Providing Public Infrastructure Competition and New Economic Geography

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Abstract

This paper describes a framework of new economic geography models that contain specific public infrastructures for reducing transportation costs. Using this framework, we consider the outcomes of the public-infrastructure-provision competition by welfare-maximizing governments. We show that, in the process of integration, the world economy experiences a phase in which a pure strategy Nash equilibrium does not exist. Instead, there is a mixed strategy Nash equilibrium in which the public infrastructure investments made by a country lacking a sector with vertical linkages vary much more than those made by a country hosting such a sector. To attract the sector, the less industrialized country invests tremendous amounts in public infrastructure. Consequently, there is a small but definitely positive probability that an industry with vertical linkage relocates.

Keywords: New economic geography; Fiscal competition; Vertical linkage; Public infrastructure; Globalization

JEL classification: F12; F15; H54; H87; R13

1 Introduction

Introducing modern industries brings economic development to a nation. These industries form complex and significant back-and-forth linkages that, as they expand, further promote economic development. These linkages, however, require large-scale transportation infrastructures such as roads and railways. In fact, one of the most important policy issues for less industrialized countries is how to increase social capital, including transportation infrastructures, in order to introduce modern industries and achieve economic development.

However, the internationalization of goods and factors markets makes matters much more serious. If the consumer markets are divided, each nation can invest in public infrastructures to attract modern industries. However, under internationalization, modern industries with significant vertical linkages tend to become concentrated in a small number of countries. Once this happens, other, less industrialized, countries find it much more difficult to industrialize, resulting in large and persistent economic disparities among countries. When providing public infrastructure, a national government will move carefully and sometimes boldly, taking into account the strategies of other countries. In fact, some less industrialized countries have managed to industrialize with huge or even moderate investments in public infrastructure. However, many others have invested tremendous amounts in public infrastructure and failed, incurring huge welfare losses in the process.

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In this paper, we consider the outcomes of competitions to provide public infrastructure that are held by nations seeking to attract mobile factors under a global economy dominated by industries with significant vertical linkages. For this purpose, we have incorporated publicly provided transportation infrastructures into the new economic geography frameworks proposed by Krugman and Venables (1995) and Venables (1996). We show that an economy in which goods markets are nearly fully integrated has a pure strategy Nash equilibrium in which a less industrialized country makes smaller investments in public infrastructure than does a more industrialized country. An industry with significant vertical linkages never relocates, and thus, international specialization and income disparities remain persistent. However, in the process of integration, the global economy experiences a phase in which a pure strategy Nash equilibrium does not exist. Instead, there is a mixed strategy Nash equilibrium in which a less industrialized country's investments in public infrastructure vary much more than those made by a more industrialized country. The less industrialized country sometimes invests tremendous amounts in public infrastructure in the hopes of attracting an industry with scale effects. In many cases, despite these huge public investments, the country fails to industrialize and incurs massive economic losses that also affect the global economy. However, there is a small but definitely positive probability that an industry with scale effects can relocate.

Most research into fiscal competitions, including analyses of providing infrastructural public goods competitions, have employed a single-sector model of a standard neoclassical, non-increasing-return-to-scale production function. Traditional fiscal competition models showed that when governments choose the rate of a source tax on a mobile factor, the rate tends to be lower (Wilson (1986), Zodrow and Mieszkowski (1986) and Wildasin (1988)). When investing in infrastructure that enhances the productivity of a mobile factor, however, the amount tends to be larger than optimal (Keen and Marchand (1997)). Under the single-sector model of the standard neoclassical production function, the allocation of a mobile factor changes continuously with the gap in the tax rate or the provision of public infrastructure. Thus, the tax rate or the provision of public infrastructure in equilibrium is symmetric between countries.

However, industries with significant scale effects exist in the real world. In such cases, the allocation of a mobile factor that is intensively used in such industries will change discontinuously with the gaps in the tax rate and the provision of public infrastructure. In other words, the factor is stable until the gaps reach a certain size, then it moves lumpily. Under such circumstances, the outcomes of fiscal competitions differ significantly from the outcomes of the traditional fiscal competition literatures. In recent years, some researches into tax competitions have employed the framework of a new economic geography. Kind et al. (2000), Ludema and Wooton (2000) and Baldwin and Krugman (2004) analyzed the outcomes of tax competition employing a framework of new economic geography. Baldwin and Krugman (2004) applied the frameworks of Krugman and Venables (1995) and Venables (1996) to show that a country hosting an industrial concentration can raise its source tax rate on a mobile factor until the tax cost equals the concentration benefit for the factor.

In contrast to the tax competition, fiscal competition scenarios of public infrastructure provision are rarely analyzed in a framework of new economic geography. The provision of infrastructural public goods has much larger impacts than the source taxes, especially in an economy in which industries with significant scale effects are prevailing and the goods markets are integrating. Martin (1999) and Bucovetsky (2005) have been among the very few studies that have explicitly introduced infrastructural public goods into models with economies of scale. However, Bucovetsky's model is not grounded on a standard new economic geography model, and so it does not explicitly explain how some factors have scale effects in modern sectors and how public investment enhances productivity. The new economic geography model explicitly introduces vertical linkages in modern sectors, and our model explicitly introduces the contribution of transportation infrastructures to the construction of such linkages among firms. By doing so, we can directly consider how a governments' public infrastructure provision policies cause the location of modern industry to change discontinuously. Martin (1999) employs the new economic geography framework, but does not explicitly analyze the strategic interdependence among governments.

Our results fundamentally differ from earlier research into tax competition and infrastructure provision competition in traditional settings, and tax competition in new economic geography settings. The effects on equilibrium of a change in international transaction costs are more complex in our model than in the tax competition model of Baldwin and Krugman (2004). In their model, the more industrialized country always has a higher the tax rate of than the less industrialized country, though the difference varies with international transaction costs.[1)] Thus, an industry with scale effects never relocates, and it is the fate of the less industrialized country to perpetually remain less industrialized. In contrast, our model shows that when the international transaction costs are at a medium level, either country may provide more public infrastructure than the other. The less industrialized country may invest tremendous amounts in public infrastructure, and there is a small but definitely positive probability that an industry with vertical linkages will relocate.

This paper is organized as follows. Section 2 presents a basic economic geography model of a sector with vertical linkage, in which we incorporate public infrastructures, and section 3 examines the international specialization patterns. In section 4 we consider the outcome of the strategic public infrastructure provision game between countries, and in section 5 we discuss its welfare implications. Section 6 gives a numerical example of the game. Concluding remarks are given in Section 7.

2 A model with final and intermediate differentiated goods

Consider an economy which consists of two countries, A and B. In each country, unit measure of households inhabits, and the government collects lump sum tax from the inhabitants to provide public infrastructure there.

Households get utility from differentiated goods (X) and traditional goods (Y). Specifically, the utility of a household residing in country i is

$$\alpha \ln C^i_X + (1-\alpha)\ln C^i_Y, \quad i=A, B, \tag{1}$$

In (1), C^i_X is a composite index of the consumption of differentiated goods, C^i_Y, denotes the consumption of traditional goods in country i. The composite index C^i_X is a subutility function defined by a constant elasticity of substitution (CES) form:

$$C^i_X = \left[\int_{\kappa \in I^A \cup I^A} (C^i(\kappa))^\gamma d\kappa\right]^{\frac{1}{\gamma}} \quad i=A, B, \tag{2}$$

where $C^i(\kappa)$ denotes differentiated goods κ consumed in country i, and I^A and I^B are the sets of differentiated goods produced in country A and B, respectively. We assume that the number of differentiated goods is fixed, set the measure of $I^A \cup I^B$ as unity, and let n^i denote the measure of I^i ($n^i \in [0,1]$ and $n^A + n^B = 1$).[2)]

The budget constraint of a household in each country is

$$E^i \equiv P^i C_X^i + p_Y^i C_Y = \frac{1}{2}\int_{\kappa \in I^A \cup I^B} \pi(\kappa) d\kappa + w^i - T^i, \quad i = A, B, \tag{3}$$

where E^i denotes per capita consumption expenditure, and P^i is the minimum cost of purchasing a unit of C_X^i in country i :

$$P^i = \left[\int_{\kappa' \in I^A \cup I^B} (p^i(\kappa'))^{1-\varepsilon} d\kappa'\right]^{\frac{1}{1-\varepsilon}}, \quad i = A, B, \tag{4}$$

where $p^i(\kappa)$ is the consumer price of goods κ in country i, and $\varepsilon = 1/(1-\gamma) \geqq 1$. Also, p_Y^i denote the price of traditional goods in country i. The right side of (3) is per capita disposable income, where w^i and T^i denote wages and lump sum tax in country i, respectively. Also, $\pi(\kappa)$ denotes monopolistic competition profits of the firm which supplies differentiated good κ. The stocks of the differentiated goods firms and then the dividends $\pi(\kappa)$ are shared equally by households. Optimization yields

$$C^i(\kappa) = \frac{(p^i(\kappa))^{-\varepsilon}}{(P^i)^{1-\varepsilon}} \alpha E^i, \quad i = A, B, \tag{5}$$

$$C_Y^i = (1-\alpha)\left(\frac{E^i}{p_Y^i}\right), \quad i = A, B. \tag{6}$$

One unit of traditional goods is produced using one unit of labor as inputs and supplied in a perfect competitive market, which implies marginal cost pricing. Assuming that the preference for traditional goods is sufficiently large for the sector to operate in both countries, the prices and then the wages are equalized between two countries. We set the wages as the numeraire. Then

$$p_Y^A = p_Y^B = w^A = w^B = 1. \tag{7}$$

Differentiated goods cannot be traded without some transportation costs, as is common in new economic geography models. Here we assume that the transportation costs are necessary even when the goods are traded within a country domestically, and the costs depend on the level of domestic public infrastructure. We assume the iceberg form of the domestic transportation costs which depends on the level of public infrastructure in that country. Specifically, to sell one unit in the country where a firm locates domestically, $1/(G^i)^\eta > 1$ units must be produced. G^i represents the level of public infrastructure in country i such as highway roads, harbors and railways which contribute in the reduction of the transportation costs, and η is assumed to be $\eta \in (0,1)$.[3] In trading differentiated goods internationally, the goods must be transported along the both countries' transportation facilities. In addition, one unit of differentiated good melts down to $\tau \in [0,1]$ units when it crosses the border. Therefore, to sell one unit in the other country, $\{1/(G^A)^\eta\}\{1/(G^B)^\eta\}(1/\tau) > 1$ units must be produced. τ less than unity is plausible in the case where countries are divided by mountains, rivers and oceans, as is often the case. Also gaps in languages and customs between countries should make τ smaller. However, as the technologies of transportation facilities such as aviation and shipping improve and the gaps in languages and trading customs diminish, τ approaches to unity. Then we let τ represent to what degree the globalization have proceeded.

To provide one unit of infrastructure, the government in each country must employ one unit of labor as inputs at market wage rate ($w=1$) with tax income T^i. Therefore, the labor force devoted to the production of the infrastructure is

$$l_G^i = G^i = T^i, \quad i = A, B. \tag{8}$$

Each differentiated good is monopolistically supplied by the firm that invented that good. In addition to labor, differentiated goods use themselves as intermediate inputs. Specifically, the production function of the differentiated goods κ located in country i is written as follows:[4)]

$$x^{ii} = (M^i)^a (l^i)^{1-a} (G^i)^\eta, \quad i = A, B, \tag{9}$$

$$x^{ij} = (M^{i*})^a (l^{i*})^{1-a} (G^A G^B)^\eta \tau, \quad i, j = A, B, i \neq j, \tag{9'}$$

where x^{ii} and x^{ij} (i, j=$A, B, i \neq j$) denote the provisions of differentiated goods per firm in country i domestically and in another country j, measured by the amount actually sold, respectively. Also, M^i and M^{i*} are composite indexes of the intermediate inputs, and l^i and l^{i*} are the devoted labor force to produce the differentiated goods in the amounts of x^{ii} and x^{ij}, respectively. The composite indexes are sub-production functions defined by a form with the same CES rate as (2). Then, the minimum costs of purchasing the units of the composite indexes can also be written as (4).

The choice of the price that maximizes profits is a constant markup (γ) over unit cost, with the markup depending on the elasticity of demand (ε) for differentiated goods by both households and firms:

$$p^{ii} = \frac{(P^i)^a}{\gamma (G^i)^\eta}, \; p^{ij} = \frac{(P^i)^a}{\gamma (G^A G^B)^\eta \tau}, \quad i = A, B, i \neq j. \tag{10}$$

where p^{ij} is the prices of the differentiated goods produced in country i and provided in country j. Inserting (10) into (4) yields

$$P^i = \left(\frac{1}{\gamma}\right)\left[n^i (P^i)^{a(1-\varepsilon)} \left(\frac{1}{G^i}\right)^{\eta(1-\varepsilon)} + n^j (P^j)^{a(1-\varepsilon)} \left(\frac{1}{G^A G^B}\right)^{\eta(1-\varepsilon)} \left(\frac{1}{\tau}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}, \quad i, j = A, B, i \neq j. \tag{11}$$

From (11), we can see that P^A and P^B can be expressed as the functions of n^A and G^i:

$$P^A = P^A(n^A, G^A, G^B), \; P^B = P^B(n^A, G^B, G^A). \tag{12}$$

The profits per differentiated goods firm in country A relative to that in country B is

$$f(G^A, G^B, n^A) = \frac{\pi^A}{\pi^B} = \left[\frac{\{\Omega_{AA} - \alpha\gamma(\Omega_{AA}\Omega_{AA} - \Omega_{AB}\Omega_{BA})\} E^A + \Omega_{AB} E^B}{\Omega_{BA} E^A + \{\Omega_{BB} - \alpha\gamma(\Omega_{AA}\Omega_{BB} - \Omega_{AB}\Omega_{BA})\} E^B}\right]\left(\frac{n^B}{n^A}\right), \tag{13}$$

where π is monopolistic competition profit per firm in country i and $\Omega_{ij} \equiv n^i (p^{ij})^{1-\varepsilon} / (P^j)^{1-\varepsilon} (i \neq j)$ is the share of the expenditure by a household in country j for the differentiated goods produced in country i out of its total expenditure for differentiated goods. Hence, $\Omega_{ii} + \Omega_{ij} = 1$ holds. See Appendix A for the derivation of (13). From (10)-(12), P^i and p^{ij} can be expressed as the functions of n^A and G^i (i=A, B). Therefore, Ω^{ii} and Ω^{ij} can also be expressed as functions of n^A and G^i. In addition, as we will see soon, E^i depends on G^i as well. Hence, π^A / π^B can also be written as a function of n^A and G^i.

We assume that there are no costs in the relocations of differentiated goods firms.Differentiated goods firms stably disperse into two countries if $n^A \in [0, 1]$ which satisfies $f(G^A, G^B, n^A) = 1$ and $\partial f(G^A, G^B, n^A) / \partial n^A < 0$ exist.[5)] We can derive the equalized profits as

$$\pi^A = \pi^B = (1-\gamma)\alpha\left(\frac{E^A + E^B}{1 - \alpha\gamma}\right). \tag{14}$$

With (3), (14) and (8), E^i can be derived as

$$E^i(G^i, G^j) = \left(\frac{1}{1-\alpha\gamma-\alpha+\alpha\gamma}\right)\left[1-\alpha\gamma-\frac{1}{2}\{(2-2\alpha\gamma-\alpha+\alpha\gamma)G^i+\alpha(1-\gamma)G^j\}\right], \quad i, j=A, B, i\neq j. \tag{15}$$

See Appendix A for the details about the derivations of (14) and (15).

Note that differentiated goods firms can agglomerate in country A (B) if $f(G^A, G^B, 1)\geq 1$ ($f(G^A, G^B, 0)\leq 1$) is satisfied. In such a case π^i and E^i ($i=A, B$) can also be calculated as (14) and (15), respectively. From (11), P^i and P^j when the firms agglomerate in country i are calculated as

$$P^i = \left(\frac{1}{\gamma}\right)^{\frac{1}{1-\alpha}}\left(\frac{1}{G^i}\right)^{\frac{\eta}{1-\alpha}}, P^j = \left(\frac{1}{\gamma}\right)^{\frac{1}{1-\alpha}}\left(\frac{1}{G^i}\right)^{\frac{\eta}{1-\alpha}}\left(\frac{1}{G^j}\right)^{\eta}\left(\frac{1}{\tau}\right), \quad i, j=A, B, i\neq j. \tag{16}$$

3 Location patterns

In this section, we consider the international allocation patterns of differentiated goods firms. As we have seen in section 2, differentiated goods firms stably disperse if $n^A \in [0,1]$ which satisfies $f(G^A, G^B, n^A)=1$. Let Q^O denote the set of (G^A, G^B) under which the firms disperse:

$$Q^O=\{(G^A, G^B)\,|\,f(G^A, G^B, n^A)=1 \text{ and } \partial f(G^A, G^B, n^A)/\partial n^A<0 \text{ with } n^A\in[0, 1]\}.$$

However, n^A can be unity if $f(G^A, G^B, 1)\geq 1$ and can be zero if $f(G^A, G^B, 0)\leq 1$. Let Q^i denote the set of (G^A, G^B) under which firms potentially concentrate in country i:

$$Q^A=\{(G^A, G^B)\,|\,f(G^A, G^B, 1)\geq 1\}, Q^B=\{(G^A, G^B))\,|\,f(G^A, G^B, 0)\leq 1\}.$$

We can write $f(G^A, G^B, 1)$ as:[6)]

$$\frac{E^A+E^B}{\{(G^B)^\eta\tau\}^{(1+\alpha)(\varepsilon-1)}E^A+\{(1-\alpha\gamma)(G^A)^{-\eta(\varepsilon-1)}\{(G^B)^\eta\tau\}^{\alpha(\varepsilon-1)}\tau^{1-\varepsilon}+\alpha\gamma\{(G^B)^\eta\tau\}^{(1+\alpha)(\varepsilon-1)}\}G^B}. \tag{17}$$

With (17) and (15), we can calculate(G^A, G^B) which satisfies $f(G^A, G^B, 1)=1$ and thus is on the border of Q^A. Let $G^A=h(G^B)$ denote the border. Due to the symmetric property, we can let $G^B=h(G^A)$ denote the border of Q^B. In contrast, complex calculations are required to analytically express the border of Q^O.

Figure 1 shows the areas of Q^O, Q^A and Q^B for some numerical examples. Figure 1(i) shows the case for a large τ and Figure 1(ii) shows the case for a small τ. The area enclosed by the dotted line is Q^O, the area on the right side of $G^A=h(G^B)$ is Q^A, and the area above $G^B=h(G^A)$ is Q^B. These areas overlap, and thus there are multiple equilibria. Figures 2(a)-(g) show how n^A in equilibrium is determined by observing the gap in π^i for each of the 7 typical points $Sa - Sg$ in Figure 1(ii), respectively. If $\pi^A-\pi^B$ is positive at $n^A=1$, firms can stably concentrate in country A. If $\pi^A-\pi^B$ is negative at $n^A=0$, firms can stably concentrate in country B. If $\pi^A-\pi^B=0$ at $n^A\in[0,1]$ and it is decreasing at that point, firms can stably disperse at the rate of n^A.

In a country with more differentiated goods, a firm can enjoy smaller production costs due to the advantage in accessibility to intermediate goods as (11) and (16) indicate. On the other hand, the firm faces fiercer competition.Whether or not agglomeration takes place depends on the relative size of these offsetting effects, which in turn depends on domestic public infrastructures G^i and international transaction efficiency τ.

First, we consider the case in which no gap exists in G^i, as in $Sa - Sg$. When G^A and G^B are very small, as in Sa included in $Q^O\backslash Q^A\backslash Q^B$ of Figure 1(ii), there is a unique stable dispersion equilibrium, as Figure 2(a) indicates. The costs of producing differentiated goods are smaller in a country with a larger number of firms, but not so small as to overcome the negative pressure on profits brought about by fiercer competition. In such cases,

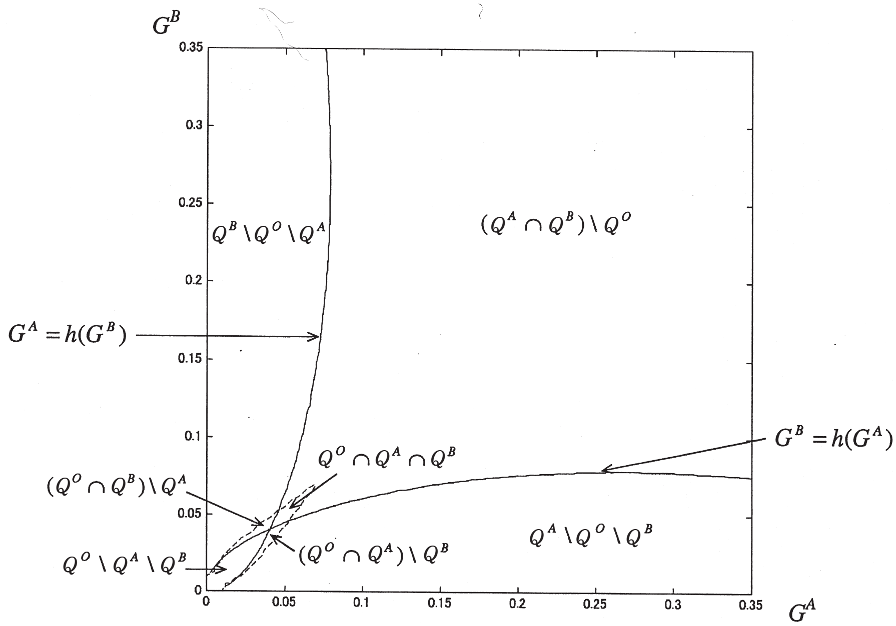


Figure 1 (i)

Sets of Q^O, Q^A, and Q^B

$\alpha = 0.5, a = 0.4, \eta = 0.1, \gamma = 0.7$ and $\tau = 0.700$

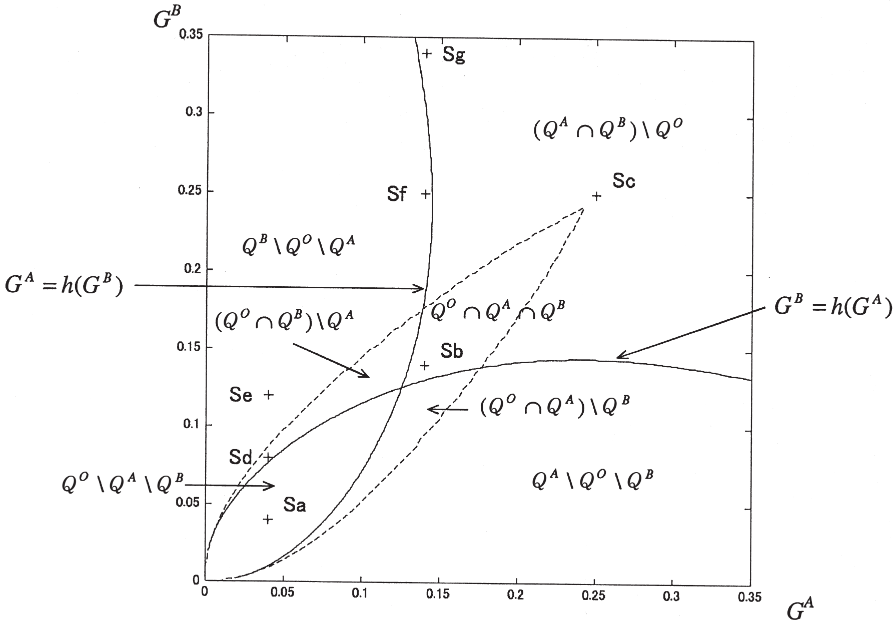


Figure 1 (ii)

Sets of Q^O, Q^A, and Q^B

$\alpha = 0.5, a = 0.4, \eta = 0.1, \gamma = 0.7$ and $\tau = 0.625$

differentiated goods firms will move to a country with fewer firms.

When G^A and G^B are medium in size, as in *Sb* in $Q^O \cap Q^A \cap Q^B$, agglomeration equilibrium potentially emerges in any country, as Figure 2(b) indicates. When all the differentiated goods firms are concentrated in a single country, the production costs can be small enough to overcome the negative pressure on profits brought about by fierce competition. However, the dispersion equilibrium is also stable. Suppose that firms initially disperse equally between two countries, but then a firm moves to the other country. The magnitude of the cost reduction caused by such tiny shifts in the locations of firms that were initially equally dispersed cannot be larger than the magnitude of the reduction in profits. It is not until G^A and G^B become much larger that the dispersion equilibrium becomes unstable. When G^A and G^B are very large, as in *Sc* in $(Q^A \cap Q^B) \backslash Q^O$, the magnitude of the costs reduction achieved by hosting more firms is always larger than the magnitude of profits reduction, as Figure 2(c) indicates.

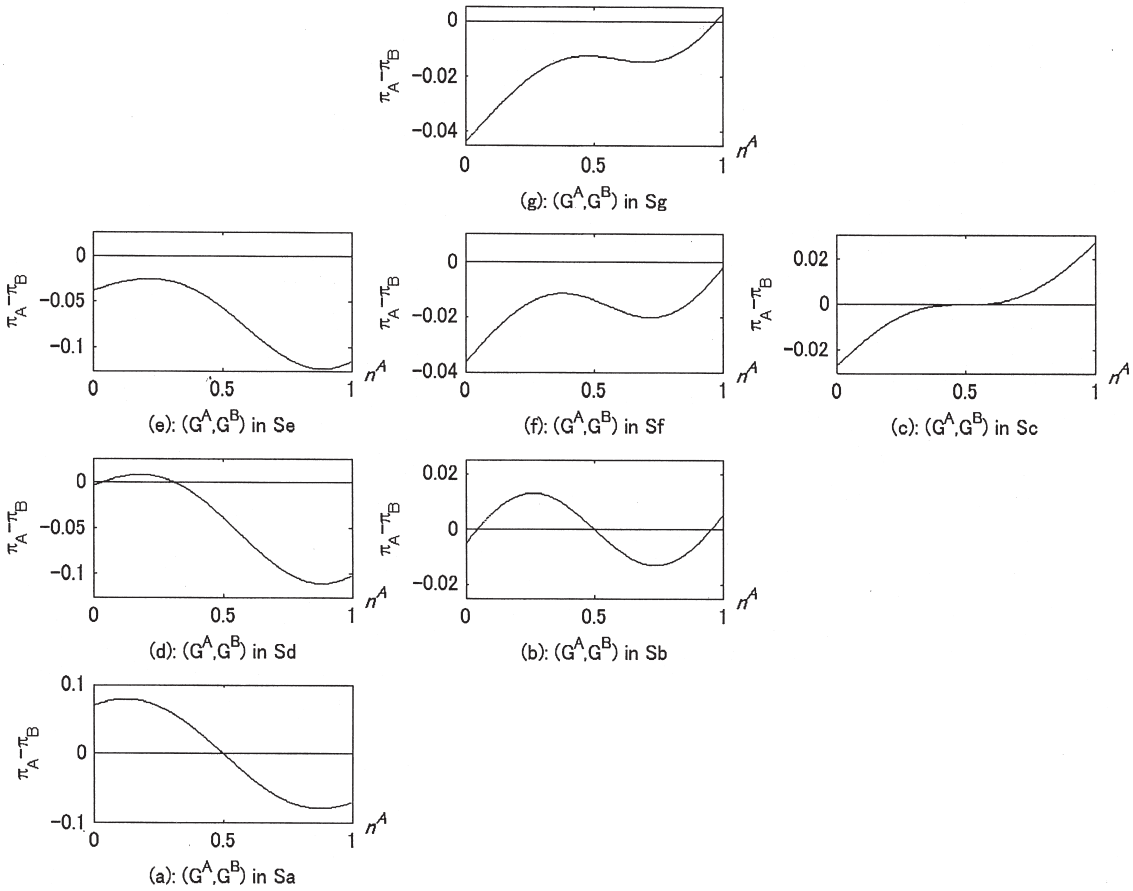


Figure 2

Gap in profits per firm between two countries: $\pi^A - \pi^B$

$\alpha = 0.5$, $a = 0.4$, $\eta = 0.1$, $\gamma = 0.7$ and $\tau = 0.625$

Next, we consider the case in which a gap exists in G^i as in $Sd-Sg$. Consider the case where G^A and G^B are small but G^B is larger than G^A, as in the *Sd* that is included in $(Q^O \cap Q^B) \backslash Q^A$ of Figure 1(ii). As Figure 2(d) indicates, in addition to stable dispersion equilibrium, agglomeration equilibrium potentially emerges in country B. The costs of producing differentiated goods are smaller in the country with the larger number of firms. However, when agglomeration takes place in country A, the absolute level of the production costs will never be small enough to overcome the negative pressure on profits caused by fiercer competition. In contrast, when agglomeration takes place in country B, which has a larger public infrastructure, the production costs can be small enough. It is not until G^B becomes much larger, as in the *Se* included in $Q^B \backslash Q^O \backslash Q^A$, that the dispersion equilibrium becomes unstable, and the industry concentration in country B comes into unique equilibrium, as Figure 2(e) indicates.

When G^A and G^B are medium in size but G^B is larger than G^A, as in the *Sf* included in $Q^B \backslash Q^O \backslash Q^A$ of Figure 1(ii), agglomeration in country B is a unique equilibrium, just as it was in *Se*. However, when G^A and G^B are, on average, medium in size but G^B is much larger than G^A, as in the *Sg* included in $(Q^A \cap Q^B) \backslash Q^O$ of Figure 1(ii), differentiated goods sector can potentially concentrate in any country. That is, in *Sb, Sf* and *Sg*, G^A is the same while G^B is larger in this order. In *Sb*, differentiated goods sector can agglomerate in any country as we have seen, but in *Sf* it can agglomerate only in country B. However, note that in *Sg*, it can agglomerate in any country again. To understand why, consider the incentive in the location choice of a firm in country A if all of the differentiated goods firms are concentrated in this country. The larger the G^B, the smaller the costs for a firm in country A to produce and sell goods to foreign market (country B in this case), and thus the larger the profits from the foreign markets. On the other hand, a firm can expect larger profits if it moves to country B, where the competition is less fierce and the infrastructure, G^B, is richer. When the gap in G^i is moderate, the latter factor dominates and the agglomeration in country A is unstable.In contrast, when the gap in G^i becomes prominent, the former factor dominates and the agglomeration in country A can be stable again.

Finally, we consider the impact of a change in international transaction efficiency on the equilibrium pattern. International transaction costs protect a domestic market from imports. Therefore, when international transaction costs are high, the domestic market is much less competitive, and so profits can be larger in the country with the smaller n^i. Thus, the dispersion tends to be stable equilibrium. In contrast, when international transaction costs are smaller, the market protection effect is less prominent and dispersion is less likely to be stable equilibrium, and agglomeration is less likely to collapse. Then, the smaller the international transaction costs (the larger τ), the smaller the area of Q^O and the larger the area of Q^A and Q^B. Accordingly, the smaller the international transaction costs (the larger τ), the lower the border between the areas $Q^B \backslash Q^O \backslash Q^A$ and $(Q^O \cap Q^B) \backslash Q^A$ while the higher the border between $Q^B \backslash Q^O \backslash Q^A$ and $(Q^A \cap Q^B) \backslash Q^O$ as we can see by comparing Figures 1(i) and (ii). Hence, when the other country outlays a very small G^j, a country can attract the whole of the differentiated goods sector by making G^i a bit larger.[7)]

In this sense, the smaller the transaction costs, the more sensitive the location patterns of differentiated goods firms to a gap in G^i (Martin and Rogers (1995)). In contrast, when the other country makes a larger G^j investment, it is more difficult or even impossible for a country to break up the agglomeration in that other country and rebuild it within its own border.[8)]

4. Strategic provision of public infrastructures

4. 1 A public infrastructure provision game

Households in a country with more differentiated goods firms can enjoy a smaller price index P^i. The government in each country therefore will provide public infrastructure to attract more differentiated goods firms. In this section, we consider the outcome of such a game between governments that maximize the utilities of the households in their own countries.

First, governments choose G^A and G^B simultaneously. Next, in response to these G^A and G^B, differentiated goods firms determine where to locate. We assume that initially differentiated goods ector agglomerates in country A, and as long as (G^A, G^B) in Q^A is chosen, the agglomeration is never collapsed.[9] The complementary set of Q^A is divided into three sets: $Q^O\backslash Q^A\backslash Q^B$, $(Q^O\cap Q^B)\backslash Q^A$ and $Q^B\backslash Q^O\backslash Q^A$ as we can see in Figure 1. When (G^A, G^B) in $Q^O\backslash Q^A\backslash Q^B$ is chosen, dispersion is a unique equilibrium, and when (G^A, G^B) in $Q^B\backslash Q^O\backslash Q^A$ is chosen, agglomeration in country B is a unique equilibrium. However, if G^B takes a middle level between the two cases above so that (G^A, G^B) is in $(Q^O\cap Q^B)\backslash Q^A$, there are potentially two equilibria: agglomeration in country B and dispersion equilibria, as Figure 2(d) indicates. However, it would be natural that starting from $n^A=1$, with a middle level G^B, country B cannot immediately attract a whole of differentiated goods sector. Therefore, we assume that when (G^A, G^B) in $(Q^O\cap Q^B)\backslash Q^A$ is chosen, not agglomeration in country B but dispersion equilibrium emerges. We let R^i denote the set of (G^A, G^B) under which differentiated goods sector agglomerates in county i: $R^A=Q^A$ and $R^B=Q^B\backslash Q^O\backslash Q^A$, and let R^O denote the set under which differentiated goods firms disperses between two countries ($((Q^O\cap Q^B)\backslash Q^A$ is included in R^O). We let $G^B=l(G^A)$ denote the border between R^B and R^O.[10] Henceforth, we call the country where differentiated goods firms agglomerate the core, and the other the periphery.

With the governments' choice of (G^A, G^B) and n^A that is consistent with it, a household's utility in each country is determined. Let $u^i(G^i, G^j, n^i)$ denote the utility. By inserting (10) into (5), (7) into (6), and these (5) and (6) into (1) yields

$$u^i(G^i, G^j, n^i)=\ln E^i(G^i, G^j)-\alpha\ln P^i(n^A, G^i, G^j),\quad i, j=A, B, i\neq j. \tag{18}$$

Especially, when (G^A, G^B) is in R^A or R^B, using (16) we can rewrite (18) as follows

$$u^A(G^A, G^B, 1)=\ln E^A(G^A, G^B)+\left(\frac{\alpha\eta}{1-a}\right)\ln G^A, \text{ if } (\mathrm{G^A}, \mathrm{G^B})\in R^A, \tag{18AC}$$

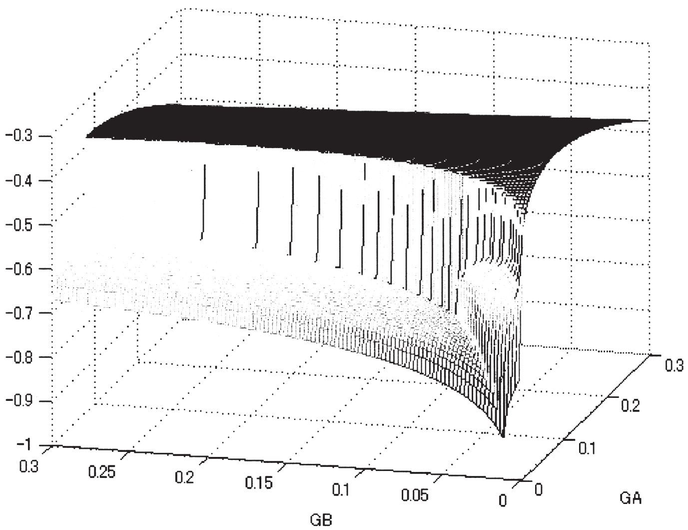
$$u^A(G^A, G^B, 0)=\ln E^A(G^A, G^B)+\left(\frac{\alpha\eta}{1-a}\right)\ln G^B+\alpha\eta\ln G^A+\alpha\ln\tau, \text{ if}(G^A, G^B)\in R^B, \tag{18AP}$$

$$u^B(G^B, G^A, 0)=\ln E^B(G^B, G^B)+\left(\frac{\alpha\eta}{1-a}\right)\ln G^A+\alpha\eta\ln G^B+\alpha\ln\tau, \text{ if}(G^A, G^B)\in R^A, \tag{18BP}$$

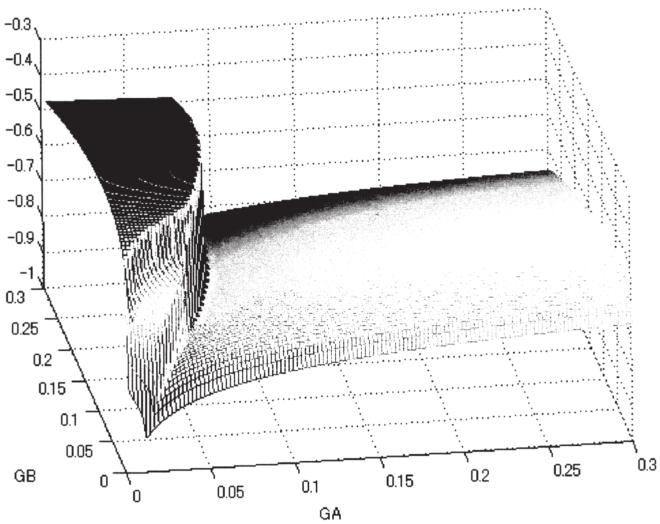
$$u^B(G^B, G^A, 1)=\ln E^B(G^B, G^A)+\left(\frac{\alpha\eta}{1-a}\right)\ln G^B, \text{ if } (\mathrm{G^A}, \mathrm{G^B})\in R^B. \tag{18BC}$$

Household's utility in each country is drawn in Figures 3(i) and 3(ii) under the same numerical example of parameters as in Figures 1(i) and 1(ii).

Note that function $u^i(G^i, G^j, n^i)$ is discontinuous on the border between R^i and R^O, as well as on the border between R^A and R^B. We can see in Figures 2(d) and 2(e) that when country B increases G^B from Sd to Se in Figure 1(ii), the stable dispersion equilibrium disappears before n^A of the dispersion equilibrium moves



Country A's utility: $u^A(G^A, G^B, n^A)$

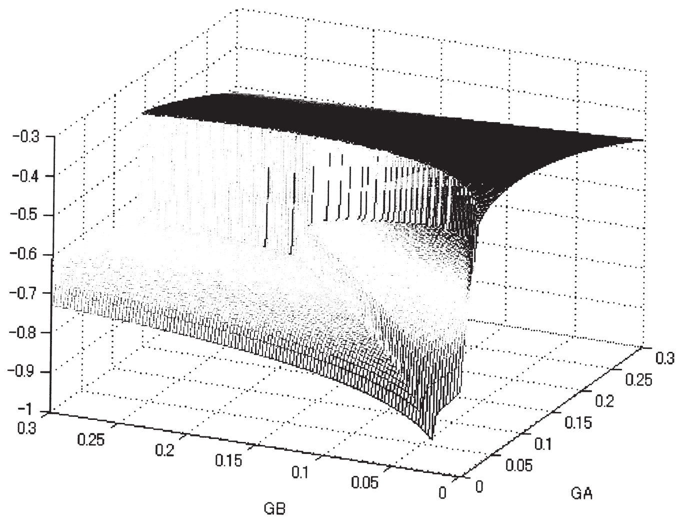


Country B's utility: $u^B(G^B, G^A, n^B)$

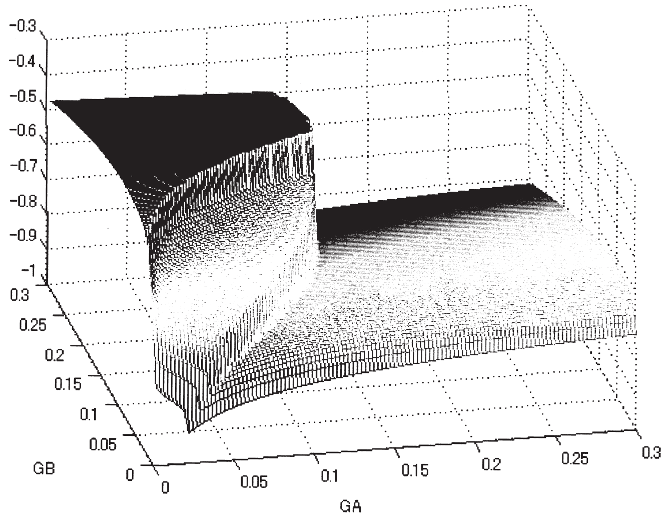
Figure 3 (i)

Utility functions

$\alpha = 0.5$, $a = 0.4$, $\eta = 0.1$, $\gamma = 0.7$ and $\tau = 0.700$



Country A's utility: $u^A(G^A, G^B, n^A)$



Country B's utility: $u^B(G^B, G^A, n^B)$

Figure 3 (ii)

Utility functions

$\alpha = 0.5, a = 0.4, \eta = 0.1, \gamma = 0.7$ and $\tau = 0.625$

sufficiently away from 0.5 and approaches 0, and the agglomeration in country B becomes a unique equilibrium. Thus, when (G^A, G^B) crosses the border from R^O to R^B, country B's utility is drastically improved. Similarly, when (G^A, G^B)crosses the border from R^O to R^A, country A's utility is drastically improved:

$$u^A(h(G^B), G^B, 1) > u^A(G^A, G^B, n^A) \text{ for } G^A < h(G^B), 0 \leq n^A < 1, \tag{19A}$$

$$u^B(h(G^B), G^A, 1) > u^B(G^B, G^A, n^B) \text{ for } G^B < h(G^A), 0 \leq n^B < 1. \tag{19B}$$

We consider the cases in which the followings are satisfied:

$$u^A(\overline{G}^P, G^B, 1) > u^A(G^A, G^B, n^A) \text{ for } G^A < h(G^B), 0 \leq n^A < 1, \tag{20A}$$

$$u^B(\overline{G}^C, G^A, 1) > u^B(G^B, G^A, n^B) \text{ for } G^B < h(G^A), 0 \leq n^B < 1. \tag{20B}$$

These are a bit more stringent than (19), yet in almost all numerical settings including the ones in Figures 1-3, we can see that any $u^i(G^i, G^j, 1)$ on R^i is not smaller than any $u^i(G^i, G^j, n^i)$ on R^j and R^O.

4. 2 The existence of a Nash equilibrium of pure strategies

In this subsection we consider the two countries reaction functions and the existence of a pure strategy Nash equilibrium.

County A's utility when it is the core (18AC) is a concave function. We denote a unique G^A that maximizes (18AC) under a given G^B as $G^A = \phi^C(G^B)$ (script C means Core):

$$\frac{\partial u^A(\phi^C(G^B), G^B, 1)}{\partial G^A} = 0. \tag{21}$$

$G^B = \phi^C(G^A)$ can maximize (18BC). Then, $G^i = \phi^C(G^j)$ gives the optimal G^i given that country i is the core and the other country j chooses G^j. Similarly, there is a unique G^B that maximizes (18BP). We denote it as $G^B = \phi^P(G^A)$ (script P means Periphery):

$$\frac{\partial u^B(\phi^P(G^B), G^A, 0)}{\partial G^B} = 0. \tag{22}$$

$G^A = \phi^P(G^B)$ can maximize (18AP). Then, $G^i = \phi^P(G^j)$ gives the optimal G^i given that country i is the periphery and the other country j chooses G^j. We let $\widetilde{G}^C$ and $\widetilde{G}^P$ denote G^A and G^B that simultaneously satisfy $G^A = \phi^C(G^B)$ and $G^B = \phi^P(G^A)$. Also, we let $\widetilde{G}^C$ denote the smallest G^A under which the initial peripheral country B cannot attract differentiated goods firms with any G^B, and define $\overline{G}^P$ as $\overline{G}^P = h^{-1}(\overline{G}^C)$.

Figures 4(i) and 4(ii) show $G^i = \phi^C(G^j)$, $G^i = \phi^P(G^j)$, $G^i = h(G^j)$, $G^B = l(G^A)$, $\widetilde{G}^C$, $\widetilde{G}^P$, $\overline{G}^C$, $\overline{G}^P$ and the reaction functions of the two countries. If country j's choice of G^j is so small that G^j and $G^i = \phi^C(G^j)$ are in R^i, country i can attract (or keep) the whole of the differentiated goods sector and achieve maximum utility by choosing $G^i = \phi^C(G^j)$. In contrast, if country j's choice of G^j is so large that G^j and $G^i = \phi^C(G^j)$ is not in R^i but in R^j or R^O, then country i cannot attract all of the differentiated goods firms with $G^i = \phi^C(G^j)$. When G^i is large enough to be in R^i, country i may be able to attract (or keep) the entire differentiated goods sector and attain much higher utility. For example, facing a very large G^B, country A will keep all of the differentiated goods sector by choosing $G^A = h(G^B)$. Similarly, facing a very large G^A, country B can attract all of the differentiated goods sector and attain much higher utility by choosing G^B that is equal to $l(G^A)$ or slightly larger than $h^{-1}(G^A)$. However, when G^A is larger than $\overline{G}^C$, country B cannot attract any differentiated goods firms at all. Given such a situation, the country B will choose $\phi^P(G^A)$. Therefore, country B's reaction function is discontinuous at $G^A = \overline{G}^C$.

Due to the discontinuity of country B's reaction function, $(G^A, G^B) = (\widetilde{G}^C, \widetilde{G}^P)$ is not necessarily a pure strategy Nash equilibrium. If the $G^A = \overline{G}^C$ at which country B's reaction function is discontinuous is smaller than $\widetilde{G}^C$,

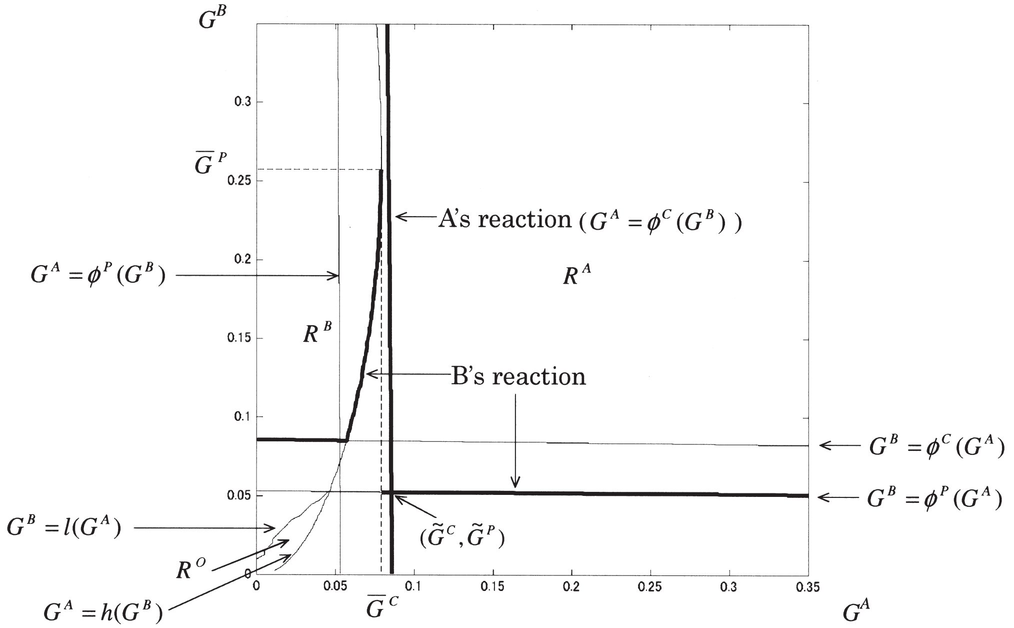


Figure 4 (i)

Reaction functions

$\alpha = 0.5, a = 0.4, \eta = 0.1, \gamma = 0.7$ and $\tau = 0.700$

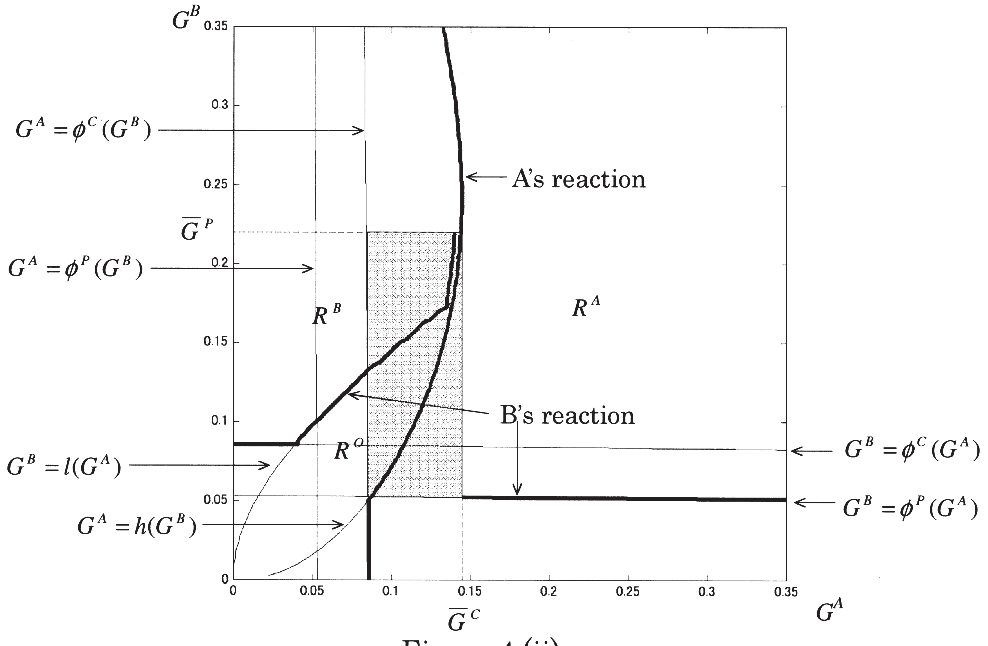


Figure 4 (ii)

Reaction functions

$\alpha = 0.5, a = 0.4, \eta = 0.1, \gamma = 0.7$ and $\tau = 0.625$

then the two countries' reaction functions will intersect. As we can see in Figures 4(i) and (ii), the smaller the international transaction costs, the more likely the two countries' reaction functions will intersect and for $(G^A, G^B)=(\tilde{G}^C, \tilde{G}^P)$ to be a pure strategy Nash equilibrium.

As discussed in section 3, when international transactions are very efficient (τ is very large), the agglomeration force is extremely prominent. Even when the periphery invests a tremendous amount G^B, the initial core country A can completely prevent the relocation of the differentiated goods sector with a relatively small $\bar{G}^C$, and so $\bar{G}^C \leq \tilde{G}^C$. Facing the core country A's public infrastructure level $\tilde{G}^C$, the peripheral country B cannot relocate any of the differentiated goods firms at all. Therefore, country B will choose public infrastructure level $\tilde{G}^P$ to maximize its utility, given that no part of the differentiated goods sector relocates. And facing such a peripheral country B's choice of public infrastructure investment, core country A will actually choose $\tilde{G}^C$ and achieve the maximum utility level, completely preventing the relocation of the differentiated goods sector. Thus, $(\tilde{G}^C, \tilde{G}^P)$ can be a pure strategy Nash equilibrium, and the differentiated goods sector never relocates.

In contrast, when international transactions are less efficient (τ is smaller), the agglomeration force is less prominent, as we have discussed in section 3. Initial core country A cannot prevent differentiated goods sector' s relocation without a very large G^C, and so $\bar{G}^C > \tilde{G}^C$. In this case, when the initial core country chooses $\tilde{G}^C$, the initial peripheral country B can attract the differentiated goods sector with a large but less than extreme amount of G^B and is accordingly willing to do so. These results are summarized by

Proposition 1

If and only if $\bar{G}^C \leq \tilde{G}^C$, $(G^A, G^B)=(\tilde{G}^C, \tilde{G}^P)$ is the pure strategy Nash equilibrium.

4. 3 The properties of a Nash equilibrium of mixed strategies

We consider the game of mixed extension in the case that $\tilde{G}^C < \bar{G}^C$ holds and there is no pure strategy Nash equilibrium.

Let $f^i(G^i)$ denotes the density function that shows the probability for country i to choose G^i. Given country i's belief about country j's strategy $f^j(G^j)$, the country i's expected utility when it chooses G^i is

$$V^i(G^i) = \int_{G^j \in [0,1]} u^i(G^i, G^j, n^i) f^j(G^j) dG^j,$$

where n^i is determined depending on which of R^A, R^B or R^O, the choice of (G^A, G^B) is included. Then, the country i determines $f^i(G^i)$ (how to mix its strategies G^i) so as to maximize

$$W^i = \int_{G^i \in [0,1]} V^i(G^i) f^i(G^i) dG^i.$$

If the $f^A(G^A)$ and $f^B(G^B)$ actually chosen are corresponds to their initial believes about the other country's behavior, then such a combination of mixed strategies is a Nash equilibrium. The next proposition gives the maximum and minimum of G^i which will be included in the strategies in equilibrium.

Proposition 2

Suppose the case that $\tilde{G}^C < \bar{G}^C$ holds. And let $G^{i\,\max}$ and $G^{i\,\min}$ denote the maximum and minimum G^i, respectively. Then,

(i) $G^{A\min}$ should satisfy $h(G^{B\min}) \leq G^{A\min}$.

(ii) $G^{B\min}$ should satisfy $\phi^P(\overline{G}^C) \le G^{B\min} \le \phi^P(0)$.
(iii) $G^{A\max} = \overline{G}^C$.
(iv) $G^{B\max} = \overline{G}^P$.

Proof See Appendix B.

In Figure 4 (ii), shadowed rectangle shows the area of G^i on which $f^i(G^i)$ can be positive under the same numerical example of parameters as in Figures 1(ii) and 3(ii).

As discussed earlier, when international transaction costs are large, the agglomeration force is less prominent. If initial core country A chooses $\widetilde{G}^C$ only, initial peripheral country B can attract all of differentiated goods sector with a large G^B, such as $l(\widetilde{G}^C)$. Thus $\widetilde{G}^C$, $\widetilde{G}^P$) cannot be a Nash equilibrium. To prevent the relocation of the sector, country A must choose a larger G^A. Particularly when G^A is as large as $\overline{G}^C$, country A can completely prevent the relocation and thus may be willing to do so. Therefore, assuming that country A includes in its strategy $\overline{G}^C$ as well as a smaller G^A, we will first consider the strategy of initial peripheral country B. Then, we will confirm our assumption about the country A's strategy is correct.

Given such a country A's strategy, country B cannot necessarily become the core even with a very large $\overline{G}^P$. Therefore, country B will include in its strategy not only a very large $\overline{G}^P$ but also a small one such as $G^B \in [\phi^P(\overline{G}^C), \phi^P(0)]$, which will be preferable in the case that the differentiated goods sector will not relocate after all. Facing such a country B's strategy, country A can completely prevent the relocation with $\overline{G}^C$, as we have discussed. However, country A still includes a G^A that is smaller than $\overline{G}^C$. Although the risk of relocation is positive, a G^A smaller than $\overline{G}^C$ is preferable when the differentiated goods sector remains in country A after all. Hence, a Nash equilibrium can be a combination of strategies in which country A chooses a large $\overline{G}^C$ as well as a smaller G^A, while country B chooses a very large $\overline{G}^P$ as well as a smaller one (such as $G^B \in [\phi^P(\overline{G}^C), \phi^P(0)]$). The differentiated goods sector can relocate in this case with positive probability.

5. Economic welfare

In this section we consider the efficiency of the outcomes of the games discussed thus far. We first consider the efficiency of the pure strategy Nash equilibrium when it exists. Before the analysis, we consider how the G^j of the other country j impacts the utility of country i, which each country will not take into consideration. From (15) and (18), these impacts are summarized as follows.

$$\frac{\partial u^A(G^A, G^B, 1)}{\partial G^B} < 0, \tag{23}$$

$$\frac{\partial u^B(G^B, G^A, 1)}{\partial G^A} > 0. \tag{24}$$

To make the transportation facilities within the country more efficient, each government must impose a higher tax burden on the households in its country. The households in the country where the tax increase takes place must reduce their consumption expenditures, leading to a fall in the profits for a differentiated goods firm. Therefore, given that the stock of the differentiated goods firm is shared by households in both countries, the decrease in the firm's profits reduces household disposable incomes in the other country where there is no tax increase as well.

However, an improvement in the transportation facilities in the core country can improve the utility of the peripheral country. When differentiated goods firms agglomerate in country A, an increase in G^A reduces the costs to transport intermediate goods back and forth within country A, which drastically reduces their production costs and prices. An increase in G^A therefore benefits not only the households in country A, but also those in country B who fully import differentiated goods from country A. In contrast, an improvement in the transportation facilities in the peripheral country has no such positive external effect on the core country.

To sum up, G^A has both positive lowering price effect and negative lowering profits income effect on country B. However, when the initial G^A is not so large and the input-output linkage of differentiated goods sector a is sufficiently large, the positive effect outweigh the negative one. This is the intuition behind (24). In contrast, G^B has only the negative effect of lowering profits income on country A. An increase in G^B necessarily decreases the core country A's utility. This is the intuition behind (23).

With (23) and (24) in hand, we obtain the following proposition on the pure strategy Nash equilibrium.

Proposition 3

Suppose the case where $(G^A, G^B)=(\tilde{G}^C, \tilde{G}^P)$ is a pure strategy Nash equilibrium. This equilibrium is inefficient. In $(G^A, G^B)=(\tilde{G}^C, \tilde{G}^P)$, the public input G^i is excessively provided in the peripheral country B and insufficiently provided in the core country A, in the sense that both countries can improve their utilities if the decrease of G^B by the periphery takes place concurrently with the increase of G^A by the core.

Proof See Appendix B.

The inefficiency in $(\tilde{G}^C, \tilde{G}^P)$ (insufficient provision in the core and excess provision in the periphery) is due to the facts that each country fails to account for the effects of its choice of G^i on the utility of the other country and that the external effects from the core to the periphery and from the periphery to the core are asymmetric as indicated in (23) and (24).

Suppose that the core country A increases G^A form $\tilde{G}^C$ and the peripheral country B decreases G^B from $\tilde{G}^P$ to the same extent (i.e., $dG^A=-dG^B>0$). For the core country A, $\tilde{G}^C$ is the level at which the marginal benefit of the improvements in the transportation facilities is just equal to the marginal tax burden on the disposable income in its own country. Thus, by slightly increasing G^A from $\tilde{G}^C$, country A cannot raise its utility. However, if the decrease in G^B is accompanied by, the core country A can be, to some extent, free from the negative external effect of lowering profits income which the core country A had suffered from. Thus, if the increase in G^A in the core takes place concurrently with the decrease in G^B in the periphery, the utilities of the core country A can be improved to the extent that the negative external effect imposed by the peripheral country B is mitigated.

For the peripheral country B, $\tilde{G}^P$ is the level at which the marginal benefit of the transportation efficiency is just equal to the marginal tax burden in its own country. Thus, by slightly decreasing G^B from $\tilde{G}^P$, the country B cannot raise its utility. In addition, if the increase of G^A by the core country A is accompanied by, the peripheral country B suffers a decrease in the profit income. Yet an increase in G^A reduces the costs to transport intermediate goods back and forth within the differentiated goods sector that agglomerates in the core country A, and thereby lowers the differentiated goods prices.Thus, the increase in G^A benefits not only the households in country A, but also those in the country B who fully import differentiated goods from country A. The larger the input-output linkage of differentiated goods sector a is, the larger the magnitude of this impact is. Thus, if the decrease in G^B in the periphery takes place concurrently with the increase in G^A in the core, the utilities of the peripheral country B can be improved to the extent that the positive external effect from the core country A is strengthen.

Next we consider the efficiency of a mixed strategy Nash equilibrium.

Proposition 4

Let $G^{B\min}$ denote the minimum G^B and let $\overline{W}^i$ denote country i's expected utility in a mixed strategy Nash equilibrium. Consider the case where country A chooses only $\overline{G}^C$ and country B chooses only $G^{B\min}$, though such a combination of the strategies cannot be the Nash equilibrium. The utilities in this combination are strictly larger than the utility $\overline{W}^i$ in the mixed strategy Nash equilibrium for the two countries:

$$\overline{W}^A < u^A(\overline{G}^C, G^{B\min}, 1),$$
$$\overline{W}^B < u^B(G^{B\min}, \overline{G}^C, 0).$$

Thus, in the mixed strategy Nash equilibrium, the public input G^i is excessively provided in the peripheral country B and insufficiently provided in the core country A, in the sense that the country B tends to provide a G^B larger than $G^{B\min}$ while the country A tends to provide a G^A less than $\overline{G}^C$.

Proof See Appendix B.

As we have seen in Proposition 2, countries A and B respectively include $\overline{G}^C$ and $G^{B\min}$ which satisfies $\phi^P(\overline{G}^C) \leq G^{B\min} \leq \phi^P(0)$ into their own strategies in a mixed strategy Nash equilibrium. This means $\overline{W}^A = V^A(\overline{G}^C) = \int_{G^B \in [G^{B\min}, \bar{G}^P]} u^A(\overline{G}^C, G^B, 1) f^B(G^B)\, dG^B$ and $\overline{W}^B = V^B(G^{B\min}) = \int_{G^A \in [h(G^{B\min}), \bar{G}^C]} u^B(G^{B\min}, G^A, 0) f^A(G^A)\, dG^A$.

As we have discussed, the core country A prefers a smaller G^B since this enables larger profit income for the households in both countries. Therefore, if country B does not choose G^B larger than $G^{B\min}$ and changes its strategy as $f(G^{B\min})=1$, then country A's expected utility when it chooses $\overline{G}^C$ could be larger. On the other hand, the peripheral country B prefers a larger G^A since this enables country B to import differentiated goods from country A at lower prices. Therefore, if country A's strategy is such that it would not choose G^A smaller than $\overline{G}^C$, then country B's expected utility when it chooses $G^{B\min}$ could be larger.

However, as we have discussed in Proposition 2, a combination of strategies where country A always chooses $\overline{G}^C$ and country B always chooses $G^{B\min}$ cannot be a Nash equilibrium. In the face of $f^B(G^{B\min})=1$, country A has an incentive to choose a G^A smaller than $\overline{G}^C$. If country B believes that country A will choose a smaller G^A, it will have an incentive to choose a very large G^B in the expectation of becoming the new core.
In this sense, in the mixed strategy Nash equilibrium G^A tends to be too little, while G^B tends to be excessive. This is the intuition behind Proposition 4.

The efficiency problem where country A provides too little G^A can be less serious than the case where ($\widetilde{G}^C$, $\widetilde{G}^P$) is a pure strategy Nash equilibrium. Given that the risk of the flight of differentiated goods sector is above zero at $G^A = \widetilde{G}^C$, the country A will provide a G^A larger than $\widetilde{G}^C$ to prevent the flight. In contrast, the problem of the excessive provision of G^B by the country B is more serious. The country B can become the core with a very large G^B with positive probability. As such, the country B is willing to choose a huge G^B and thereby heavily reduce the profit incomes of economy-wide households.

6. Numerical example

We present a numerical example of the Nash equilibrium of mixed strategies we have analytically discussed. To make the analysis more comprehensive, here we show the numerical example of a finite game where countries' feasible sets of strategies are finite ones. We let Θ^i denote the finite sets of G^i feasible to country i, which include zero as minimum, unity as maximum, and the points equally spaced between zero and unity with a distance of δ (thus the number of the elements in Θ^i is $1+1/\delta$). The combination of the probability functions $f^{A\#}(G_k^A)$ and $f^{B\#}(G_k^B)$ on Ξ^A and Ξ^B, which are the subsets of Θ^i and Θ^i, and have the same number K elements, is a Nash equilibrium of mixed strategy if

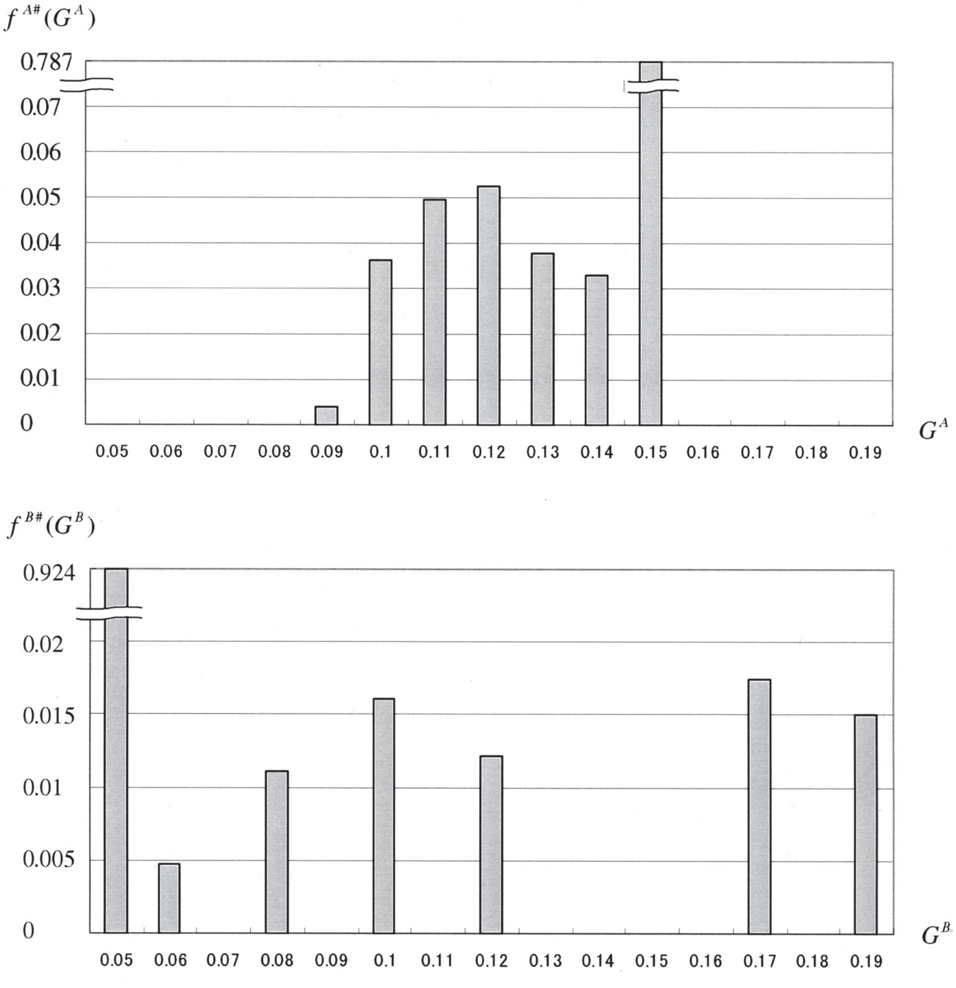


Figure 5

$f^{A\#}(G^A)$ and $f^{B\#}(G^B)$ on the mixed strategy Nash equilibrium

$f^{\#i}(G_k^i) \in (0,1)$ and $\Sigma_{k=1}^K f^{\#i}(G_k^i) = 1$ on Ξ^i,

$\Sigma_{k=1}^K u^i(G_r^i, G_k^j, n^i) f^{\#j}(G_k^j) = \Sigma_{k=1}^K u^i(G_{r'}^i, G_k^j, n^i) f^{\#j}(G_k^j)$, for any two G_r^i and $G_{r'}^i$ on Ξ^i,

$\Sigma_{k=1}^K u^i(G_r^i, G_k^j, n^i) f^{\#j}(G_k^j) > \Sigma_{k=1}^K u^i(G_{r'}^i, G_k^j, n^i) f^{\#j}(G_k^j)$, for any $G_r^i \in \Xi^i$ and $G^i \in \Theta^i \backslash \Xi^i$,

where G_k^i is kth smallest elements on Ξ^i. If country i includes the points G^i out of the set of Ξ^i into its own strategy, the expected utilities do necessarily decrease. In the case where country i limits its choice on the set of Ξ^i but changes $f^i(G_k^i)$ from $f^{i\#}(G_k^i)$, there is no change in the expected utilities W^i under the given $f^{j\#}(G_k^j)$ Therefore, there is no reason for both countries to deviate from $f^{i\#}(G_k^i)$.

Figure 5 shows an example of such functions under the same numerical example as in Figures 1(ii), 3(ii) and 4(ii). G^B has much larger variance than G^A. In the numerical example, the largest G^A is 1.5 times as large as the smallest one, but the largest G^B is 4 times as large as the smallest one. These very large values are chosen with very small but definitely positive probabilities. Since the country A chooses larger G^A with larger probabilities, in many case the country B fails to attract differentiated goods sector in spite of very large G^B. However, since the country A also chooses smaller G^A with positive probabilities, the relocation of differentiated goods sector can emerge with very small but definitely positive probability.

The utility levels of country A and B on the mixed strategy Nash equilibrium can be calculated as $\overline{W}^A = V^A(G_1^A) = \cdots = V^A(G_K^A) = -0.3728$ and $\overline{W}^B = V^B(G_1^B) = \cdots = V^B(G_K^B) = -0.6724$ with $u^i(G^i, G^j, n^i)$ in Figure 3(ii) and $f^{i\#}(G^i)$ in Figure 5. On the other hand, the utility levels on the strategies where country A chooses only G_K^A and country B chooses only G_1^B are $W^A = V^A(G_K^A) = u^A(G_K^A, G_1^B, 1) = -0.3720$ and $W^B = V^B(G_1^B) = u^B(G_1^B, G_K^A, 0) = -0.6688$. The combination of these strategies cannot be the Nash equilibrium, but the utilities in these strategies are strictly larger than those in the mixed strategy Nash equilibrium for the two countries as Proposition 4 indicates.

7. Conclusion

In this study, we considered the outcomes of the strategic public infrastructure provision game by welfare-maximizing national governments in a globalized economy in which industries with scale effects prevail.

When international transactions are very efficient, the industry agglomeration force is extremely prominent. Once the differentiated goods sector has been completely agglomerated in one country, it is very hard for other less industrialized countries to attract that sector even with tremendous investments in public infrastructure. However, if international transactions are less efficient, the industry agglomeration force is less prominent. The expectation of an easier relocation gives less industrialized countries the incentive to invest tremendous amounts in public infrastructure. More industrialized countries may anticipate such moves, however, and make very large public investments in order to prevent its industries from relocating in other countries. Then, the less industrialized country may very well fail to industrialize in spite of huge investments in public infrastructure.

In such a situation, a pure strategy Nash equilibrium does not exist. We therefore investigated the properties of a mixed strategy Nash equilibrium. A more industrialized country can completely prevent the relocation of its differentiated goods sector by investing a very large amount in public infrastructure. However, if it believes that the less industrialized country will not always invest huge amounts in public infrastructure, it will not always choose to make such a large investment. If the less industrialized country believes that the more industrialized country will often invest sufficient amounts to prevent the relocation, actually it will not always invest huge amounts for fear of failing at industrialization. However, if the less industrialized country believes that the more industrialized country will sometimes opt for smaller public investments, the positive probability of success in industrializing will compel the less industrialized country to consider huge investments in public infrastructure as a strategic option. Consequently, in a mixed-strategy equilibrium, public infrastructure investments made by a less industrialized country will vary much more than those made by a more industrialized country. Tremendous investments in public infrastructure by a less industrialized country are observed with positive probability. Accordingly, there is a small but definitely positive probability that an industry with scale effects can relocate.

Our model can be extended in various directions. By incorporating migration in the model, we can also analyze fiscal competition among the states within a country. Migration will encourage industry agglomeration, but the results do not differ fundamentally.[11] If we assume that governments do not take into account migration reaction to their decisions, the welfare implications of our model will hold. Suppose a pure strategy Nash equilibrium emerges in which a more industrialized country makes larger investments in public infrastructure and has a larger population than the less industrialized countries. On the one hand, the people in the more industrialized country will enjoy higher utility from the consumption of cheaper differentiated goods, but on the other hand, they will face more congestion, and thus utility is equalized among the countries. Suppose that the more industrialized country increases G^i and the less industrialized country decreases G^j by the same extent. This produces a gap in utility level, resulting in migration. However, the newly attained utility level cannot be lower than the original level, since the utility levels before migration will be improved in both countries, as discussed in section 5. Then the Nash equilibrium is inefficient. In contrast, if governments take into account the migration reaction, the inefficiencies in the provision of public goods can be improved. However, there still remains inefficiency in the migration processes, which has been discussed by Flatters, Henderson and Mieszkowski (1974), and Boadway and Flatters (1982) in standard neoclassical production function settings. Inefficiencies in migration process in the new economic geography model requires further research.

We can also extend the model by incorporating dynamic aspects such as private and public capital accumulation processes. We can introduce R&D investments that expand the variety of differentiated goods. Dynamic but local technological externalities in R&D activities strengthen the propensity to agglomerate industry, with the pecuniary externalities discussed in this paper.[12] However, the results of our original model do not fundamentally differ from those of this more complicated version.

In addition, we should consider the long-term investment aspects of infrastructure accumulation. In our model, public goods are flow inputs. Introducing an infrastructure accumulation process makes our analysis more realistic but much more complex. We must consider the dynamic scenarios in which governments choose long-term investment plans that maximize their intertemporal benefits. However, when governments cannot revise their plans, the levels of infrastructure which their long-term plans target will exhibit fundamentally the same propensities as the flow inputs in our model exhibit. Moreover, when governments can revise their investment plans, a less industrialized country may make tremendous public investments, though it may at some point change the plans and give up industrialization.

8. Appendix A

A.1 Derivations of (13) and (14)

The unit costs c^i and c^{i*} in producing x^{ii} and x^{ij} are derived as follows:

$$c^i = \frac{(P^i)^\alpha (w^i)^{1-\alpha}}{(G^i)^\eta}, c^{i*} = \frac{(P^i)^\alpha (w^i)^{1-\alpha}}{(G^A G^B)^\eta \tau}, \quad i = A, B. \tag{A1}$$

Applying the Shepard's Lemma to (A1) yields factor demands per differentiated good firm in country i:

$$m^i(\kappa)+m^{i*}(\kappa)\frac{a(p^i(\kappa))^{-\varepsilon}}{(P^i)^{1-\varepsilon}}(c^ix^{ii}+c^{i*}x^{ij}),\quad \kappa\in I^i, i,j=A,B, i\neq j, \tag{A2}$$

$$l^i(\kappa)+l^{i*}(\kappa)=(1-a)(c^ix^{ii}+c^{i*}x^{ij}),\quad i,j=A,B, i\neq j, \tag{A3}$$

where $m^i(\kappa)$ and $m^{i*}(\kappa)$ are the devoted differentiated goods κ as intermediate inputs in the productions of x^{ii} and x^{ij}, respectively. From (A2) and (A3), the demands for the differentiated goods in country i as intermediate inputs from the differentiated goods sector inside that country i and from the sector in another country j, and the labor demand in country i from the differentiated goods sector inside that country, are calculated as follows:

$$m^{ii}\equiv\int_{\kappa\in I^i}\{m^i(\kappa)+m^{i*}(\kappa)\}d\kappa=a\int_{\kappa\in I^i}\frac{(p^i(\kappa))^{-\varepsilon}}{(P^i)^{1-\varepsilon}}(c^ix^{ii}+c^{i*}x^{ij})d\kappa,\quad i,j=A,B,i\neq j, \tag{A4}$$

$$m^{ij}\equiv\int_{\kappa\in I^i}\{m^{j*}(\kappa)+m^j(\kappa)\}d\kappa=a\int_{\kappa\in I^i}\frac{(p^j(\kappa))^{-\varepsilon}}{(P^j)^{1-\varepsilon}}(c^{j*}x^{ji}+c^jx^{jj})d\kappa,\quad i,j=A,B,i\neq j, \tag{A5}$$

$$l_X^i\equiv(1-a)\int_{\kappa\in I^i}(l^i+l^{i*})d\kappa=(1-a)(n^ic^ix^{ii}+n^ic^{i*}x^{ij}),\quad i,j=A,B,i\neq j. \tag{A6}$$

With (10), (A1) and the definitions of Ω_{ij}, these can be rewritten as follows:

$$n^ip^{ii}m^{ii}=\Omega_{ii}\alpha\gamma(n^ip^{ii}x^{ii}+n^ip^{ij}x^{ij}),\quad i,j=A,B,i\neq j, \tag{A4'}$$

$$n^jp^{ij}m^{ij}=\Omega_{ij}\alpha\gamma(n^jp^{ji}x^{ji}+n^jp^{jj}x^{jj}),\quad i,j=A,B,i\neq j, \tag{A5'}$$

$$l_X^i=(1-\alpha)\gamma(n^ip^{ii}x^{ii}+n^ip^{ij}x^{ij}),\quad i=A,B,i\neq j. \tag{A6'}$$

With (A4)' and (A5)' and the demands from the households (5), the demand and supply structure of the differentiated goods sector can be written as follows:

$$\begin{pmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{pmatrix}\begin{pmatrix}n^Ap^{AA}x^{AA}\\n^Ap^{AB}x^{AB}\\n^Bp^{BA}x^{BA}\\n^Bp^{BB}x^{BB}\end{pmatrix}=\alpha\gamma\begin{pmatrix}\Omega_{AA}&\Omega_{AB}&0&0\\0&0&\Omega_{AB}&\Omega_{AB}\\\Omega_{BA}&\Omega_{BA}&0&0\\0&0&\Omega_{BB}&\Omega_{BB}\end{pmatrix}\begin{pmatrix}n^Ap^{AA}x^{AA}\\n^Ap^{AB}x^{AB}\\n^Bp^{BA}x^{BA}\\n^Bp^{BB}x^{BB}\end{pmatrix}+\alpha\begin{pmatrix}\Omega_{AB}E^A\\\Omega_{AB}E^B\\\Omega_{BA}E^A\\\Omega_{BB}E^B\end{pmatrix}. \tag{A7}$$

Inserting $n^ip^{ij}x^{ij}(i,j=A,B)$ obtained by solving (A7) into (A6)', the total labor force employed in the differentiated goods sector is derived as

$$l_X^i=(1-a)\gamma\alpha\left[\frac{\{\Omega_{ii}-a\gamma(\Omega_{AA}\Omega_{BB}-\Omega_{AB}\Omega_{BA})\}E^i+\Omega_{ij}E^j}{1-a\gamma(\Omega_{AA}+\Omega_{BB})-(a\gamma)^2(\Omega_{\mathrm{AB}}\Omega_{\mathrm{BA}}-\Omega_{AA}\Omega_{BB})}\right],\quad i,j=A,B,i\neq j. \tag{A8}$$

The shares of $(1-\alpha)\gamma$ and $\alpha\gamma$ of total revenue are paid for labor and intermediate inputs, respectively, and the rest $1-\gamma$ is retained as profits. Then, the profits per firm in each country can be derived as follows:

$$\pi^i=\left(\frac{(1-\gamma)\alpha}{n^i}\right)\left[\frac{\{\Omega_{ii}-a\gamma(\Omega_{AA}\Omega_{BB}-\Omega_{AB}\Omega_{BA})\}E^i+\Omega_{ij}E^j}{1-a\gamma(\Omega_{AA}+\Omega_{BB})-(a\gamma)^2(\Omega_{\mathrm{AB}}\Omega_{\mathrm{BA}}-\Omega_{AA}\Omega_{BB})}\right],\quad i,j=A,B,i\neq j. \tag{A9}$$

With (A9), relative profit is derived as (13). v And by solving $f(G^A, G^B, n^A)=1$ for n^A and inserting it into (A9), we can derive the equalized profits as follows:

$$\pi^A=\pi^B=(1-\gamma)\alpha\left[\frac{\{1-a\gamma(\Omega_{AA}\Omega_{BB}-\Omega_{AB}\Omega_{BA})\}E^A+E^B}{1-a\gamma(\Omega_{AA}+\Omega_{BB})-(a\gamma)^2(\Omega_{\mathrm{AB}}\Omega_{\mathrm{BA}}-\Omega_{AA}\Omega_{BB})}\right]. \tag{A10}$$

Since $\Omega_{ii}+\Omega_{ji}=1$ holds, $1-\alpha\gamma(\Omega_{AA}\Omega_{BB}-\Omega_{AB}\Omega_{BA})$ can be rewritten as $(1-\alpha\gamma)-\alpha\gamma(\Omega_{AA}+\Omega_{BB})$, and $1-\alpha\gamma(\Omega_{AA}+\Omega_{BB})-(\alpha\gamma)^2(\Omega_{AB}\Omega_{BA}-\Omega_{AA}\Omega_{BB})$ can be rewritten as $(1-\alpha\gamma)\{(1+\alpha\gamma)-\alpha\gamma(\Omega_{AA}\Omega_{BB})\}$. Then (A10) can be simplified as (14).

A.2 Derivation of (15)

Inserting (7), (8) and (14}) into (3) yields

$$E^i = 1+\left(\frac{(1-\gamma)\alpha}{2}\right)\left(\frac{E^A+E^B}{1-\alpha\gamma}\right)-G^i,\ i = A, B. \tag{A11}$$

Summing them for i=A, B and solving it for E^A+E^B yields

$$E^A+E^B = \left(\frac{1-\alpha\gamma}{1-\alpha\gamma-\alpha+\alpha\gamma}\right)\{2-(G^A+G^B)\}. \tag{A12}$$

(A12) can also be obtained by calculating the labor market clearing condition. The condition in each country is

$$l^i_X+l^i_Y+l^i_G=1,\ i=A, B \tag{A13}$$

By aggregating the households' demand for traditional goods (6) and inserting (7) into it, we can derive the labor force devoted to the traditional goods sector in each country as:

$$l^i_Y=s^i(1-\alpha)(E^A+E^B),\ i=A,B, \tag{A14}$$

where s^i ($s^i \in (0, 1)$, $s^A+s^B=1$) denotes the market share of country A in the production of traditional goods. Inserting (8), (A8) and (A14) into (A13) and summing them for i=A, B yields

$$\left[\frac{(1-a)\gamma\alpha\{1-a\gamma(\Omega_{AA}\Omega_{BB}-\Omega_{AB}\Omega_{BA})\}}{1-a\gamma(\Omega_{AA}+\Omega_{BB})-(a\gamma)^2(\Omega_{AB}\Omega_{BA}-\Omega_{AA}\Omega_{BB})}+(1-\alpha)\right](E^A+E^B)+(G^A+G^B) = 2. \tag{A15}$$

Since $\Omega_{ii}+\Omega_{ji}=1$ holds, $1-\alpha\gamma(\Omega_{AA}\Omega_{BB}-\Omega_{AB}\Omega_{BA})$ can be rewritten as $(1+\alpha\gamma)-\alpha\gamma\,(\Omega_{AA}+\Omega_{BB})$, and $1-\alpha\gamma(\Omega_{AA}+\Omega_{BB})-(\alpha\gamma)^2(\Omega_{AB}\Omega_{BA}-\Omega_{AA}\Omega_{BB})$ can be rewritten as $(1-\alpha\gamma)\{(1+\alpha\gamma)-\alpha\gamma(\Omega_{AA}+\Omega_{BB})\}$. Then (A15) can be simplified as

$$\left(\frac{1-a\gamma-\alpha+\alpha\gamma}{1-a\gamma}\right)(E^A+E^B)+(G^A+G^B) = 2. \tag{A15'}$$

For either case that differentiated goods firms disperse between countries so as to satisfy $f(G^A, G^B, n^A)=1$ or that they agglomerate in one country, (A15)' can be rewritten as (A12). Inserting (A12) into (A11) yields (15).

9. Appendix B

B.1 Proof of Proposition 2

First we prove that $G^{A\max} \le G^C$ and $G^{B\max} \le \bar{G}^P$, a part of (iii) and (iv), respectively. Next, we prove (i) and (ii), and finally we complete the proofs of (iii) and (iv).

Proof of $G^{A\max} \le \bar{G}^C$

When country A chooses G^A that is strictly larger than $\bar{G}^C$, it is free from the risk that the differentiated goods sector leaves there. Then, for any G^A that is larger than $\bar{G}^C$, $V^A(G^A)=\int_{G^B\in[0,1]} u^A(G^A, G^B, 1) f^B(G^B)\,dG^B$ necessarily holds. Since $\phi^C(G^B)<\bar{G}^C$ holds for any G^B, $u^A(G^A, G^B, 1)<u^A(\bar{G}^C, G^B, 1)$ and thus $V^A(G^A)<V^A(\bar{G}^C)$ hold for any G^A that is larger than $\bar{G}^C$. Then, country A will not choose G^A that is strictly larger than $\bar{G}^C$.

Proof of $G^{B\max} \le \bar{G}^P$

When the periphery chooses G^B larger than $\bar{G}^P=h(\bar{G}^C)$, the probability that it can attract the differentiated goods decreases. In addition, both $u^B(G^B, G^A, 1)$ and $u^B(G^B, G^A, 0)$ decrease with G^B larger than $\bar{G}^P$. Then, any $V^B(G^B)$ with G^B larger than $\bar{G}^P$ are smaller than $V^B(\bar{G}^P)$.

Proof of (i)

When country A choose G^A that is strictly smaller than $h(G^{B\min})$, its expected utility is $V^A(G^A)= \int_{G^{B\min}}^{\bar{G}^P} u^A(G^A, G^B, n^A)\, f^B(G^B)dG^B$ where n^A cannot be unity since (G^A, G^B) is included in R^B or R^O. This $V^A(G^A)$ is strictly dominated by $V^A(\bar{G}^C)$:

$$\begin{aligned} V^A(G^A) &= \int_{G^B \in [G^{B\min}, \bar{G}^P]} u^A(G^A, G^B, n^A) f^B(G^B) dG^B \\ &= \int_{G^B \in [G^{B\min}, l(G^A)]} u^A(G^A, G^B, n^A) f^B(G^B) dG^B \\ &+ \int_{G^B \in [l(G^A), \bar{G}^P]} u^A(G^A, G^B, 0) f^B(G^B) dG^B \qquad \text{from (20A)} \\ &< \int_{G^B \in [G^{B\min}, l(G^A)]} u^A(\bar{G}^C, G^B, 1) f^B(G^B) dG^B \\ &+ \int_{G^B \in [l(G^A), \bar{G}^P]} u^A(\bar{G}^C, G^B, 1) f^B(G^B) dG^B \\ &= V^A(\bar{G}^C). \end{aligned}$$

Then country A will not take G^A strictly smaller than $h(G^{B\min})$.

Proof of (ii)

Suppose that minimum G^B is larger than $\phi^P(0)$: $\phi^P(0) < G^{B\min}$. We have seen that $G^{A\min}$ is not smaller than than $h(G^{B\min})$, whatever G^B will be. Therefore, country B's expected utility when it takes $G^{B\min}$ is $V^B(G^{B\min}) = \int_{G^A \in [h(G^{B\min}), \bar{G}^C]} u^B(G^{B\min}, G^A, 0) f^A(G^A) dG^A$ where n^B is always zero since (G^A, G^B) is included in R^A. $u^B(G^{B\min}, G^A, 0)$ is strictly smaller than $u^B(\phi^P(0), G^A, 0)$ since $u^B(G^B, G^A, 0)$ is monotonous decrease function of G^B on the interval of $\phi^P(0) \leq G^B \leq G^{B\min}$. Then, $V^B(G^{B\min})$ is strictly dominated by $V^B(\phi^P(0))$, which contradicts our initial presumption that country B never chooses $\phi^P(0)$. Next, suppose that minimum G^B is smaller than $\phi^P(\bar{G}^C)$: $G^{B\min} < \phi^P(\bar{G}^C)$. The country B's expected utility when it takes $G^{B\min}$ is $V^B(G^{B\min}) = \int_{G^A \in [h(G^{B\min}), \bar{G}^P]} u^B(G^{B\min}, G^A, 0) f^A(G^A) dG^A$. $u^B(G^{B\min}, G^A, 0)$ is strictly smaller than $u^B(\phi^P(\bar{G}^C), G^A, 0)$ since $u^B(G^B, G^A, 0)$ is monotonous increase function of G^B on the interval of $G^{B\min} \leq G^B \leq \phi^P(\bar{G}^C)$. Then, $V^B(G^{B\min})$ is strictly dominated by $V^B(\phi^P(\bar{G}^C))$, which contradicts our initial presumption that $G^{B\min} < \phi^P(\bar{G}^C)$.

Proof of (iii)

Suppose that country A will not choose $\bar{G}^C$ and thus $G^{A\max} < \bar{G}^C$ follows. Facing such a country A's strategy, country B's expected utility when it takes $\bar{G}^P$ is $V^B(\bar{G}^P) = \int_{G^A \in [h(G^{B\min}), G^{A\max}]} u^B(\bar{G}^P, G^A, n^B) f^A(G^A) dG^A$ where n^B cannot be zero since (G^A, G^B) is included in R^B or R^O. This $V^B(\bar{G}^P)$ strictly dominates $V^B(G^B)$ with G^B of $\phi^P(\bar{G}^C) \leq G^B \leq \phi^P(0)$ since

$$\begin{aligned} V^B(\bar{G}^P) &= \int_{G^A \in [h(G^{B\min}), G^{A\max}]} u^B(\bar{G}^P, G^A, n^B) f^A(G^A) dG^A \\ &> \int_{G^A \in [h(G^{B\min}), G^{A\max}]} u^B(\phi^P(G^A), G^A, 0) f^A(G^A) dG^A \quad \text{from (20B)} \\ &> \int_{G^A \in [h(G^{B\min}), G^{A\max}]} u^B(G^B, G^A, 0) f^A(G^A) dG^A \\ &= V^B(G^B). \end{aligned} \tag{19}$$

Then, country B will never choose G^B on the interval of $\phi^P(\bar{G}^C) \leq G^B \leq \phi^P(0)$, which contradicts Proposition 2(ii).

Proof of (iv)

Suppose that country B will not choose $\bar{G}^P$: $G^{B\max} < \bar{G}^P$. Facing such a country B's strategy, country A will not choose $\bar{G}^C$, since with G^A a bit smaller than $\bar{G}^C$ country A can still keep all the differentiated firms within its border and $u^A(G^A, G^B, 1)$ is monotonous decrease function on the interval of $\phi^C(G^B) \leq G^A$. For country A not to choose $\bar{G}^C$ contradicts Proposition 2 (iii).

B.2 Proof of Proposition 3

With changes in G^i such that G^B is decreased but G^A is increased to the same extent ($dG^A = -dG^B = dG > 0$) from ($\tilde{G}^C$, $\tilde{G}^P$), the utility varies as follows:

$$du^A(\tilde{G}^C, \tilde{G}^P, 1) = \left\{ \frac{\partial u^A(\tilde{G}^C, \tilde{G}^P, 1)}{\partial G^A} - \frac{\partial u^A(\tilde{G}^C, \tilde{G}^P, 1)}{\partial G^B} \right\} dG, \tag{B1}$$

$$du^B(\tilde{G}^P, \tilde{G}^C, 0) = \left\{ \frac{\partial u^B(\tilde{G}^P, \tilde{G}^C, 0)}{\partial G^B} + \frac{\partial u^B(\tilde{G}^P, \tilde{G}^C, 0)}{\partial G^A} \right\} dG. \tag{B2}$$

The first terms in the right hand sides of (B1) and (B2) are zero by the definition of ($\tilde{G}^C$, $\tilde{G}^P$). (23) and (24) give the signs to the second terms, and then gives the positive signs to du^A and du^B.

B.3 Proof of Proposition 4

From Proposition 2, $\phi^P(\bar{G}^C) \leq G^{B\min} \leq \phi^P(0)$ is satisfied. Also from proposition 2, country A includes $\bar{G}^C$ into its strategy. The fact that country A chooses $\bar{G}^C$ means $\bar{W}^A = V^A(\bar{G}^C) = \int_{G^B \in [G^{B\min}, \bar{G}^P]} u^A(\bar{G}^C, G^B, 1) f^B(G^B) dG^B$. Since $u^A(\bar{G}^C, G^B, 1)$ is the function decreasing with respect to G^B, $\bar{W}^A$ falls between $u(\bar{G}^C, \bar{G}^P, 1)$ and $u^A(\bar{G}^C, G^{B\min}, 1)$: $u(\bar{G}^C, \bar{G}^P, 1) < \bar{W}^A < u^A(\bar{G}^C, G^{B\min}, 1)$. Also, the fact that country B chooses $G^{B\min}$ means $\bar{W}^B = V^B(G^{B\min}) = \int_{G^A \in [h(G^{B\min}), \bar{G}^C]} u^B(G^{B\min}, G^A, 0) f^A(G^A)\, dG^A$. Since $u^B(G^{B\min}, G^A, 0)$ is the function increasing with respect to G^A, $\bar{W}^B$ satisfies $u^B(G^{B\min}, h(G^{B\min}), 0) < \bar{W}^B < u^B(G^{B\min}, \bar{G}^C, 0)$.

Notes

1) When the international transaction costs take medium level, the industries with scale effects agglomerate most firmly and thus the gap in the tax rate is largest.
2) The number of differentiated goods blueprints should be endogenous. In the differentiated goods number expansion types of growth models, the amounts of R&D investments and new entries are determined at the level where the R&D investment costs equal to the stock price (the sum of the present value of profits' sequence in the future) per blueprint, as in the neoclassical growth models, investments is determined at the level where the investment costs including set up costs equal to the Tobin's marginal q (Romer (1990)). In contrast to these growth models, we exogenously fix the number of differentiated goods. However, it is similar to the settings of tax competition models where the total mass of physical, knowledge, or human capital is fixed In this sense, our model is on the similar start point with tax competition models.
3) Investments in the construction of industrial park can also be included in G^i since it let some firms locate there and thus reduce the transportation costs among them.
4) In the new economic geography models, producing differentiated goods requires an amount of fixed inputs, and there occur entries until the profit per firm is equal to the entry cost. The size of the fixed costs determines the size of each firm and the number of differentiated goods firms in each country. In contrast to the new economic geography models, we do not assume such types of fixed inputs but assume that each good had been developed by making an amount of R&D investments only once in the past and the profits have been distributed to households that financed the R&D investments with their savings see also footnote 2.)
5) The latter is the condition under which the dispersion is locally stable in the sense that no firm will move if all the other stay. It does not necessarily means that the dispersion is globally stable and the

unique equilibrium.

6) π^B, the denominator of (13), is the profits which will be attained by a firm that initially locates in country A with all the other firms but moves to country B alone, which is not actually observed.

7) For example, suppose that country A outlays G^A in the amount in *Sa, Sd* and *Se*. Country B cannot attract the entire differentiated goods sector with an outlay of G^B in Sd if the transaction costs are high (τ is small as in Figure 1(ii)), but it can if the costs are small (τ is large as in Figure 1(i)).

8) For example, suppose that country A makes an investment of G^A in *Sb, Sf* and *Sg*. Country B can break up the concentration of industry in country A with a G^B investment in Sf when the transaction costs are high as in Figure 1(ii). However, if the transaction costs are small as in Figure 1(i), country B may not be able to attract and keep the concentration of industry.

9) If (G^A, G^B) in $Q^A \cup Q^B$ is chosen by governments, not only for differentiated goods firms to stay in the country where they initially agglomerate, but also for them to relocate to the other country altogether, can be Nash equilibrium. However, in order for the Nash equilibrium of the relocation to emerge, the expectation among all the firms must be well coordinated, which is not plausible. If we assume the slight but definitely positive mobile costs, the profits on the Nash equilibrium of the relocation becomes (18) minus epsilon, while the ones on the Nash equilibrium of staying is (18). Then the former is less plausible.

10) By the definitions of R^A and $R^{B,}$ the border between R^A and R^B, $G^A=h(G^B)$, is included in R^A, and the one between R^B and R^O, $G^B=l(G^A)$, is included in R^B.

11) Puga (1999) hybrids the vertical linkage model of Krugman and Venables (1995) and the migration model of Krugman (1991). The model is too complex to solve analytically.

12) Grossman and Helpman (1991) incorporate local technological externalities in R&D investments into Romer (1990)'s endogenous growth model. However, industries with vertical linkage and thus pecuniary externalities are absent.

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