Industrial Agglomeration and Dispersion in Gate and Hinterland Regions*

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Abstract

This paper investigates the impact of globalization and regional integration on the economic geography within a country consisting of gate and hinterland regions, which have asymmetric accessibilities to overseas markets. To better explain the reality of developing countries, we assumed that unskilled workers are employed in both traditional and manufacturing sectors. Our analytical results could explain both why and where industrial agglomeration and dispersion arise. We show that when the international trade cost is very high, the space economy has full agglomeration in the hinterland and then experiences a process of dispersion until an even industrial distribution exists between the two domestic regions. When the home country is open enough to world markets, firms will first concentrate in the hinterland and then gradually move to the gate region until a full agglomeration occurs during regional integration. With further regional economic integration, half of firms will relocate to the hinterland again, with another half of them still remaining in the gate region.

Key words: asymmetrical accessibilities; spatial agglomeration; trade and transport costs; industrial relocation

1. Introduction

The main conclusions of early NEG models (Krugman, 1991; Ottaviano et al., 2002; Forslid and Ottaviano, 2003) tell us that high transport costs lead to the dispersion of industry in two symmetrical regions and that industrial agglomeration occurs when transport costs are low. This is also known as the core-periphery theory. As economic integration proceeds, we must ask: after the core-periphery what will the pattern of

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industrial distribution be, and how will the economic landscape change over time? Moreover, with agglomeration increasing, the greater concentrations of firms and mobile workers in the core regions will lead to the rise of extra costs related to production and living, such as workers' wages, higher land rents, and commuting costs. The further integration between regions causes the core regions to become over-concentrated, and some industries will tend to relocate to the periphery. That is to say that the evolution of spatial development undergoes a bell-shaped process in the long term. When we investigate the space economy of cities or regions within a country, we find that industrial deconcentration and the growth of hinterland regions do not seem to be exclusive phenomena. It has been observed that in some developed countries, such as the United Kingdom, the space economy has experienced the process of industrial redispersion (Geyer and Kontuly, 1996). Similarly, there is ample evidence to show that manufacturing activities in the United States were heavily agglomerated in the Northeast and Great Lakes in the 1950s. In the ensuing decades, manufacturing has clearly become much more dispersed, and firms are much more spread out to the other parts of the country (Holmes and Stevens, 2004). Also, industrial relocation from the central region to the hinterlands has even been witnessed in some emerging economies. As demonstrated by Haddad et al. (2002), the southern regions of Brazil actually experienced industrial redispersion due to the improvement of infrastructure and regional integration. Note also that Deichmann et al. (2005) investigated the issue of industrial relocation in Indonesia and found that the potential improvements in transport encouraged firm relocation from the core region to the lagging eastern part of the country. Given the facts outlined above, as Williamson (1965) observed, countries first go through a period of regional inequality and industrial agglomeration in some specific region and then experience industrial deconcentration and a move towards regional convergence as economic development proceeds. From the foregoing discussion, empirical evidence supports the idea that industry tends to agglomerate in some specific urban areas or regions during the initial stage of industrialization and that some industries then relocate to hinterland regions away from congestion or the higher-waged core region.

It goes without saying that the theory of New Economic Geography (Krugman, 1991) has been successful in providing the rationales for the occurrence of economic agglomeration. NEG models tell us why agglomeration occurs, but they are largely unconcerned with where the agglomeration arises. In the early core-periphery models, the decrease in transport costs led to industrial agglomeration in one of the two regions. In other words, the two homogeneous regions seem to enjoy the same opportunity to become the center. This is obviously inconsistent with the real economic world. Generally speaking, the natural advantages of a region play important roles in choosing the center through their interaction with pure economic forces. Empirical evidence reveals that the regional disparity increased due to economic liberalization and globalization between 1985 and 1994 in China and that massive manufacturing firms agglomerated near the coastal regions, which have better access to the overseas markets (Fujita and Hu, 2001). Similarly, Gallup et al. (1999)

argue that in sub-Saharan Africa and some regions in Eastern Europe, the share of the population living near to coastal areas or ocean-navigable rivers is not high. The extremely high international trade costs and domestic transport costs result in such agglomeration within the hinterland. They further show that agglomeration is likely to take place in the region that has better accessibility when interregional transport costs and international trade costs are low enough. Thus, we find that the occurrence of industrial agglomeration is not equally likely in any location. The agglomeration generally arises in specific locations that are endowed with certain natural advantages, such as transport accessibility.

As Behrens et al. (2006) discussed, NEG has allowed us to combine old ingredients via a new recipe to explain the formation of economic agglomeration, and the weak point of the NEG theory is geography itself. When we investigate developed core regions, we find that they are always endowed with some inherent advantage, such as natural resources or a good location for transport. However, most NEG models rely heavily on the abstract two-region model for deducing analytical tractability. As Fujita and Mori (2005) advocated, it is imperative to go beyond the simple two-region models and use asymmetric many-region models of trade and geography in order to acquire practical and useful policy implications. We need to give an explicit picture of industrial location during trade liberalization and regional integration. The same is true of the models of industrial redispersion. The related models of industrial redispersion are able to offer a reasonable mechanism explaining the occurrence of industrial deconcentration. Their weakest point is that they fail to tell us where the agglomeration occurs and where deconcentration comes from. Regarding the research into industrial redispersion, Tabuchi (1998) observes industrial redispersion by incorporating the urban costs as additional centrifugal forces. Furthermore, Tabuchi and Thisse (2002) show that the distribution of industry and trade costs presents a bell-shaped relationship when taste heterogeneity is employed in their model. It is worth mentioning that Picard and Zeng (2005, 2010) investigate the process of industrial redispersion by considering the agricultural sector and a different production technique. Although these researches give reasonable explanations for redispersion, where the agglomeration arises and where redispersion originates are also at issue. In terms of spatial set-up, only a hypothetical two-region economy is investigated. In contrast to symmetrical considerations, Behrens et al. (2006) incorporate geographic features into the NEG model. It is a pity that we could not witness the process of redispersion and that the full agglomeration is always in the gate region, even if the transport costs are extremely low.

To settle the foregoing issues, it is necessary to add geographical elements into the original NEG models to explain the explicit industrial location pattern, especially the process of industrial redispersion. The present paper attempts to merge the study of industrial redispersion and geographical features within a single model. We develop a three-region model based on Picard and Zeng (2010). Unskilled workers are invested both in the traditional sector and in manufacturing firms. This is consistent with the situation in most developing countries, where unskilled workers are massively employed in producing low-end manufacturing goods. More than that, we consider a two-country, three-region case in which the home country is asymmetric in terms of its access to overseas markets. This allows us to analyze the impacts of inherent geography on the reshaping of space economy, along with the joint role of economic mechanisms. Because there are various spatial scales in our model, we are able to investigate the complicated interactions between international trade liberalization and regional integration, as well as their effect on the distribution of industry.

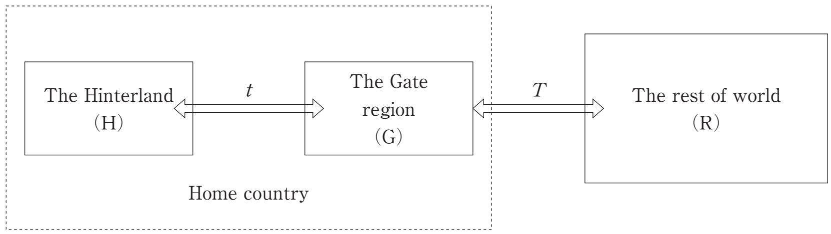
Using this framework, our analytical results reveal that there are abundant location patterns resulting from the process of globalization and regional integration. We find that when the home country is closed to global markets, poor domestic infrastructure allows the hinterland attract all of the manufacturing firms. With the further integration of the domestic economy, there will be a balanced distribution of industry between the gate region and the hinterland. When the country is open to global markets, starting with full agglomeration in the hinterland, a decrease in transport costs will trigger the firms to gradually move to the gate region during the integration of domestic regions. When this happens, the full concentration in the gate region will be maintained for a long while, even though the decrease in transport costs continues. With further regional economic integration, half of firms will relocate to the hinterland once again, with the other half of them remaining in the gate region.

The remainder of this paper is structured as follows. A three-region theoretical model is presented in Section 2. In Sections 3 and 4, we analyze the impacts of trade liberalization and regional integration on industrial location within a country. Section 5 provides a brief summary.

2. The model

We extend the work of Picard and Zeng (2010) to a richer spatial setting and consider a spatial economy consisting of two domestic regions denoted H and G, i. e., the hinterland, the gate region, and the rest of the world (henceforth, R). Regions G and H are located in the home country. In the following, variables associated with each region will be subscripted accordingly. The gate region (G) in the domestic economy exhibits a geographical advantage in terms of better access to world markets, whereas those in the hinterland must go through the gate region to reach the overseas markets. The geographical access to trade and transportation is illustrated in Figure 1. There are two production factors in the economy: geographically mobile skilled workers and immobile unskilled workers. We denote the mass of skilled workers and unskilled workers in the three regions by L_G (resp. A_G), L_H (resp. A_H), and L_R (resp. A_R), respectively. We assume that the immobile unskilled workers, A, are evenly split between the domestic regions H and G, which means that $A_H = A_G$. In addition to these assumptions, the workers are supposed to be internationally immobile. Hence, the masses of skilled workers in the home country ($L = L_G + L_H$) and the rest of the world (L_R) are considered to be given and fixed. There

Figure 1. A model of two countries and three regions



Notes: t is the interregional transport cost, and T is the international trade cost.

are two production sectors in each region. The traditional sector only employs unskilled workers at constant returns to scale and supplies a traditional good under perfect competition. The second sector, called the manufacturing sector, produces a mass N of a variety of differentiated manufacturing good under increasing returns to scale and sells its products under monopolistic competition.

All products can be traded across countries and regions and consequently incur various unit transport costs. Traditional goods are freely transported between the regions. Transporting differentiated manufacturing goods across regions is costly. More precisely, we assume a unit of transport cost of $t>0$ for shipping any variety of good between domestic regions, whereas transporting manufacturing goods from the gate region to rest of the world entails a unit trade cost of $T>0$. Because we assume that transporting manufacturing goods from hinterland H to R requires going through gate region G, this implies that firms located in region H incur trade costs of $T+t$ to access the external global market. Here, transport costs reflect the level of infrastructure in the home country, and trade costs express the freeness of international trade, i. e., tariffs, transport costs, and even service costs. Given our assumption of asymmetric transport costs, we have:

$$\tau_{rs}=\begin{cases} T & \text{if } r=G,\ s=R \text{ or } r=R,\ s=G \\ t & \text{if } r=H,\ s=G \text{ or } r=G,\ s=H \\ T+t & \text{if } r=H,\ s=R \text{ or } r=R,\ s=H \end{cases}$$

2.1 Consumers

Each worker is endowed with one unit of labor and has quasi-linear preferences for three types of goods: manufacturing goods ($q(i)$), traditional goods (q_G^A, q_G^A and q_R^A), and homogenous goods (q_0) as a numéraire. As in Picard and Zeng (2010), a typical consumer in region r has the following quasi-linear utility with a quadratic sub-utility function and chooses her consumption problem:

$$U=\alpha\int_0^N q_r(v)dv-\frac{\beta-\gamma}{2}\int_0^N[q_r(v)]^2dv-\frac{\gamma}{2}\left[\int_0^N q_r(v)dv\right]^2+\left[q_G^A-\frac{1}{2}(q_G^A)^2\right]$$

$$+\left[q_H^A-\frac{1}{2}(q_H^A)^2\right]+\left[q_R^A-\frac{1}{2}(q_R^A)^2\right]+q_0$$

$$s.t.\ \int_0^N p_r(v)q_r(v)dv+p_G^Aq_G^A+p_H^Aq_H^A+p_R^Aq_R^A+q_0=y_r+\bar{q}_0$$

where $\alpha>0$ measures the intensity of the preference for the differentiated products, and $\beta-\gamma>0$ implies that skilled workers have a preference for variety. q_r^A denotes the consumption of traditional varieties of goods, which are perfectly differentiated and respectively produced at a constant returns-to-scale sector in the region $r=H, G, R$. $p_r(v)$ is the consumer price of variety v in region r, and y_r is the consumer's earnings, which depends on his or her skilled/unskilled status. In addition, q_0 is the consumption of the homogenous good that is used as a numéraire good. Each worker is endowed with $\bar{q}_0$ initial units of the numéraire, which is supposed to be large enough for consumption. Finally, the numéraire is assumed to be transported at zero cost. Its price can be normalized to one without losing generality.

Using these notations, each consumer maximizes his or her utility given budget constraints. It is readily verified that the linear demand function of manufacturing varieties in region r is as follows:

$$q_r(i)=a-(b+cN)p_r(i)+cP_r \tag{1}$$

where a, b, and c are positive coefficients given by

$$a=\frac{\alpha}{\beta-(N-1)\gamma},\ b=\frac{1}{\beta+(N-1)\gamma},\ c=\frac{\gamma}{(\beta-\gamma)[\beta+(N-1)\gamma]}$$

And where

$$P_r=\int_0^N p_r(v)dv \tag{2}$$

is the aggregate price index of the differentiated industry in region r. Then, $\bar{P}_r=P_r/N$ can be interpreted as the average price of the manufacturing products in region r.

Meanwhile, the first-order conditions of the consumer plan yield the individual demand for varieties of goods from the traditional sector in region r. Let p_r^A be the price of traditional varieties of goods produced in region r. Then, the individual demands in region r are simply given by

$$q_r^A=1-p_r^A \tag{3}$$

2.2 Productions

Turning to the supply side, we assume that product markets are segmented and that labor markets are made up of two groups of workers. Skilled workers are perfectly mobile between the domestic regions, and immobile unskilled workers exist only in local supplies. There are two kinds of sectors in the economy. The traditional sector requires one unit of A in order to produce one unit of output in any region. This represents free trade in traditional goods. In the other sector, the manufacturing sector, as in Forslid and Ottaviano (2003), both skilled and unskilled workers are employed as production investments. We assume that manufacturing technology requires one unit of L and ϕ units of local, immobile, unskilled workers as fixed costs. According to the NEG tradition, the marginal cost of production of variety is set to equal zero. Because the labor requirements of each firm are identical across the three regions, there is a one-to-one correspondence between the firm and variety. Thus, the number of manufacturing firms or varieties produced in region r equals the number of skilled workers. We denote the share of firms by $\lambda \in [0, 1]$ in the gate region of the home country.

n_r ($r=G, H, R$) means the variety of goods produced in region r. Under these assumptions, labor market cleaning in each region implies that

$$n_G = \lambda L,\ n_H = (1-\lambda)L,\ n_R = L_R \tag{4}$$

Then, we denote the market size of region r via $M_r = A_r + L_r$. Based on the foregoing notation, each firm's profit in region r, whose products are sold to the three regions, is equal to the revenues from sales minus the costs of both types of labor.

$$\pi_r = M_r p_{rr} q_{rr} + M_s (p_{rs} - \tau_{rs}) q_{rs} - w_r^M - \phi w_r^A,\ s \neq r \tag{5}$$

where the first two terms refer to the firm's sales in local and other markets, and the last two terms refer to local factors' costs.

In the traditional sector, unskilled workers under the constant returns to scale produce one variety of traditional goods. Like Picard and Zeng (2010), we assume that each worker produces one unit of a traditional good. As the unskilled workers are supplied locally, traditional goods are distinguished according to the local endowment of the production factor.

2.3 Market equilibrium

Each firm is assumed to choose its price by taking the price index as a given. Profit maximization implies optimal prices as follows:

Intraregional price:

$$p_{rr} = \frac{a + cP_r}{2(b + cN)} \tag{6}$$

Interregional price:

$$p_{rs} = p_{rr} + \frac{\tau_{rs}}{2} \tag{7}$$

Using the symmetry between firms, the aggregate price index (2) in region r can be written as

$$P_r = \int_0^{n_G} p_{Gr}(v)\,dv + \int_0^{n_H} p_{Hr}(v)\,dv + \int_0^{n_R} p_{Rr}(v)\,dv \tag{8}$$

After solving for the price equilibrium, the equilibrium wages in the manufacturing industry are determined by the zero profit condition, as is usual in a perfect labor market. Hence, there are no pure profits, so all operating profits are absorbed by the wage bill, which implies that

$$w_r^M = M_r p_{rr} q_{rr} + M_s (p_{rs} - \tau_{rs}) q_{rs} - \phi w_r^A \tag{9}$$

Because we assume that local factors are employed at unit productivity and zero transport costs for traditional goods, perfect competition in the markets of the traditional sector implies that the price of products is equal to the marginal costs. This means that

$$w_r^A = p_r^A \tag{10}$$

The individual demands for traditional goods in any region are as follows:

$$q_r^A = 1 - p_r^A = 1 - w_r^A \tag{11}$$

The total demand for traditional products in region r is equal to $q_r^A M$. Here, M $(M = M_G + M_H + M_R)$ means the total market size of all three regions. The supply of this good is equal to the number of units of local factor that are not used by manufacturing firms. As a consequence of market clearing, we can obtain:

$$q_r^A M = A_r - \lambda \phi \tag{12}$$

Then, according to Equations (11) and (12), the wage of unskilled workers in region r can be expressed as follows:

$$w_r^A = 1 - q_r^A = 1 - \frac{1}{M}(A_r - \lambda_r \phi) \tag{13}$$

Based on the above analysis, the wage differential of unskilled workers between the gate region and hinterland can be expressed as follows:

$$w_G^A - w_H^A = \frac{2\phi}{M}\lambda - \frac{\phi}{M} \tag{14}$$

We now determine the T and t conditions needed for trade to occur between any two regions at these equilibrium prices. In particular, there will be two-way trade between domestic regions as long as the price of manufacturing p_{rs} can compensate for the transport costs. That is to say, $p_{rs} - t_{rs} \geq 0$ as long as the transport costs are low enough. Using the equilibrium price (6), there is trade between the two domestic regions if

$$t_{rs} < t_{trade} = \frac{2a + cL_R T}{2b + cL} \tag{15}$$

As discussed in Behrens (2011), decreasing the international trade costs of T may well spur interregional trade within the liberalizing country due to more manufacturing goods being imported from the overseas market. For the same reason, the occurrence of international trade between the gate region and region R means that $p_{GR} - T_{GH} \geq 0$. Furthermore, the local factors should be large enough to supply the traditional sector. We impose the following restrictions:

$$T_{rs} < T_{trade} = \frac{2a}{2b + cL},\ A_r > \lambda_r \phi \tag{16}$$

3. Spatial Equilibrium

As shown in Ottaviano et al. (2002), the indirect utility of skilled workers in region r can be written as follows:

$$V = S_r^M + S_r^A + w_r^M + \bar{q}_0 \tag{17}$$

where

$$S_r^M = \frac{a^2 N}{2b} - a\int_0^N p_r(v)dv + \frac{b+cN}{2}\int_0^N [p_r(v)]^2 dv - \frac{c}{2}\left[\int_0^N p_r(v)dv\right]^2 \tag{18}$$

is the individual consumption surplus of manufacturing goods, and S_r^A is the corresponding surplus of traditional goods. The skilled workers are mobile between the domestic regions and migrate between them according to the difference in indirect utility levels (ΔV). The consumer's indirect utility differential between the domestic regions can be defined as follows:

$$\Delta V(\lambda) = S_G^M - S_H^M + w_G^M - w_H^M + S_G^A - S_H^A \tag{19}$$

Because the access to traditional varieties of goods in each region is same, the differential of surplus in terms of traditional goods (S_r^A) between any two regions is zero. Thus, the indirect utility differential between the two domestic regions can be written as $\Delta V(\lambda) = S_G^M - S_H^M + w_G^M - w_H^M$ for short.

Here, we assume that the home country and the rest of the world have an identical market size ($L = n_G + n_H = n_R \equiv n, N = 2n$, $A_R = A_H + A_G = A$) and that the unskilled workers are evenly distributed between the domestic regions ($A_G = A_H = A/2$). By using Equations (6), (7), and (8), the equilibrium price index of the two domestic regions can be written as

$$P_G = \frac{2an + (b+2cn)(n_H t + nT)}{2b+2cn},\ P_H = \frac{2an + (b+2cn)(n_G t + nT + nt)}{2b+2cn} \tag{20}$$

Based on some straightforward yet cumbersome calculation, we can obtain the differential of consumption surplus for manufacturing goods and the differential of skilled workers' wages between the gate region and the hinterland as follows:

$$S_G^M - S_H^M = \frac{b+2cn}{8\phi_m(b+cn)^2}[(\alpha_1 t^2 + \alpha_2 t + 4c^2n^3Tt)\lambda + \alpha_3 Tt] \tag{21}$$

$$\alpha_1 = -(4b^2n + 8bcn^2) < 0 \tag{21-1}$$

$$\alpha_2 = (8abn + 16acn^2) > 0 \tag{21-2}$$

$$\alpha_3 = -[4c^2n^3 + 8bcn^2 + 4b^2n] < 0 \tag{21-3}$$

$$w_G^M - w_H^M = \frac{b+2cn}{8\phi_m(b+cn)^2}[(\zeta_1 t^2 + \zeta_2 t + \zeta_3 Tt)\lambda + \psi_1 t + \psi_2 t^2 \psi_3 Tt] - \frac{2\phi}{M}\lambda + \frac{\phi}{M} \tag{22}$$

$$\zeta_1=-(4c^2n^3+4Ac^2n^2+4Abcn+4bcn^2+2b^2n)<0 \quad (22\text{-}1)$$

$$\zeta_2=4abn>0 \quad (22\text{-}2)$$

$$\zeta_3=4bcn^2+2c^2n^3>0 \quad (22\text{-}3)$$

$$\phi_1=4Aab+4Aacn>0 \quad (22\text{-}4)$$

$$\phi_2=-(2Ab^2+2Abcn)<0 \quad (22\text{-}5)$$

$$\phi_3=-(2c^2n^3+4bcn^2+2Ac^2n^2+6Abcn+2b^2n+4Ab^2)<0 \quad (22\text{-}6)$$

where α_1, α_2, α_3, ζ_1, ζ_2, ζ_3, ϕ_1, ϕ_2, and ϕ_3 are bundles of parameters independent of trade and transport costs.

According to Equations (21) and (22), we can explain where the agglomeration and dispersion forces arise. The agglomeration forces can be observed in the first bracketed term in Equations (21) and (22). When the coefficient of λ is positive, these terms increase in λ. That is, when more skilled workers relocate to the gate region, the skilled workers' wages and net surplus of manufacturing goods will increase correspondingly. To go into more detail, agglomeration forces derive from the home market effects, which are caused by the *demand linkage* and the *cost linkage*. When more skilled workers agglomerate in the gate region, the larger demand will increase the profits of firms and then improve the wages of skilled workers (see (21)). Meanwhile, more firms (skilled workers) agglomerate in the gate region; the fierce competition lowers the price of a variety of goods and increases the consumption surplus of manufacturing (see (22)). These agglomeration forces are called the second-nature force and are mentioned in Krugman (1991) and Ottaviano et al. (2002).

Performing another role in the spatial equilibrium, the dispersion forces in our model mainly derive from the product market crowding effect. In addition, unskilled workers that are employed in the manufacturing sector contribute to the spatial configuration as another centrifugal force. Firstly, when the coefficient of λ is negative in the first bracketed terms in (21) and (22), more skilled workers agglomerate in the gate region, and the skilled workers' wage and the net surplus of manufacturing decrease in λ. Indeed, when more firms agglomerate in the gate region, the fierce competition decreases the price of the products and the skilled workers' wage. In particular, when trade costs T and transport costs t are extremely large, the dispersion forces dominate the economic system. At the same time, when more firms locate in the gate region, the skilled workers' wage decreases in λ, as described in the second term in Equation (22). With more skilled workers locating in the gate region, the larger demand increases the profits of manufacturing firms. Because unskilled workers are employed as fixed costs as well as the skilled workers in the manufacturing sector, the revenue of firms is equal to the wages of the skilled and unskilled workers. The increase of the wage share of unskilled workers extrudes the amount of wage that is allocated to skilled workers. This additional dispersion force derived from the traditional sector has rarely been observed in prior papers, except those of Picard and Zeng (2005 and 2010). When we detect the second term of Equation (22), we note that it is independent of trade and transport costs. This means that even with full agglomeration in one region, dispersion could emerge again if the dispersion force increases.

In the equilibrium, the skilled worker never intends to move to another location. When there is a tiny marginal deviation from the equilibrium, the skilled workers still return to the equilibrium state. We call such a state stable equilibrium. Formally, such a stable spatial equilibrium can be expressed by using following (in) equalities:

$$\lambda \in (0, 1) \text{ if } \Delta V = 0 \tag{23}$$

$$\lambda = 0 \text{ if } \Delta V \leq 0 \tag{24}$$

$$\lambda = 1 \text{ if } \Delta V \geq 0 \tag{25}$$

Such an equilibrium always occurs because ΔV is a continuous function of λ. The stable equilibrium can be divided into interior and corner equilibriums. An interior equilibrium is stable if and only if the slope of the utility differential equation (19) is non-positive in a neighborhood of this equilibrium, whereas a corner equilibrium is stable if $\lambda = 1$ and $\Delta V \geq 0$ or $\lambda = 0$ and $\Delta V \leq 0$.

After substituting (21) and (22) into (19), the differential of indirect utility between the gate region and the hinterland can be written as follows:

$$\Delta V(\lambda) = [(\theta_1 t + \theta_2 t^2 + \theta_3 tT - \eta_1)\lambda + (\varphi_1 t + \varphi_2 t^2 + \varphi_3 tT + \eta_2)] \tag{26}$$

where

$$\theta_1 = \frac{b+2cn}{8(b+cn)^2}(12abn + 16acn^2) > 0 \tag{26-1}$$

$$\theta_2 = -\frac{b+2cn}{8(b+cn)^2}(4c^2n^3 + 12bcn^2 + 4Ac^2n^2 + 6b^2n + 4Abcn) < 0 \tag{26-2}$$

$$\theta_3 = \frac{b+2cn}{8(b+cn)^2}(4bcn^2 + 6c^2n^3) > 0 \tag{26-3}$$

$$\varphi_1 = \frac{b+2cn}{8(b+cn)^2}(4Aab + 4Aacn) > 0 \tag{26-4}$$

$$\varphi_2 = -\frac{b+2cn}{8(b+cn)^2}(2Ab^2 + 2Abcn) < 0 \tag{26-5}$$

$$\varphi_3 = -\frac{b+2cn}{8(b+cn)^2}(6c^2n^3 + 12bcn^2 + 2Ac^2n^2 + 6Abcn + 6b^2n + 4Ab^2) < 0 \tag{26-6}$$

$$\eta_1 = \frac{8(b+cn)^2}{b+2cn}\frac{2\phi}{M} \tag{26-7}$$

$$\eta_2 = \frac{8(b+cn)^2}{b+2cn}\frac{\phi}{M} \tag{26-8}$$

are bundles of constant parameters. Thus the differential of indirect utility between the two domestic regions depends only on the two exogenous variables, transport costs, t, and trade costs, T. We note that the utility differential is a simple linear function of λ.

Following the above-mentioned discussion, the distribution of skilled workers in the home country can be shown as follows. According to Equations (23), (24), and (25), the agglomeration of skilled workers in the gate region is a stable equilibrium if and only if $\Delta V(1)>0$. This means that the differential of utility in the gate region is larger than that in the hinterland. Some straightforward calculations tell us that $\Delta V(\lambda=1)\geq 0$ is equivalent to:

$$\Delta V=(\theta_2+\varphi_2)t^2+[\theta_1+\varphi_1+(\theta_3+\varphi_3)T]t-\eta>0 \tag{27}$$

where

$$\theta_1+\varphi_1=\frac{b+2cn}{8(b+cn)^2}(12abn+16acn^2+4Aab+4Aacn)>0 \tag{27-1}$$

$$\theta_2+\varphi_2=-\frac{b+2cn}{8(b+cn)^2}(4c^2n^3+12bc^2n^2+4Ac^2n^2+6b^2n+6Abcn+2Ab^2)<0 \tag{27-2}$$

$$\theta_3+\varphi_3=-\frac{b+2cn}{8(b+cn)^2}(8bcn^2+2Ac^2n^2+6Abcn+6b^2n+4Ab^2)<0 \tag{27-3}$$

$$\eta=\frac{8(b+cn)^2}{b+2cn}\frac{\phi}{M} \tag{27-4}$$

are parameters independent of transport and trade costs. If we write $F(t,T)=(\theta_2+\varphi_2)t^2+[\theta_1+\varphi_1+(\theta_3+\varphi_3)T]t-\eta$, the foregoing condition can be written as $F(t,T)\geq 0$. Similarly, $\lambda=0$ is also a stable equilibrium if and only if $\Delta V(0)\leq 0$. The full agglomeration in the hinterland means that skilled workers enjoy a lower indirect utility in the gate region. This is equivalent to $\Delta V(\lambda=0)=\varphi_2t^2+(\varphi_1+\varphi_3T)t+\eta<0$. If we write $G(t,T)=\varphi_2t^2+(\varphi_1+\varphi_3T)t+\eta_2$, we can have $G(t,T)<0$.

Finally, $\lambda\in(0,1)$ is an interior stable equilibrium if and only if $\Delta V(\lambda)=0$ and the coefficient of λ is negative in (26). For skilled workers, there is no incentive to move to another location. Because $\Delta V=[(\theta_1t+\theta_2t^2+\theta_3tT-\eta_1)\lambda+(\varphi_1t+\varphi_2t^2+\varphi_3tT+\eta_2)]$, these two conditions for the interior stable equilibrium show that $\lambda=\frac{G(t,T)}{-H(t,T)}\in(0,1)$ and $H(t,T)<0$, where $H(t,T)=\theta_1t+\theta_2t^2+\theta_3tT-\eta_1$. This means that this condition is equal to $G(t,T)>0$ and $G(t,T)+H(t,T)<0$. Also, because $F(t,T)=G(t,T)+H(t,T)$, the foregoing conditions of spatial equilibrium, (23), (24), and (25), can be rewritten as follows:

$$\lambda=1 \text{ if } F(t,T)\geq 0 \tag{28}$$

$$\lambda=0 \text{ if } G(t,T)<0 \tag{29}$$

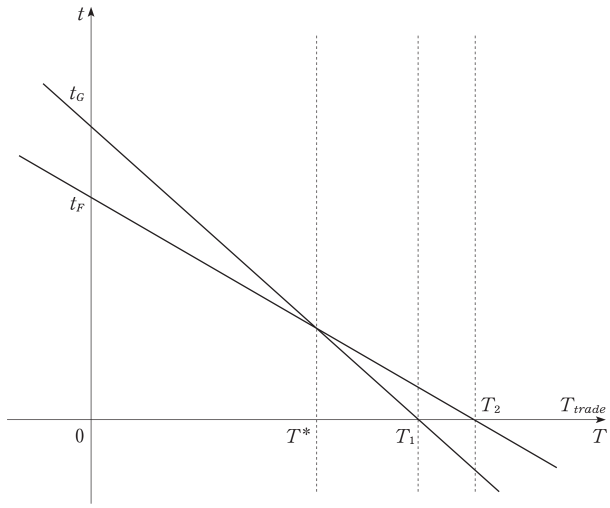
$$\lambda\in(0,1) \text{ if } G(t,T)>0 \text{ and } F(t,T)<0 \tag{30}$$

Based on the above discussion, we then study the impacts of the asymmetrical geographical access on the national equilibrium during the trade liberalization and regional integration.

4. The Effects of Trade Liberalization and Regional Integration

Because $F(t,T)$ and $G(t,T)$ are functions of t and T, this allows us to investigate how

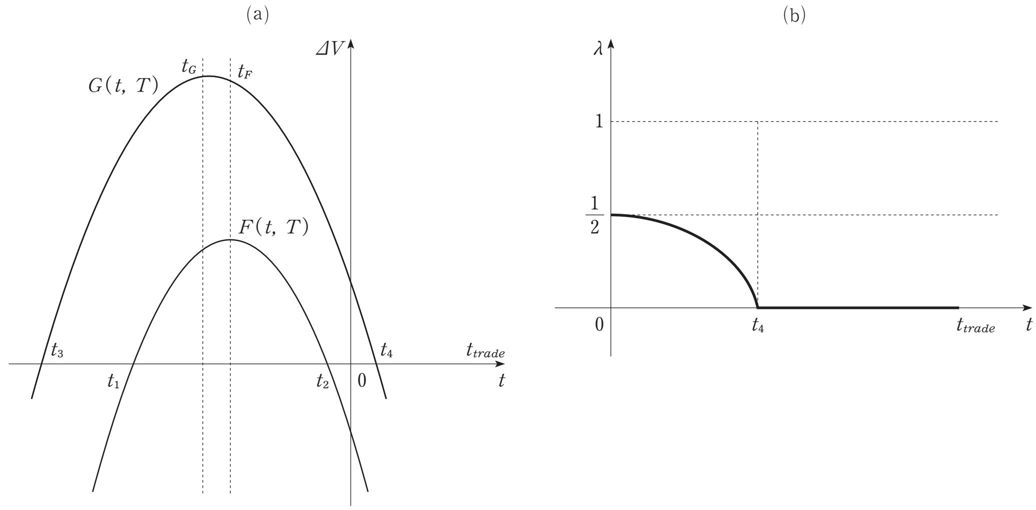
Figure 2. The relationship between t_F and t_G T



international trade liberalization and regional integration affect the distribution of manufacturing firms in the home country. For the sake of simplicity, the aim of this paper is to focus on how regional integration may affect the equilibrium distribution of manufacturing firms in the country by assuming differentiated international trade environments. In other words, we concentrate on the analysis of domestic transport cost t by assuming international trade cost T to be a series of different values. In addition, $F(t, T)$ and $G(t, T)$ are quadratic function of t. When $F(t, T)$ and $G(t, T)$ are put in the same coordinate system, we find that the relationship between $F(t, T)$ and $G(t, T)$ mainly depends on the locations of their corresponding symmetric axes, which are also related to T. Here, we denote the symmetric axes of quadratic functions $F(t, T)$ and $G(t, T)$ to be t_F and t_G, respectively. Thus, we can write $t_F=\dfrac{\theta_1+\varphi_1+(\theta_3+\varphi_3)T}{-2(\theta_2+\varphi_2)}$ and $t_G=\dfrac{\varphi_1+\varphi_3 T}{-2\varphi_2}$, which can be expressed as two lines in the plane of (T, t). If we compare the slopes and intercepts of the two lines, we can write $\dfrac{\theta_3+\varphi_3}{-2(\theta_2+\varphi_2)}>\dfrac{\varphi_3}{-2\varphi_2}$ and $\dfrac{\theta_1+\varphi_1}{-2(\theta_2+\varphi_2)}<\dfrac{\varphi_1}{-2\varphi_2}$ according to the signs of the parameters in (26). Then, we can show these two lines in the following figure.

As can be seen from Figure 2, When $t_F= t_G$, $t_G=0$, and $t_F=0$, we can obtain T^*, T_1, and T_2, respectively. The three points divide the horizontal axis into four intervals, i. e., $[0, T^*]$, $[T^*, T_1]$, $[T_1, T_2]$, and $[T_2, T_{trade})$. In the following discussion, we mainly focus on two cases: when international trade costs are very high and when they are very low, i. e., $T\in[0, T^*]$ and $[T_2, T_{trade})$. The discussion of the other two cases, i. e., $T\in[T^*, T_1]$ and $[T_1, T_2]$ is given in Appendix A. The two cases to be discussed here are concerned with the following two regional integrations.

Figure 3. Industry location when T is very high



4.1 Regional Integration When a Country is Closed to the Global Markets

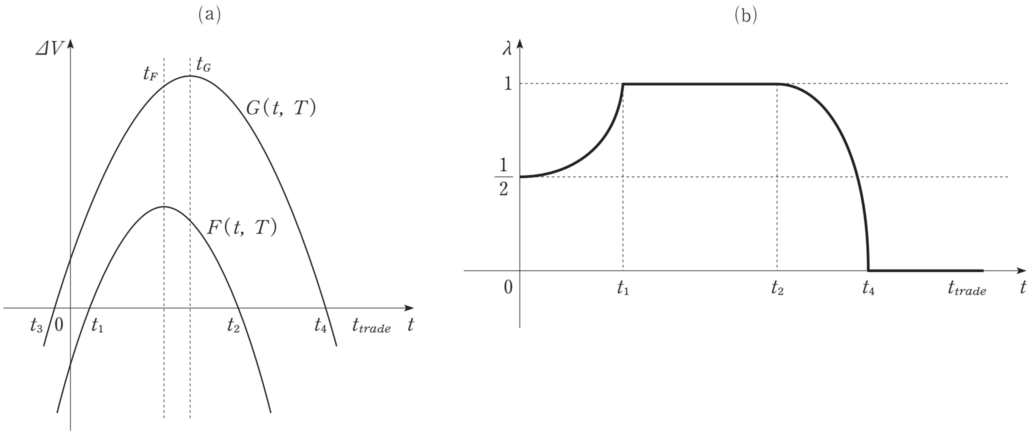
We first investigate the impacts of domestic regional integration on countries that are endowed with relatively closed international trade environments. To do so, we assume that the international trade costs are sufficiently high, i.e., $T \in [T_2, T_{trade})$. As shown in Figure 2, when T is in $[T_2, T_{trade})$, t_F and t_G have negative values of t simultaneously. This means that the symmetrical axis of quadratic curves $F(t, T)$ and $G(t, T)$ both lie on left side of the plane of $(t, \Delta V)$. We can then depict them in the following figure, which involves the relationship between $F(t, T)$ and $G(t, T)$. As Figure (3a) shows, when $t \in [t_4, t_{trade})$, we can see that $G(t, T) < 0$. This means that $\Delta V < 0$, and thus, $\lambda = 0$ according to (29). When $\lambda = 0$, this means all the firms agglomerate in the hinterland. Following closely, in the interval $[0, t_4]$, we can see that $G(t, T) > 0$ and $F(t, T) < 0$ in Figure (3a). Thus, we have $\lambda \in (0, 1)$ according to Equation (30). Because function $\lambda(t) = G(t)/-H(t)$ is a monotonic and continuous function of t and the endpoints are $\lambda(0) = 1/2$ and $\lambda(t_4) = 0$, we then know that when $t \in [0, t_4]$, this interior solution λ is larger than 0 and smaller than 1/2. Based on the foregoing discussion, the relationship can be drawn in Figure (3b), and the aforementioned results can be summarized as follows.

Consider a country with two asymmetrical domestic regions and very high international trade costs, i.e., $T \in [T_2, T_{trade})$. When interregional transport costs, t, are extremely high, all manufacturing firms will locate in the hinterland so as to avoid competition from rest of the world. When transport costs decrease considerably, firms will move from the hinterland to the gate region until an even distribution is reached.

4.2 Regional Integration When a Country is Open to Global Markets

In contrast to the previous subsection, here, we attempt to investigate the effects of regional integration on the space economy in a home country characterized by advantageous international trade environments. This implies that international trade costs are

Figure 4. Industrial location when T is very low



extremely low, i. e., $T \in [0, T^*]$ and that there is a large volume of trade between the home country and global markets. As can be seen from Figure 2, when $T \in [0, T^*]$, t_G and t_F are both positive, and t_G is located on the right side of t_F. In addition, when $t_G > t_F$, it can be verified that the larger roots of equation $F(t, T)=0$ are larger than those of $G(t, T)=0$ (see Appendix B). In this circumstance, we can show an explicit relationship between ΔV and t in Figure (4a). When$t \in [t_4, t_{trade})$, we know that $G(t, T)<0$, as shown in Figure (4a). As argued in the previous subsection, we can have $\lambda=0$ according to Equation (29). As transport costs gradually decrease, when $t \in [t_2, t_4]$, we can see that $G(t, T)>0$ and $F(t, T)<0$, as shown in Figure (4a). This then implies that $0<\lambda<1$ based on (30). When t surpasses t_2, there exists an interval $[t_1, t_2]$, and we can obtain $F(t, T)>0$ from Figure (4a). As can be seen from (28), we now have $\lambda=1$. With the further decrease of transport costs, Figure (4a) tells us that $G(t, T)>0$ and $F(t, T)<0$ when $t \in [0, t_1]$. As occurred in the interval of $[t_2, t_4]$, this satisfies the condition of $0<\lambda<1$ in accordance with (30). Here, as discussed in the foregoing subsection, $\lambda(t)$ is a monotonic and continuous function of t, and the endpoints are $\lambda(0)=1/2$ and $\lambda(t_1)=0$. We then know that when $t \in [0, t_1]$, this interior solution λ is larger than 1/2 and smaller than 1. To sum up, the relationship between λ and t is illustrated in Figure (4b).

Based on the foregoing discussion, we can summarize that when the home country is open to global markets, i. e., $T \in [0, T^*]$, the migration of the home country adopts several spatial patterns. When transport costs are high, similar to the situation described in Subsection 4.1, when the trade costs are high, all firms will locate in the hinterland. The gradual decrease in transport costs will trigger the firms to move to the gate region, where they can save on the trade costs for exporting goods to global markets. There is an interval, i. e., $[t_1, t_2]$, in which a full agglomeration in the gate region will happen during the regional integration. With further decreases in transport costs, firms will relocate again and move from the gate region to the hinterland, where the wage of unskilled workers is lower. Eventually, an even distribution of firms between the two regions occurs.

4.3 Interpretation and discussion

The aforementioned analytical results show the impacts of regional integration and trade liberalization on the space economy of the home country. Firstly, when trade costs are sufficiently high, the spatial economy has a full agglomeration of industries in the hinterland and then experiences a process of dispersion until an even industrial distribution between the two domestic regions occurs during regional integration. Secondly, when trade costs are very low and transport costs are high, industrial firms will first concentrate in the hinterland, but a decrease in transport costs will trigger a relocation of firms from the hinterland to the gate region until a full agglomeration occurs in the gate region, which will be sustained for a good while. With a further decrease in transport costs, regional integration will result in an even spatial distribution of firms between the two regions. In our model, the domestic regions are endowed with asymmetric accessibility to the external world market, which reflects the reality in many countries, such as Mexico and China. This allows us to give a more realistic explanation for the spatial evolution in many developing countries. As shown in Krugman and Elizondo (1996), high trade costs caused manufacturing firms to concentrate in the Mexico City region, which is far away from the US-Mexico border. However, during the rapid trade liberalization, a large share of industry relocated to the US border region. Meanwhile, Gallup et al. (1999) find that when domestic regions are poorly integrated, the population is agglomerated in the hinterland rather than in the coastal areas. This is supported by the fact that a greater share of the people live away from coastal regions in Sub-Saharan African. This paper's analytical results also show how industrial firms are relocated to the gate region. In this way, as Fujita and Hu (2001) point out, economic development in China has caused a strong agglomeration toward the coastal regions. This can be attributed to the fact that the coastal regions in China are endowed with better accessibility for exporting goods to global markets. The asymmetric considerations in our model not only explain why economic agglomeration occurs but also show where agglomeration arises.

In the literature, asymmetry in terms of accessibility has been employed in other recent papers (Crozet and Koenig Soubeyran, 2004; Behrens et al., 2006). Unlike Crozet and Koenig Soubeyran, we successfully show the analytical results. Moreover, international trade costs and interregional transport costs are considered simultaneously in order to investigate their impacts on the space economy of a country. In the present model, skilled workers and unskilled workers are both hired in the manufacturing sector. The employment of unskilled workers in manufacturing firms constitutes another dispersion force that generates redispersion during economic integration. In Behrens et al. (2006), firms would always concentrate in the gate region when the domestic regions were well-integrated, but they failed to show industrial redispersion. Concerning industrial redispersion, since Williamson (1965), reasons behind the disparity between regions (countries) in terms of divergence and convergence have always been debated. During the initial period of industrialization, manufacturing firms tend to agglomerate in some special regions or major cities and then experience a process of deconcentration. In Brazil, some industries have relocated from the metropolitan areas of Sao Paulo and Rio de Janeiro to the adjacent areas of Santa Catarina and Minas Gerais, as discussed by Haddad and Peroblli (2003a and 2003b). Even in some small countries, such as South Korea, Kwon (1985) pointed out that plants were relocated from the core metro areas of Seoul, Pusan, and Taegu and their satellite cities to the rest of the country. The impetus for this deconcentration is mainly derived from the improvement in infrastructure and economic liberalization that occurred after the 1970s in South Korea. In China, the growth rate of per capita GDP exhibited some convergence between the late 1990s and 2006, when there was a large gap between the hinterland and coastal regions (Fan and Sun, 2008). This recent empirical evidence suggests that the improvements in transport infrastructure have effects in terms of attracting industries to periphery regions or hinterlands.

In previous papers, the process of industrial redispersion has been obtained by using urban costs and various investment mechanisms (Tabuchi, 1998; Tabuchi and Thisse, 2002). In the real world, the dispersion forces generated from the employment of unskilled workers seem to be more widely observed in developing countries. Picard and Zeng (2005) investigated the process of industrial redispersion by considering the agricultural sector and a different production function. Compared with their symmetrical two-region model, our model also takes into account the considerations of asymmetry in terms of accessibility. The results obtained in our paper seem to approach nearer to the real economy. The previous models of industrial redispersion offer reasonable mechanisms to explain the occurrence of industrial deconcentration, but their weak point is that they fail to describe where the agglomeration occurs and where the deconcentration comes from. In China, during the past three decades, the eastern coastal provinces, with better accessibility for exporting goods, have dominated the inlands and become the core region during economic liberalization and development. Moreover, in the past ten years, industrial redispersion has been observed. Our model not only gives an explanation of where the industrial agglomeration occurs but also where the redispersion comes from by considering asymmetrical regions.

5. Conclusions

The importance of geography itself has always been ignored in the previous NEG studies designed to investigate industrial location during economic integration. Despite the attention given to the role of market access in shaping the landscape of the economy in developed countries, little concern is paid to developing countries, particularly in the field of theoretical work. In this paper, it is assumed that the hinterland must go through the gate region to access to overseas markets, and the rest of the world is considered to be an overseas market. To better reveal the current situation in developing countries, we assumed that unskilled workers are employed both in the manufacturing sector and the traditional sector, as did in Forslid and Ottaviano (2003). As a result, industrial redispersion was analytically derived within our framework.

We found that when the home country is closed to overseas markets, the high interregional transport costs allow the hinterland to attract all of manufacturing firms. However, with the sufficient integration of the domestic economy, there will be a balanced distribution of industry between the gate region and the hinterland. When the home country is open enough to world markets, the firms initially agglomerate in the hinterland and then gradually move to the gate region until a full concentration occurs during the integration of the domestic regions. With further regional economic integration, half of firms will relocate to the hinterland again, with the other half of them remaining in the gate region. Thus, industrial redispersion occurs.

References

Behrens, K., 2011. International integration and regional inequalities: how important is national infrastructure? *The Manchester School* 79 (5), 952–971.

Behrens, K., Gaigne, C., Ottaviano, G. I. P. and Thisse, J.-F., 2006a. Is remoteness a locational disadvantage? *Journal of Economic Geography* 6, 347–368.

Crozet, M. and Koenig-Soubeyran, P., 2004. EU enlargement and the internal geography of countries. *Journal of Comparative Economics* 32, 265–279.

Deichmann, U., Kaiser, K., Lall, S., and Shalizi, Z., 2005. Agglomeration, transport and regional development in Indonesia. Policy Research Working Paper 3477. *World Bank, Washington, D. C.*

Fan, C. C. and Sun, M. 2008. Regional inequality in China: 1978–2006. *Eurasian Geography and Economics* 49(1), 1–20.

Forslid, R. and Ottaviano, G. T., 2003. An analytically solvable core-periphery model. *Journal of Economic Geography* 3, 229–240.

Fujita, M. and Hu, D. 2001. Regional disparity in China 1985–1994: The effects of globalization and economic liberalization. *The Annals of Regional Science* 35, 3–37.

Fujita, M. and Mori, T. 2005. Frontiers of the New Economic Geography. *Papers in Regional Science* 84, 377–407.

Gallup, J. L., Sachs, J. D. and Mellinger, A. 1999. Geography and economic development. *International Regional Science Review* 22, 179–232.

Geyer, H. S. and Kontuly, T. M., Differential Urbanization: Integrating Spatial Models (London: Arnold, 1996.

Haddad, E. A., Domingues, E. P. and Perobelli, F. S., 2002. Regional Effects of Economic Integration: the Case of Brazil, *Journal of Policy Modeling* 24, 453–482.

Haddad, E. A. and Perobelli, F. S., 2003a. Interdependence among the Brazilian States: an Input-Output Approach, REAL *Discussion Paper* 03–T–18, University of Illinois at Urbana-Champaign.

Haddad, E. A. and Perobelli, F. S., 2003b. An Exploratory Spatial Data Analysis of Brazilian Interregional Trade (1985–1996), REAL *Discussion Paper* 03–T–22, University of Illinois at Urbana-Champaign.

Holmes, T. J. and Stevens, J. J., 2004. 'Spatial Distribution of Economic Activities in North America', in J. V. Henderson and J.-F. Thisse (eds), Handbook of Regional and Urban Economics, Vol. 4, Amsterdam, North-Holland 2797–2843.

Krugman, P., 1991. Increasing returns and economic geography. *Journal of Political Economy* 99, 483–499.

Krugman, P. and Elizondo, L. R., 1996. Trade policy and the third world metropolis. *Journal of Development Economics* 49, 137–150.

Kwon, W. G ., 1985. Issues and problems in Planning and Implementing Industrial Location Policy in Korea. Discussion paper, World Bank, Washington DC.

Ottaviano, G. T., Tabuchi, T. and Thisse, J.-F., 2002. Agglomeration and trade revisited. *International Economic Review* 43, 409–436.

Picard, P. and Zeng, D.-Z., 2005. Agricultural sector and industrial agglomeration. *Journal of Development Economics* 77, 75–106.

Picard, P. M. and Zeng, D.-Z., 2010. A harmonization of first and second natures. *Journal of Regional Science* 50, 973–994.

Tabuchi, T., 1998. Agglomeration and dispersion: A synthesis of Alonso and Krugman. *Journal of Urban Economics* 44, 333–351.

Tabuchi, T. and Thisse, J-F., 2002. Taste heterogeneity, labor mobility and economic geography. *Journal of Development Economics* 69, 155–177.

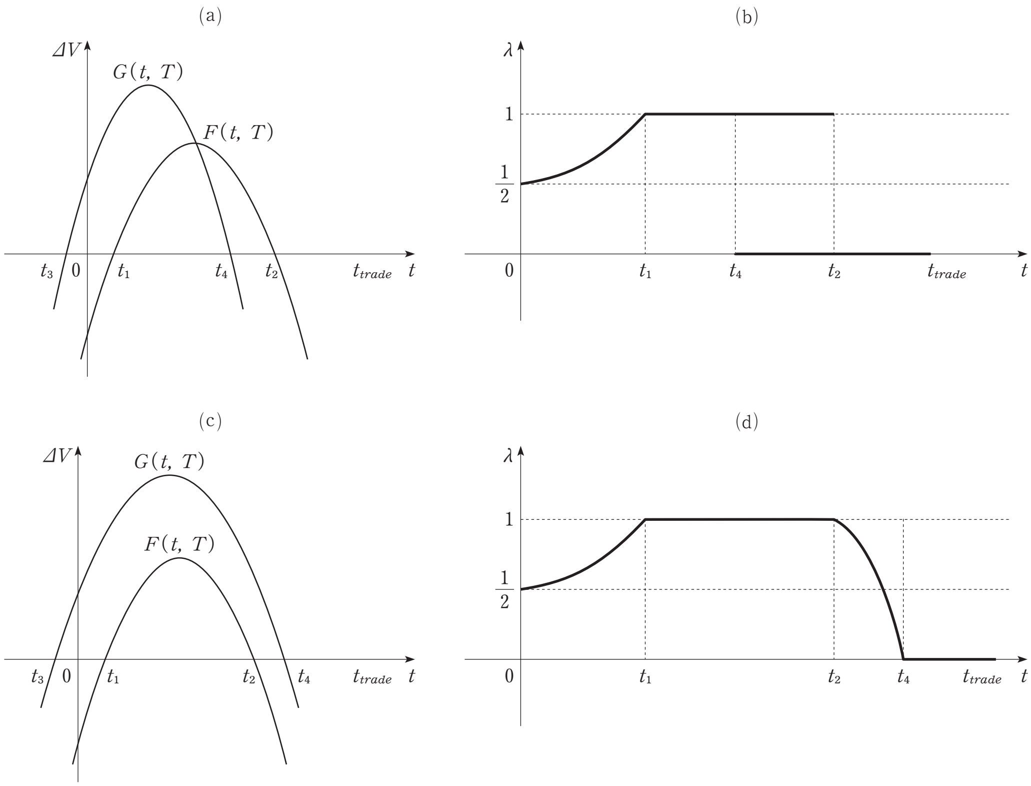
Williamson, J. G., 1965. Regional inequality and the process of national development. *Economic Development and Culture Change* 13, 3–45.

Appendix A:

(A-1) The Case of $[T^* < T < T_1]$

We know that $t_F > t_G > 0$ according to the analysis in Figure 2. The possible relationship between differential of indirect utility and transport costs and the corresponding industrial patterns are depicted in Figure A1. Starting from full agglomeration in the hinterland, a gradual decrease in transport cost t causes the industrial firms to catastrophically (or gradually) move to the gate region and remain in a symmetric distribution between the two regions eventually.

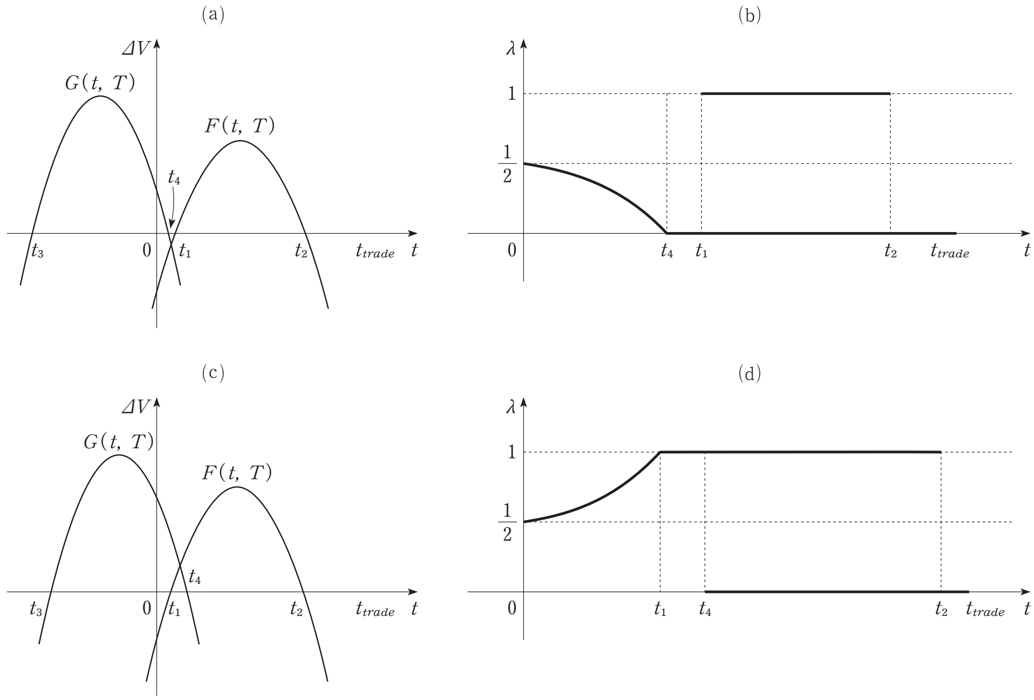
Figure A1. Industry location and interregional transport costs



(A-2) The Case of $[T_1 < T < T_2]$

In Figure 2, we know that $t_F > 0$ and $t_G < 0$. There are two possible relationships between $F(t)$ and $G(t)$ when their symmetrical axes are fixed, which is shown in Figure A2. In this case, full agglomeration is the main location pattern. The agglomeration of firms first occurs in the hinterland and then either in the hinterland or the gate region. However, further decreases in interregional transport costs trigger the gradual symmetric distribution of industrial firms between the two domestic regions.

Figure A2. Industry location and interregional transport costs



Appendix B:

We can write $F(t)=at^2+bt-\eta$ and $G(t, T)=a't^2+b't+\eta$, where $a=(\theta_2+\varphi_2)<0$, $b=\theta_1+\varphi_1+(\theta_3+\varphi_3)T>0$; $a'=\varphi_2<0$, $b'=\varphi_1+\varphi_3 T>0$, and $\eta>0$. The larger root values of $F(t)=0$ and $G(t)=0$ can be written as $t_2^F=\dfrac{b+\sqrt{b^2+4a\eta}}{-2a}$ and $t_2^G=\dfrac{b'+\sqrt{b'^2-4a'\eta}}{-2a'}$, respectively.

$$\text{Thus, } t_2^G-t_2^F=\left(\frac{b'}{-2a'}+\frac{\sqrt{b'^2-4'a\eta}}{-2a'}\right)-\left(\frac{b}{-2a}+\frac{\sqrt{b^2+4a\eta}}{-2a}\right)$$
$$=\left(\frac{b'}{-2a'}-\frac{b}{-2a}\right)+\left(\frac{\sqrt{b'^2-4a'\eta}}{-2a'}-\frac{\sqrt{b^2+4a\eta}}{-2a}\right) \qquad \text{(B1)}$$

During the interval of $[0, T^*]$, s_G is larger than s_F, as shown in Figure A1. This means that the symmetrical axis of $G(t)$ is located on the right side of $F(t)$ and that $\dfrac{b'}{-2a'}>\dfrac{b}{-2a}$ for equations $F(t)=0$ and $G(t)=0$. We then know that the first term in (B1) is positive. In addition, $\left(\dfrac{\sqrt{b'^2-4a'\eta}}{-2a'}\right)^2-\left(\dfrac{\sqrt{b^2+4a\eta}}{-2a}\right)^2=\dfrac{b'^2-4a'\eta}{4a'^2}-\dfrac{b^2+4a\eta}{4a^2}=\dfrac{b'^2}{4a'^2}$ $-\dfrac{b^2}{4a^2}-\left(\dfrac{a+a'}{a'a}\right)\eta$. Noting that $\dfrac{b'}{-2a'}>\dfrac{b}{-2a}>0$, $a<0$, $a'<0$, and $\eta>0$, it is readily verifiable that $\frac{b'^2}{4a'^2}-\frac{b^2}{4a^2}-\left(\frac{a+a'}{a'a}\right)\eta>0$. Then, we can deduce that the second term in (B1) is also positive. It is equivalent to $t_2^G>t_2^F$. Additionally, when $t=0$, $F(t)<0$, and $G(t)>0$, we are able to depict the parabolas of functions $F(t)$ and $G(t)$ in the same coordinate axis, as shown in Figure 2.