_1)(B_1 X)^{\frac{2A_1}{1-2A_1}}\left(\frac{1}{2}\right)^{\frac{2A_1}{1-2A_1}}. \tag{56}$$

Comparing (54) to (45), we obtain

$$k_i^O > k_i^U \geq k_i^F > k_i^G > k_i^P \text{ if } \alpha_{ma}\beta w_1 \leq \frac{1}{2}\ln 2,$$
$$k_i^O > k_i^F > k_i^U > k_i^G > k_i^P \text{ if } \alpha_{ma}\beta w_1 > \frac{1}{2}\ln 2.$$

Comparing (55) to (46), we get

$$c^O < c^F < c^U < c^G < c^P.$$

Comparing (56) to (47), we obtain

$$\begin{aligned} \frac{W^F - \overline{\overline{W}}}{W^O - \overline{\overline{W}}} &= \left(\frac{1-A_1}{1-2A_1}\right)\left(\frac{1}{2}\right)^{\frac{2A_1}{1-2A_1}} < 1, \\ \frac{W^F - \overline{\overline{W}}}{W^G - \overline{\overline{W}}} &= \left(\frac{e}{2}\right)^{\frac{1}{1-2A_1}} > 1, \\ \frac{W^F - \overline{\overline{W}}}{W^U - \overline{\overline{W}}} &= (1-A_1)\left(\frac{e}{2}\right)^{\frac{2A_1}{1-2A_1}}. \end{aligned} \tag{57}$$

Consider the RHS of (57). We have

$$W^F \gtreqless W^U \Leftrightarrow \left(\frac{2}{e}\right)^{\frac{2A_1}{1-2A_1}} - 1 + A_1 \lesseqgtr 0.$$

Let θ to be the solution of the following equation:$(2/e)^{\frac{2\theta}{1-2\theta}} - 1 + \theta = 0$. Then, we get[23]

$$W^F \gtreqless W^U \Leftrightarrow A_1 \gtreqless \theta.$$

[23] This outcome is derived as follows. Let $h(x) = (2/e)^{\frac{2x}{1-2x}}$. Then, function $h(x)$ satisfies

$$h(0) = 1, h'(0) > -1, \lim_{x \to \frac{1}{2}} h(x) = 0, h'(x) < 0 \text{ for } 0 < x < \frac{1}{2}.$$

Thus, there is a unique point $\theta \in \left(0, \frac{1}{2}\right)$ such that $h(\theta) - (1-\theta) = 0$.We also have

$$h(x) - (1-x) \gtreqless 0 \;\Leftrightarrow\; x \lesseqgtr \theta.$$

Thus, the ordering of the regimes with respect to the global welfare is given by

$$W^O > W^U \geq W^F > W^G > W^P \text{ if } \alpha_{ma}\beta w_1 \leq \theta,$$

$$W^O > W^F > W^U > W^G > W^P \text{ if } \alpha_{ma}\beta w_1 > \theta.$$

Proof of Proposition 4

In this proposition, we derive how the population distribution affects the outcome of Regime F. Among the variables determining the investment level, X_1 and X_2 depend on the population distribution as follows

$$X_1 = s_1 (l_1 + l_2) \exp\left(-\alpha_{ma} p_2^2\right), \tag{58}$$

$$X_2 = (1 - s_1)(l_1 + l_2) \exp\left(-\alpha_{ma} p_1^1\right). \tag{59}$$

Differentiating (51) and (52) with respect to s_1, we have

$$\begin{aligned}
\frac{1}{k_1^F}\frac{\partial k_1^F}{\partial s_1} &= \frac{1 - A_2 - s_1}{(1 - A_1 - A_2) s_1 (1 - s_1)}, \\
\frac{1}{k_2^F}\frac{\partial k_2^F}{\partial s_1} &= \frac{A_1 - s_1}{(1 - A_1 - A_2) s_1 (1 - s_1)}, \\
\frac{\partial c^F}{\partial s_1} &= \frac{\beta (w_1 + w_2)}{(1 - A_1 - A_2) s_1 (1 - s_1)} \left[s_1 - \frac{w_1}{w_1 + w_2} \right].
\end{aligned}$$

Thus, we have

$$\begin{aligned}
&\frac{\partial k_1^F}{\partial s_1} \gtreqless 0 \Leftrightarrow s_1 \lesseqgtr 1 - \alpha_{ma}\beta w_2, \quad \frac{\partial k_2^F}{\partial s_1} \gtreqless 0 \Leftrightarrow s_1 \lesseqgtr \alpha_{ma}\beta w_1, \\
&\frac{\partial c^F}{\partial s_1} \gtreqless 0 \Leftrightarrow s_1 \gtreqless \frac{w_1}{w_1 + w_2}.
\end{aligned}$$

Next, we suppose that $w_1 = w_2$ and $a_1^1 = a_2^2$. The global welfare, (53), becomes

$$W^F = \overline{W} + \frac{\alpha_{mb}}{\alpha_{ma}} (l_1 + l_2) \exp\left(-\alpha_{ma} p_2^2\right) (1 - A_1) (B_1 X_1)^{\frac{A_1}{1-2A_1}} (B_2 X_2)^{\frac{A_1}{1-2A_1}}.$$

Differentiating W^F with respect to s_1, we obtain

$$\frac{\partial W^F}{\partial s_1} = \left(W^F - \overline{W}\right) \frac{A_1 (1 - 2s_1)}{(1 - 2A_1) s_1 (1 - s_1)}.$$

Since $W^F - \overline{W} > 0$, we have

$$\frac{\partial W^F}{\partial s_1} \gtreqless 0 \Leftrightarrow s_1 \lesseqgtr \frac{1}{2}.$$

Proof of Proposition 5

In this proposition, we explore the relationship between the population distribution and the outcome of Regime r (r=O, G, P, U). First, consider the infrastructure charge. From the pricing rule, the infrastructure charges in Regime G are given by

$$f_1^G = \frac{X_2}{\alpha_{ma} X},\ f_2^G = \frac{X_1}{\alpha_{ma} X}, \text{ and } f^G = \frac{1}{\alpha_{ma}},$$

where X_1 and X_2 are given by (58) and (59). Then, differentiating f_i^G and f^G with respect to s_1 yields

$$\frac{\partial f_1^G}{\partial s_1} < 0, \frac{\partial f_2^G}{\partial s_1} > 0, \text{ and } \frac{\partial f^G}{\partial s_1} = 0.$$

In Regimes O, P, and U, the infrastructure charge does not depend on the population. Thus, we have

$$\frac{\partial f_i^r}{\partial s_1} = \frac{\partial f^r}{\partial s_1} = 0 \text{ for } r = O, P, U.$$

The investment levels in Regimes O, G, P, and U are given by (45). Among the independent variables of k_i^r, X depends on the population distribution. Differentiating (45) with respect to s_1 yields

$$\frac{1}{k_i^r} \frac{\partial k_i^r}{\partial s_1} = \frac{(l_1 + l_2) \left[\exp\left(-\alpha_{ma} p_2^2\right) - \exp\left(-\alpha_{ma} p_1^1\right)\right]}{(1 - A_1 - A_2) X} \text{ for } r = O, G, P, U.$$

Thus, we have

$$\frac{\partial k_i^r}{\partial s_1} \gtreqless 0 \Leftrightarrow p_1^1 \gtreqless p_2^2.$$

The transport cost in Regime r (r=O, G, P, U) is given by (46). We get

$$\frac{\partial c^r}{\partial s_1} = \frac{-\beta\left(w_1 + w_2\right)\left(l_1 + l_2\right)\left[\exp\left(-\alpha_{ma} p_2^2\right) - \exp\left(-\alpha_{ma} p_1^1\right)\right]}{1 - A_1 - A_2},$$

which implies that

$$\frac{\partial c^r}{\partial s_1} \lesseqgtr 0 \Leftrightarrow p_1^1 \gtreqless p_2^2.$$

Finally, we suppose that $w_1 = w_2$ and $a_1^1 = a_2^2$ and investigate the global welfare. Under this assumption, we have

$$\frac{\partial X}{\partial s_1} = 0 \text{ and } \frac{\partial \overline{W}}{\partial s_1} = 0$$

Then, we get

$$\frac{\partial W^r}{\partial s_1} = 0 \text{ for } r = O, G, P, U.$$

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