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On the Evolution of the Spatial Economy with Multi-unit・Multi-plant Firms: The Impact of IT Development

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Abstract

This paper examines how the decline of communication costs between management and production facilities within firms and the decrease in trade costs of manufactured goods affect the spatial organization of a two-region economy with multi-unit・multi-plant firms.

The development of information technology decreases the costs of communication and trade costs. Thus, the fragmentation of firms is promoted. Our result indicates that, with decreasing communication costs, firms producing low trade-cost products (such as consumer electronics) tend to concentrate their manufacturing plants in low wage countries. In contrast, firms producing high trade-cost products (such as automobiles) tend to have multiple plants serving to segmented markets, even in the absence of wage differentials.

Keywords: agglomeration, headquarters, plants, supply chain, re-location, monopolistic competition, information technologies

JEL classification: F12, L13, R13

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1 Introduction

Firms have fragmented their production activity dramatically in recent years. However, depending on industrial type, there exist significant differences in the location pattern of production activity. For example, the location pattern of consumer electronics production is quite different from that of automobile industry.

Hard disc drive industry, for example, separated the location of assembly process globally. Gourevitch, Bohn and Mckendrick (2000) have explored the following story in detail. In 1980, over 80% of the world's hard disks were assembled in the United States. While 15 years later over 80% of the world's hard disks were made *by* US firms, but less than 5% of drives were assembled in the United States. Most disk drives are assembled in-house through overseas production networks. Southeast Asia, especially Singapore, occupies the 64% of world final assembly in 1997. Subassembly with low skilled and labor intensive activity is done mainly in China. Whereas, R&D is located mainly in Silicon Valley where the close collaborative process of firms yields strong knowledge externalities (Saxenian 1996). Furthermore, such consumer electronics sector developed many global standards.

On the other hand, large automobile companies have established manufacturing plants recently in nearly all of major regional markets around the world because of high trade costs due to government regulations and cultural differences. New plants are also located in the emerging markets such as Thailand and Indonesia. Rugman and Hodgets (2001) suggests that regional production and large local sales occur in North America, Europe and Japan.

Such a fragmentation of production activity has been caused by several major factors. One is the large wage-differentials among countries. In connection with the example of hard disc drive industry above, the hourly wage rate for people involved in assembly in 1995 is as follows: China, $.25; Singapore, $7.28; and United States, $17.20 (Gourevitch, Bohn and Mckendrick 1997). Another motivation to separate productions arises from the recent development of information technology (IT). In general, the information transfer between headquarters and plants involves more costs when HQs communicate with remote plants, where HQs provide their plants with various services such as management, R&D, marketing and finance. For example, Kim (1999) mentioned about U.S. manufacturing that "the cost of coordinating the activities of plants located in different regions was higher than the cost of managing a similarly sized firm with only one plant". However, the rapid progress in communication technology has been decreasing communication costs greatly. Bernstein (2000) shows, for example, that the use of modern communication equipments reduces significantly the variable costs for Canadian manufacturing industry, which is highly integrated with the U.S. economy. The third major cause is, of course, the significant decrease in trade costs of products, which reflects the progress in transportation technology (based on IT).

The objective of this paper is to provide an analytical framework within which we can assess the impact of the decrease in communication costs between HQs and plants and in transportation costs of products on the spatial organization of multi-unit firms. The recent literature on economic geography mostly assumes that firms are integrated, with each firm conducting its entire operation at a single location (Fujita, Krugman and Venables 1999). Fujita and Thisse (2002) is an exception, considering a general equilibrium model in which each firm has the headquarters and a plant. In this paper, we extend Fujita and Thisse (2002) by introducing multi-plant firms. Indeed, many multinational firms have a large number of plants in different countries.

The setting of our model is as follows. The economic space consists of two regions, A and B. The economy has two production sectors, the modern sector ($\mathbb{M}$) and the traditional sector ($\mathbb{T}$). There are two production factors, the high-skilled workers and the low-skilled workers. The economy is endowed with given populations of unskilled and of skilled workers. The skilled workers are perfectly mobile between regions whereas the unskilled are immobile. The $\mathbb{M}$-sector produces a continuum of varieties of horizontally differentiated products under increasing returns, using both skilled and unskilled workers. The $\mathbb{T}$-sector produces a homogeneous good under constant returns, using unskilled labor as the only input. The productivity of unskilled workers in the $\mathbb{T}$-sector is assumed to be higher in region A than in region B. Each variety of $\mathbb{M}$-good is produced by a separate firm. Each firm has the headquarter and one or two plants. When a plant is not located with HQ, communication cost are involved. The second plant requires an additional fixed cost. To send the differentiated products to the other region, transportation cost is required. We endogenise the entry decision of firms. Each firm can choose whether to have a plant in either region or a plant in each region. We focus on equilibria in which all headquarters are agglomerated in region A (the core region), while plants may be dispersed. Using our model, we investigate how different levels of transportation costs, communication costs, and the fixed costs for the second plant may generate different spatial patterns of production.

Following the presentation of the model in Section 2, we determine in Section 3 the conditions for the location pattern of plants and the agglomeration of all headquarters in the core. Section 4 examines the impact of decreasing trade costs and communication costs on the location pattern of plants. We show that each firm has a single plant that locates together with the HQ, when 1) the fixed costs to build an additional plant are large, 2) the trade costs of manufactured goods are small, and 3) communication costs are high. By contrast, each firm has a single plant which locates in the separate region from the HQ, when 1)the fixed costs to build an additional plant are large, 2)the trade costs of manufactured goods are small, and 3)the communication costs are low. Whereas multi-plant firms emerge when 1)the fixed costs to build an additional plant are small, 2)the trade costs of manufactured goods are large and 3)the communication costs are medium. [1] In Section 5, we conduct the welfare analysis, examining the impact of decreasing communication costs on the welfare of skilled and unskilled workers. Section 6 concludes the paper.

2 The model

Based on the general setting introduced in the preceeding section, we specify our model as follows. Preferences are identical across all workers and expressed by a Cobb-Douglas utility:

$$U = Q^{\mu}\Upsilon^{1-\mu}/\mu^{\mu}(1-\mu)^{1-\mu} \qquad 0 < \mu < 1 \tag{1}$$

where Q is an index of the consumption of $\mathbb{M}$ varieties, while Υ stands for the consumption of the output of the traditional sector. When the modern sector provides a continuum of differentiated varieties of size m, the index Q is given by

$$Q = \left[\int_0^m q(i)^{\rho} di\right]^{1/\rho} \qquad 0 < \rho < 1 \tag{2}$$

where $q(i)$ represents the consumption of variety $i \in [0, m]$. In (2), the parameter ρ represents the inverse of the intensity of love for variety over the

[1]These result are consistent with these in Markusen and Venables(2000). However, they consider only transport costs for products while focusing on how the difference in the endowments of labor and capital may generate spatial patterns of production.

differentiated products. When ρ is close to 1, differentiated goods are close to perfect substitutes; when ρ decreases, the desire to consume a greater variety of manufactured goods increases. If we set

$$\sigma \equiv \frac{1}{1-\rho} \qquad 1 < \sigma$$

then σ is the elasticity of substitution between any two varieties. Because there is a continuum of firms, each firm is negligible and the direct interactions between any two firms are zero, but the aggregate market conditions affect each firm.

If Y is the consumer income, $p^{\mathbb{T}}$ the price of the traditional good and $p(i)$ the price of variety i, then the demand functions are

$$\Upsilon = (1-\mu)Y/p^{\mathbb{T}} \tag{3}$$

$$q(i) = \frac{\mu Y}{p(i)} \frac{p(i)^{-(\sigma-1)}}{P^{-(\sigma-1)}} \qquad i \in [0, m] \tag{4}$$

where P is the price index of differentiated products, given by

$$P \equiv \left[\int_0^m p(i)^{-(\sigma-1)} di \right]^{-1/(\sigma-1)} \tag{5}$$

Substituting (3) and (4) into (1) yields the indirect utility function

$$v = YP^{-\mu}(p^{\mathbb{T}})^{-(1-\mu)}$$

Technologies in each of the two sectors differ from what is usually assumed in economic geography models. The technology in the $\mathbb{T}$-sector is such that one unit of output requires $a_r \geq 1$ units of unskilled labor in region $r = A, B$. Without loss of generality, assuming that the ratio of land to population is large in region A and small in region B, we set $a_A = 1$ and $a_B \geq 1$, thus allowing unskilled workers in the traditional sector to be more productive in region A than in region B. Let L_A and L_B be the number (mass) of unskilled workers in region A and B, respectively. In order to retain the standard assumption of symmetry between the two regions, we assume that the spatial distribution of unskilled workers is such that both regions have the same amount of effective units of unskilled labor:

$$L_A = \frac{L_B}{a_B} = \frac{L}{2} \tag{6}$$

The output of the $\mathbb{T}$-sector is costlessly traded between any two regions and is chosen as the numéraire so that $p^{\mathbb{T}} = 1$. We further assume that the expenditure share $(1 - \mu)$ on the $\mathbb{T}$-good is sufficiently large for the $\mathbb{T}$-good to be always produced in both regions. In this case, the equilibrium wages for the unskilled are such that

$$w_A^L = 1 \qquad w_B^L = 1/a_B \leq 1 \tag{7}$$

Hence, a factor-price motive may explain the multinationalization of firms. However, as will be seen below, factor price differential is not the only reason for vertical fragmentation.

The technology of the $\mathbb{M}$-sector is more complex. The setting of a headquarter requires a fixed amount f of skilled workers when the firm has a single plant. Whereas, when the firm has two plants, the setting of a headquarter(HQ) needs a fixed amount $(1 + \alpha)f$ of skilled workers, where $0 < \alpha < 1$. If w_r^H denotes the skilled workers' wage in region r, then, using (6) and (7), the total income of region r is

$$Y_r = S_r w_r^H + L/2 \qquad r = A, B \tag{8}$$

where S_r is the number of skilled worker in region r. When the HQ is located in region r and the plant in region s, producing $q(i)$ units of variety i requires $l(i)$ units of unskilled labor;

$$l(i) = c_{rs} q(i)$$

where $c_{rs} > 0$ is the plant's marginal labor requirement. The value of c_{rs} decreases with the effectiveness of the services provided by the HQ to its plant, which depends itself on the following two factors. First, the accumulation of human capital and face-to-face communications within the same region generates Marshallian externalities which make the HQ of firm i more effective in its supply of services to its plant. This implies that c_{rs} decreases with the number $S_r \geq 0$ of skilled workers living in region r. Second, the distance between the HQ and its plant affects negatively the effectiveness of the HQ-services. This is because (i) it is easier to monitor the effort of the plant manager when the plant is located near the HQ than across borders (Grossman and Helpman 2004) and (ii) the transmission of information at a distance is often imperfect (Leamer and Storper 2001). More precisely, when both the HQ and its plant are located in the same region ($r = s$) we have

$c_{rs} = c(S_r)$, whereas $c_{rs} = c(S_r)T_H$ holds when they are located in different regions ($r \neq s$). Here, $T_H > 1$ expresses all the difficulty to communicate within the firm when the HQ and a plant are physically separated, which is represented by the iceberg transfer technology of HQ-services to the plant. When the information is not easily transferred, T_H may become large.

When the plant is set up with its HQ in region r, the plant production function is thus given by

$$l(i) = c(S_r)q(i) \qquad r = s$$

By contrast, when the plant is located in a different region, we have:

$$l(i) = c(S_r)T_H q(i) \qquad r \neq s$$

This specification has two implications. First, when the plant is not located with its HQ, it is less efficient and therefore needs a larger amount of local input. That is, we recognize that the physical separation of HQs and plants generates a cost for firms. However, we also recognize that the development in communication technologies means the decrease of T_H. Second, unskilled workers are equally productive under the same level of HQ-services once they work in firms. This is because firms are able to organize their production in the same way whatever the plant's location. Furthermore, because of the existence of a perfectly competitive traditional sector in each of the two regions, the nominal wage rate of the unskilled (7) is unaffected by the relocation of the industrial plants.

The output of the $\mathbb{M}$-sector is shipped at a positive cost according to the iceberg technology: when one unit of the differentiated product is moved from region r to region $s \neq r$, only a fraction $1/T_{rs}$ arrives at destination where $T_{rs} > 1$. Here, T_{rs} may be different from T_{sr}, representing an asymmetry in transport conditions. Within each region, transportation is costless. Thus, if a firm has a single plant for variety i in region r, and serves the two regions from the plant, then using (4), the demand for variety i (including the consumption in transportation) is such that

$$q_r(i) = \mu Y_r p_r(i)^{-\sigma} P_r^{\sigma-1} + \mu Y_s [p_s(i)T_{rs}]^{-\sigma} P_s^{\sigma-1} T_{rs} \qquad (9)$$

where P_r (resp. P_s) is the price index of the differentiated good in region r (s), which is defined later. Next, given that the marginal production cost of a variety at a plant in each region is a constant while fixed costs are needed for an additional plant, it never happens that a firm has a plant in both regions while one region is served from the two plants. Thus, if a firm has a plant for variety i in both regions, each plant serves the regional demand given respectively by

$$q_r(i) = \mu Y_r p_r(i)^{-\sigma} P_r^{\sigma-1} \tag{10}$$

$$q_s(i) = \mu Y_s p_s(i)^{-\sigma} P_s^{\sigma-1} \tag{11}$$

Let M_s^r (resp. m_s^r) be the set (resp. the mass) of firms whose headquarters are in region r and a single plant in region s, with $r, s = A, B$.The profit of firm $i \in M_r^r$ with $r = A, B$ is as follows:

$$\pi_r^r = p_r(i)q_r(i) - w_r^H f - w_r^L c(S_r)q_r(i)$$

which yields, using (9), the equilibrium mill price charged by the plant located in region r:

$$p_r^*(i) = \frac{w_r^L c(S_r)}{\rho} \qquad i \in M_r^r \tag{12}$$

Similarly, the profit of firm $i \in M_s^r$ with $r \neq s$ is

$$\pi_s^r = p_s(i)q_s(i) - w_r^H f - w_s^L c(S_r)T_H q_s(i) \tag{13}$$

So that the equilibrium mill price charged by the plant located in region s is as follows:

$$p_s^*(i) = \frac{w_s^L c(S_r)T_H}{\rho} \qquad i \in M_s^r \textit{ and } r \neq s \tag{14}$$

Let M_{mp}^r (resp. m_{mp}^r) be the set (resp. the mass) of multi-plant (mp) firms whose headquarters are in region r and a plant in each region. The profit of firm $i \in M_{mp}^r$ is

$$\begin{aligned}\pi_{mp}^r &= p_r(i)q_r(i) + p_s(i)q_s(i) \\ &\quad -w_r^H(1+\alpha)f - w_r^L c(S_r)q_r(i) - w_s^L c(S_r)T_H q_s(i)\end{aligned} \tag{15}$$

which yields, using (10) and (11), we have the same equilibrium mill price charged by each plant in region r and region s as (12) and (14) respectively.

Using (5), (12) and (14), and recalling that a plant of each multi-plant firm serves only the region where it locates, we have the regional price index in region r as follows:

$$P_r = \left\{ \left(m_r^r + m_{mp}^r\right) \left(\frac{w_r^L c(S_r)}{\rho}\right)^{-(\sigma-1)} + \left(m_r^s + m_{mp}^s\right) \left(\frac{w_r^L c(S_s) T_H}{\rho}\right)^{-(\sigma-1)} + T_{sr}^{-(\sigma-1)} \left[m_s^r \left(\frac{w_s^L c(S_r) T_H}{\rho}\right)^{-(\sigma-1)} + m_s^s \left(\frac{w_s^L c(S_s)}{\rho}\right)^{-(\sigma-1)} \right] \right\}^{-1/(\sigma-1)} \tag{16}$$

in which the first two terms correspond to the varieties produced in region r and the last two for those imported from region s. The real wages of the unskilled and skilled workers are defined as follows:

$$\omega_r^L = w_r^L / P_r^{\mu} \qquad r = A, B$$

$$\omega_r^H = w_r^H / P_r^{\mu} \qquad r = A, B$$

For a given distribution of HQs and plants between the two regions, the equilibrium profits may be obtained as follows:

$$\pi_r^{r*} = k_1 [w_r^L c(S_r)]^{-(\sigma-1)} (Y_r P_r^{\sigma-1} + Y_s P_s^{\sigma-1} T_{rs}^{-(\sigma-1)}) - w_r^H f \qquad r \neq s \tag{17}$$

$$\pi_s^{r*} = k_1 [w_s^L c(S_r) T_H]^{-(\sigma-1)} (Y_r P_r^{\sigma-1} T_{sr}^{-(\sigma-1)} + Y_s P_s^{\sigma-1}) - w_r^H f \qquad r \neq s \tag{18}$$

$$\pi_{mp}^{r*} = k_1 [w_r^L c(S_r)]^{-(\sigma-1)} Y_r P_r^{\sigma-1} + k_1 [w_s^L c(S_r) T_H]^{-(\sigma-1)} Y_s P_s^{\sigma-1} - w_r^H (1+\alpha) f \qquad r \neq s \tag{19}$$

where

$$k_1 \equiv \frac{\mu(\sigma-1)^{\sigma-1}}{\sigma^{\sigma}}$$

is a positive constant. Therefore, the free entry condition becomes

$$max\{\pi_A^{A*}, \pi_B^{A*}, \pi_{mp}^{A*}, \pi_A^{B*}, \pi_B^{B*}, \pi_{mp}^{B*}\} = 0 \tag{20}$$

which implies that the wage paid to the skilled workers comes from the operating profits earned by plants.

Finally, since the HQ of each single-plant firm requires a fixed amount of skilled workers f, and that of each multi-plant firm requires $(1+\alpha)f$, the skilled-labor constraint in the economy is:

$$\sum_{r=A,B} (m_A^r + m_B^r) f + m_{mp}^r (1+\alpha) f = S \tag{21}$$

3 Spatial equilibrium when the HQs are agglomerated

In the rest of the paper, we focus on the case where all HQs locate in region A, and examine the equilibrium patterns of plant distribution. In this section, we obtain the equilibrium conditions for each possible pattern of plant distribution.

The assumption that all HQs are agglomerated in region A implies that

$$m^A = m,\ m_A^A + m_B^A + m_{mp}^A = m,\ m_A^B = m_B^B = m_{mp}^B = 0$$

and the skilled labor constraint (21) becomes

$$(m_A^A + m_B^A)f + (m - m_A^A - m_B^A)(1+\alpha)f = S \tag{22}$$

Using (12) and (14), and recalling the note bellow (15), the equilibrium mill price at the production site in each region is given by

$$p_A^* = p_A^*(i) = \frac{c(S)}{\rho} \qquad i \in M_A^A \ \ and \ \ i \in M_{mp}^A \tag{23}$$

$$p_B^* = p_B^*(i) = \frac{c(S)T_H}{\rho a_B} \qquad i \in M_A^A \ \ and \ \ i \in M_{mp}^A \tag{24}$$

For convenience, we introduce the following notation:

$$\theta_A^A \equiv \frac{m_A^A}{m} \qquad \theta_B^A \equiv \frac{m_B^A}{m} \qquad \theta_{mp}^A \equiv \frac{m_{mp}^A}{m} = 1 - \theta_A^A - \theta_B^A \tag{24a}$$

$$\phi_H \equiv \left(\frac{p_A^*}{p_B^*}\right)^{\sigma-1} = \left(\frac{a_B}{T_H}\right)^{\sigma-1} \qquad \phi_{AB} \equiv T_{AB}^{-(\sigma-1)} \qquad \phi_{BA} \equiv T_{BA}^{-(\sigma-1)}$$

By definition, $\phi_H^{1/(\sigma-1)}$ represents the ratio of the mill price in region A over that in region B, which account for both the communication costs and the wage differential (i.e. the productivity differential of unskilled workers in the T-sector). When information transfer were costless, then $T_H = 1$, and hence ϕ_H takes the values $a_B^{\sigma-1} \geq 1$; when information transfer were impossible, then $T_H = \infty$, so $\phi_H = 0$. The index ϕ_{AB} (resp. ϕ_{BA}) measures the accessibility of the differentiated varieties produced in region A (in region B) to the market in region B (in region A), taking values between 0 (when prohibitive transport costs) and 1 (zero transport costs). Thus, ϕ_{AB} and ϕ_{BA} represent the degree of market integration in the two-region economy.

When all HQs locate in region A, using (7), (16) and (21), we have the price index in each region as follows:

$$P_A = \frac{c(S)}{\rho} m^{-1/(\sigma-1)} \left[\left(1-\theta_B^A\right) + \theta_B^A \phi_H \phi_{BA}\right]^{-1/(\sigma-1)} \tag{25}$$

$$P_B = \frac{c(S)}{\rho} m^{-1/(\sigma-1)} \left[\left(1-\theta_A^A\right)\phi_H + \theta_A^A \phi_{AB}\right]^{-1/(\sigma-1)} \tag{26}$$

whereas regional incomes become

$$Y_A = Sw_A^H + L/2 \qquad Y_B = L/2 \tag{27}$$

Using (7), (16), (17), (18), (19), (21) and (27), we obtain the profit of firms in each type as follows:

$$\begin{aligned} \pi_A^{A*} &= \frac{\mu f(1+\alpha-\alpha\theta_A^A-\alpha\theta_B^A)}{\sigma S} \\ &\times \left[\frac{Sw_A^H + L/2}{(1-\theta_B^A)+\theta_B^A\phi_H\phi_{BA}} + \frac{L/2\phi_{AB}}{(1-\theta_A^A)\phi_H+\theta_A^A\phi_{AB}}\right] - w_A^H f \end{aligned} \tag{28}$$

$$\begin{aligned} \pi_B^{A*} &= \frac{\mu f(1+\alpha-\alpha\theta_A^A-\alpha\theta_B^A)}{\sigma S}\phi_H \\ &\times \left[\frac{(Sw_A^H + L/2)\phi_{BA}}{(1-\theta_B^A)+\theta_B^A\phi_H\phi_{BA}} + \frac{L/2}{(1-\theta_A^A)\phi_H+\theta_A^A\phi_{AB}}\right] - w_A^H f \end{aligned} \tag{29}$$

$$\begin{aligned} \pi_{mp}^{A*} &= \frac{\mu f(1+\alpha-\alpha\theta_A^A-\alpha\theta_B^A)}{\sigma S} \\ &\times \left[\frac{Sw_A^H + L/2}{(1-\theta_B^A)+\theta_B^A\phi_H\phi_{BA}} + \frac{\phi_H L/2}{(1-\theta_A^A)\phi_H+\theta_A^A\phi_{AB}}\right] - (1+\alpha)w_A^H f \end{aligned} \tag{30}$$

3.1 Six locational patterns of plant distribution - a preliminary exposition

In our economy, when all HQs are agglomerated in region A, there exist six possible patterns of plant distribution:

Pattern A All plants are located in region A (together with their HQs).

Pattern B All plants are located in region B (separated from their HQs).

Pattern A-B All firms have single plants, some of which locate in region A, whereas the rest in region B.

Pattern A-mp Some firms have single plants in region A, whereas the rest are multi-plant firms with a single plant in each region.

Pattern B-mp Some firms have single plants in region B, whereas the rest are multi-plant firms with one plant in each region.

Pattern mp All firms are of multi-plant, with one plant in each region.

For each pattern, we examine the conditions under which it is an equilibrium. Before conducting formal analyses (in the next subsection), however, in this subsection we explain intuitively which pattern is likely to be realized when. To do so, it is convenient to introduce the following indexes:

$$\xi_B^A \equiv \left(\frac{w_A^L c(S)}{w_B^L c(S) T_H T_{BA}}\right)^{\sigma-1} = \left(\frac{a_B}{T_H T_{BA}}\right)^{\sigma-1} = \phi_{BA}\phi_H \tag{31}$$

$$\xi_A^B \equiv \left(\frac{w_B^L c(S) T_H}{w_A^L c(S) T_{AB}}\right)^{\sigma-1} = \left(\frac{T_H}{a_B T_{AB}}\right)^{\sigma-1} = \frac{\phi_{AB}}{\phi_H} \tag{32}$$

implying that

$$\xi_B^A \xi_A^B = \left(\frac{1}{T_{AB} T_{BA}}\right)^{\sigma-1} < 1 \tag{33}$$

$$\frac{\xi_A^B}{\xi_B^A} = \left\{\left(\frac{T_H}{a_B}\right)^2 \frac{T_{BA}}{T_{AB}}\right\}^{\sigma-1} \tag{34}$$

By definition, $\left(\xi_B^A\right)^{1/(\sigma-1)}$ represents the ratio of the marginal production cost of a variety in region A (and supplying it to region A) over the marginal cost of producing a unit of a variety in region B and transporting to region A. In other word, ξ_B^A *measures the relative cost advantage of region* B *over region* A *when serving to the market* A *(i.e., the market in region* A*).* If $\xi_B^A > 1$, region B has a cost advantage in market A; whereas if $\xi_B^A < 1$, region A has a cost advantage in market A. Likewise, ξ_A^B *measures the relative cost advantage of region* A *over region* B *when serving to the market* B *(i.e., the* *market in region B).* If $\xi_A^B > 1$, region A has a cost advantage in market B; whereas if $\xi_A^B < 1$, region B has a cost advantage in market B.

Since the inequality (33) means that

$$\xi_B^A > 1 \Rightarrow \xi_A^B < 1$$

we can conclude that

$$\xi_B^A > 1 \Rightarrow \{\textit{region B has a cost advantage in both markets}\} \tag{35}$$

Likewise, since

$$\xi_A^B > 1 \Rightarrow \xi_B^A < 1$$

we can conclude that

$$\xi_A^B > 1 \Rightarrow \{\textit{region A has a cost advantage in both markets}\} \tag{36}$$

For a preliminary study, let us first consider an extreme case such that $\alpha = 1$ and hence no multi-plant firm emerge. [2] In this case, there exist only three possible equilibrium patterns, i.e., Pattern A, Pattern B and Pattern A-B. For an illustration, we set $\alpha = 1$ and $\mu/\sigma = 0.5$. Then, we can obtain the domain of each equilibrium pattern in the (ξ_B^A, ξ_A^B) space as in Figure 1. (For the exact derivation of the results in Figure 1, see Section 3.2.)

Figure 1

In Figure 1, the horizontal axis (resp. vertical axis) represents the parameter ξ_B^A (resp. ξ_A^B). Because of condition (35), the relevant region of two parameters is below the hyperbola, $\xi_B^A \xi_A^B = 1$. Consider first point a in the figure. Since $\xi_A^B > 1$ at this point, we know by (35) that region A has a cost advantage in both markets; hence, all firms should have plants in region A. By the same reason, in the parameter area where $\xi_A^B > 1$ and $\xi_B^A \xi_A^B < 1$, all firms should have plants in region A. By (32)

$$\xi_A^B > 1 \Leftrightarrow \frac{T_H}{a_B} > T_{AB}$$

[2] When $\alpha = 1$, no multi-plant firm can exist in equilibrium. Indeed, if a multi-plant firm (producing the same variety at two plants) earns the zero profit (i.e., the equilibrium profit), then the combined profits of two independent firms, each producing a new different variety, should be positive (because of less competition). This contradicts the equilibrium.

Hence, all single-plants choose to locate in region A, when the communication cost T_H (between HQs in region A and plants) is very high, the wage rate in region B, $1/a_B$, is not too low, while the transport cost from region A to B is not too high, which is not surprising.

By contrast, in the area where $\xi_B^A > 1$ and $\xi_B^A \xi_A^B < 1$, region B has a cost advantage in both markets, and hence all single-plants should locate in region B. By (31),

$$\xi_B^A > 1 \Leftrightarrow a_B > T_H T_{BA}$$

This happens, again not surprisingly, when the labor cost advantage, a_B, of region B is very large, the communication cost T_H is not very high, while the transport cost from region B to A is relatively low.

Inside the square in Figure 1, since $\xi_B^A < 1$ and $\xi_A^B < 1$, no region has a cost advantage in both regions, implying that region A has a cost advantage only in market A whereas region B only in market B. Hence, it is not clear a priori which region is better for single-plant firms. However, at point a' in Figure 1, for example, the ratio ξ_A^B/ξ_B^A is relatively large, implying that for the location of single-plants, region A has a more cost advantage in comparison with region B. In particular, suppose that transport costs are symmetric so that $T_{AB} = T_{BA}$. Then, we have by (34) that

$$\frac{\xi_A^B}{\xi_B^A} = \left(\frac{T_H}{a_B}\right)^{2(\sigma-1)} \quad when \quad T_{AB} = T_{BA}$$

Hence, when T_H/a_B is relatively large (i.e., communication costs are relatively high in comparison with the labor cost advantage, a_B, of region B), then region A has a more cost advantage in comparison with region B. Furthermore, we can see by (27) that region A has a larger market than region B. Hence in the area A above the broken curve cd in Figure 1, all firms choose region A for the location for their plants. [3] By the opposite reason, in the domain to the right of the broken curve ec in Figure 1, firms choose region B for their plants.

Finally, in the domain A-B in Figure 1, it happens that some firms choose region A for their plants, whereas the rest choose region B. Each point in the domain A-B is either close to the origin O and/or close to the diagonal Oc. When a point is close to the origin, each region is in a big disadvantage

[3] In Figure 1, apart of the broken curve cd is below the diagonal 0c. This is because the market A is larger than market B, and hence firms choose region A for their plants even when the ratio ξ_B^A/ξ_A^B is a little smaller than 1.

in supplying the product to the other region. Hence, some plants should locate in region A while focusing on market A, whereas the rest in region B while focusing on market B. When a point is close to the diagonal Oc, the relative cost advantage of neither region is large. In this case, in order to avoid competition, plants should be dispersed between the two regions. In particular, we can see by (31) and (32) that when transportation costs T_{AB} and T_{BA} are very large, both ξ_B^A and ξ_A^B are very small. Hence, not surprisingly, plants should be dispersed between the two regions.

We can also show that when μ/σ becomes smaller (i.e., the expenditure share μ on the differentiated goods is smaller and/or the degree of product differentiation, $1/\sigma$, is smaller), the two broken curves in Figure 1 become more symmetric with respect to the diagonal Oc. This is because the aggregate income Sw_A^H of skilled workers in region A becomes smaller as μ/σ becomes smaller (see (28) and (29)), and hence the difference between the aggregate incomes of two regions becomes smaller.

Now, we consider the more realistic case such that $\alpha < 1$, and examine the emergence of multi-plant firms. For an illustration, we set $\alpha = 0.2$ and $\mu/\sigma = 0.5$, and obtain the domain of each equilibrium location pattern of plants in the (ξ_B^A, ξ_A^B) space as in Figure 2, which is a modified version of Figure 1. (Note that we keep $\mu/\sigma = 0.5$ is both figures.) Given $\alpha = 0.2 < 1$, the additional cost for setting up the second plant is relatively small. Thus, as shown in Figure 2, multi-plant firms emerge when both ξ_B^A and ξ_A^B are small. Indeed, Figure 2 happens to represent the generic case for equilibrium location patterns under the possibility of multi-plant firms.

Figure 2

In the domains outside the square in Figure 2 where $\xi_B^A > 1$ and $\xi_A^B > 1$ there is no change from Figure 1. Indeed, when $\xi_A^B > 1$, for example, region A has a lower marginal cost for providing a variety to either market. Thus, every firm chooses to have a single plant in region A, without bothering about the second plant. Likewise, when $\xi_B^A > 1$, all firms have single plants in region B.

Inside the square in Figure 2 where $\xi_B^A < 1$ and $\xi_A^B < 1$, region A (resp. region B) has a lower marginal cost in providing a variety to market A (resp. market B), but a higher marginal cost in providing it to market B (resp. market A). Thus, now, each firm must face the trade-off between the additional fixed cost from setting the second plant and a high marginal cost in serving the two markets from a single-plant.

In the domain A inside the square in Figure 2, the value of ξ_A^B is rather close to 1, implying that, in terms of marginal supply cost to the market B, region A dose not have a great disadvantage to region B. Thus, avoiding the additional fixed cost from setting up the second plant, every firm chooses to have a single-plant in region A and to serve the product to the two markets. Likewise, in the domain B inside the square in Figure 2, all firms choose to have single-plants in region B.

In the domain mp in Figure 2, however, both ξ_B^A and ξ_A^B are very small, meaning that, in terms of marginal supply cost, a plant in one region has a big disadvantage in supplying the product to the other region in comparison with a plant in the other region. Hence, accepting the additional fixed cost of the second plant, all firms choose to have two plants, one in each region. Next, in the domain A-mp in Figure 2, ξ_A^B is in the middle between 1 and 0, implying that, in terms of the marginal cost in serving the product to market B, a plant in region A has a significant, but not fatal, disadvantage in comparison with a plant in region B. In this situation, some firms choose to have single plants in region A, whereas the rest choose to have two plants. Notice that, in market B, each two-plant firm has a larger market share than a single-plant firm (having a plant in region A), due to the fact that $\xi_A^B < 1$ and the marginal cost pricing given by (23) and (24). However, these multi-plant firms involve an additional fixed costs. Thus, the two type of firms can co-exist in the domain A-mp in Figure 2. Likewise, in the domain B-mp, some firms have single-plants in region B, while the rest have two plants.

When the values of α and μ/σ change, the boundary of each domain in Figure 2 change, of course. To examine this issue precisely, however, we need to determine the boundary of each domain precisely, which is the task of the next subsection.

3.2 Equilibrium conditions for six locational patterns

In this subsection, we obtain the equilibrium conditions for each locational pattern, using the profit functions (28) to (30). First, the next lemma identifies the necessary and sufficient condition for all HQs to be agglomerated in region A (See Appendix B for the proof).

Lemma 3.1 *All HQs are agglomerated in region A when the following con-*

dition holds:

$$c(0) \geq \frac{T_H}{T_{AB}^{\mu/(\sigma-1)}}\, c(m). \tag{37}$$

In the right-hand side of (37), the term T_H represents the decrease in communication costs made by a firm when its HQ moves together with its plant from A to B, whereas the term $T_{AB}^{\mu/(\sigma-1)}$ reflects the increase in the price index of the $\mathbb{M}$-good borne by the skilled workers who move to B with the HQ. Hence, the inequality above means that all firms choose to agglomerate their HQs provided that the Marshallian externalities are sufficiently strong with respect to the ratio of these two opposite effects.

In the rest of the paper, we always assume that condition (37) holds, and hence all HQs are agglomerated together in region A. Then, utilizing parameters ξ_B^A and ξ_A^B defined by (31) and (32), we obtain the equilibrium conditions for each pattern of plant-distribution. By definition (31) and (32), the effective domain of the parameter space, (ξ_B^A, ξ_A^B), is always restricted to the area,

$$\xi_B^A > 0, \quad \xi_A^B > 0 \quad and \quad \xi_B^A \xi_A^B < 1 \tag{38}$$

which is taken as granted in the following discussion.

3.2.1 Pattern A

Setting $\pi_A^{A*} = 0$ in (28), the wage rate of skilled labor in region A under Pattern *A* can be obtained as follows (See Appendix C for the derivation):

$$w_A^H = \frac{L\mu/\sigma}{S(1-\mu/\sigma)} \tag{39}$$

Clearly, w_A^H increases when the share of the industrial sector (μ) and the degree of product differentiation ($1/\sigma$) rise. This is because the demand for each variety increases. Likewise, w_A^H increases with the increase of unskilled labor (L). This is because the income in both regions increases. Whereas w_A^H decreases with the increase of skilled labor (S). The increase in the size of skilled workers causes two effects: first, the income increases in region A; second, the equilibrium number of firms increases. The second effect cancels out the first effect on the consumption by skilled workers. But the second effect remains on the consumption by unskilled workers. Furthermore, the wage of skilled labor is independent from the communication costs and the transportation costs because of the iceberg technology.

Substituting (39) into (27), the ratio of regional incomes in the two regions is given by

$$\frac{Y_A}{Y_B} = 1 + \frac{2\mu/\sigma}{1-\mu/\sigma} \tag{39a}$$

which increases as μ/σ increases, not surprisingly.

Using the wage function (39), we can obtain the following lemma which gives the equilibrium condition for Pattern A (See Appendix C for the proof).

Lemma 3.2 *Suppose that (37) holds. Then, Pattern A in which all plants are located in region A together with their HQs is a spatial equilibrium when the following condition holds:*

$$\xi_A^B \geq \max\left\{\frac{1-\mu/\sigma}{1-\mu/\sigma+2\alpha}, \frac{1-\mu/\sigma}{2-(1+\mu/\sigma)\xi_B^A}\right\} \tag{40}$$

Notice that when $\alpha \geq \frac{1+\mu/\sigma}{2}$, condition (40) reduces to the following one:

$$\xi_A^B \geq \frac{1-\mu/\sigma}{2-(1+\mu/\sigma)\xi_B^A} \tag{41}$$

which represents the domain A shown in Figure 1. By contrast, when $\alpha < \frac{1+\mu/\sigma}{2}$, condition (40) defines the domain A shown in Figure 2. It can be readily seen by (40) that the domain A in Figure 2 continuously expands downwards as the value of the fixed cost parameter, α, of the second plant increases up to $(1+\mu/\sigma)/2$.

3.2.2 Pattern B

Setting $\pi_B^{A*} = 0$ in (29), we obtain the wage rate of skilled labor in region A, which turns our to be exactly the same as (39) (See Appendix D for the derivation). The following lemma gives the equilibrium condition for Pattern B (See Appendix D for the proof).

Lemma 3.3 *Suppose that (37) holds. Then, Pattern B in which all plants are located in region B is a spatial equilibrium when the following condition holds:*

$$\xi_B^A \geq \max\left\{\frac{1+\mu/\sigma}{1+\mu/\sigma+2\alpha}, \frac{1+\mu/\sigma}{2-(1-\mu/\sigma)\xi_A^B}\right\} \tag{42}$$

Notice that when $\alpha \geq \frac{1-\mu/\sigma}{2}$, condition (42) reduces to the following one:

$$\xi_B^A \geq \frac{1+\mu/\sigma}{2-(1-\mu/\sigma)\xi_A^B} \tag{43}$$

which represents the domain B shown in Figure 1. By contrast, when $\alpha < \frac{1-\mu/\sigma}{2}$, condition (42) defines the domain B shown in Figure 2. It can be readily seen by (42) that the domain B in Figure 2 continuously expands toward the left as the value of the fixed cost parameter, α, of the second plant increases up to $(1-\mu/\sigma)/2$.

3.2.3 Pattern A-B

In terms of the shares of the three types of firms defined in (24a), Pattern *A-B* means $\theta_{mp}^A = 0$, $0 < \theta_A^A < 1$ and $0 < \theta_B^A = 1 - \theta_A^A < 1$. Setting $\pi_A^{A*} = \pi_B^{A*} = 0$ in (28) and (29), again, we obtain exactly the same wage rate of skilled labor as (39) (See Appendix E for the derivation). Thus, the income ratio Y_A/Y_B remains the same as (39a). We also have the following share of firms whose plants are located in region B (See Appendix E for the derivation):

$$\theta_B^A = \frac{(1+\mu/\sigma)\xi_B^A\xi_A^B + (1-\mu/\sigma) - 2\xi_A^B}{2(1-\xi_A^B)(1-\xi_B^A)} \equiv \tilde{\theta}_B^A \tag{44}$$

Since $\xi_B^A\xi_A^B < 1$, this implies that the share of firms which locate their plants only in region B increases as μ/σ decreases, that is, the income ratio Y_A/Y_B decreases.

The following lemma gives the equilibrium condition for Pattern *A-B* (See Appendix E for the proof).

Lemma 3.4 *Suppose that (37) holds. Then, Pattern A-B in which all firms have single plants, some of which locate in region A, whereas the rest in region B, is a spatial equilibrium when the following condition holds:*

$$\max\left\{\frac{2\xi_B^A - 1 - \mu/\sigma}{(1-\mu/\sigma)\xi_B^A},\ \frac{1-\xi_B^A-\alpha}{1-(1+\alpha)\xi_B^A},\ 0\right\} < \xi_A^B < \frac{1-\mu/\sigma}{2-(1+\mu/\sigma)\xi_B^A} \tag{45}$$

The left-hand side of (45) defines the border between the domain A-B and the domain A in Figure 2. On the other hand, the right-hand side of (45) defines the lower border of the domain A-B. When $\frac{1-\mu/\sigma}{2} \geq \alpha$ (which is the case for Figure 2), the left-hand side of (45) gives the V-shaped lower boundary of domain A-B depicted in Figure 2. Whereas, when $\frac{1-\mu/\sigma}{2} < \alpha$, the bottom part of the V-shaped lower boundary of the domain A-B is cut by the horizontal axis.

3.2.4 Pattern A-mp

In terms of the shares of the three types of firms defined in (24a), Pattern *A-mp* means $\theta_B^A = 0$, $0 < \theta_A^A < 1$ and $0 < \theta_{mp}^A = 1 - \theta_A^A < 1$. Setting $\pi_A^{A*} = \pi_{mp}^{A*} = 0$ in (28) and (30), again, we obtain exactly the same wage rate of skilled labor as (39) (See Appendix F for the derivation). We also have the following share of firms whose plants are located in region A (See Appendix F for the derivation):

$$\theta_A^A = \frac{\{(1-\alpha) - (1+\alpha)\mu/\sigma\} - (1+\alpha)(1-\mu/\sigma)\xi_A^B}{\alpha(1-\mu/\sigma)(1-\xi_A^B)} \equiv \hat{\theta}_A^A \tag{46}$$

The following lemma gives the equilibrium condition for Pattern *A-mp* (See Appendix F for the proof).

Lemma 3.5 *Suppose that (37) holds. Then, Pattern A-mp in which some firms have single plants in region A, whereas the rest are multi-plant firms with a single plant in each region, is a spatial equilibrium when the following condition holds:*

$$\max\left\{\frac{1-\alpha-\mu/\sigma-\alpha\mu/\sigma}{1+\alpha-\mu/\sigma-\alpha\mu/\sigma},\ 0\right\} < \xi_A^B$$
$$< \min\left\{\frac{1-\xi_B^A-\alpha}{1-(1+\alpha)\xi_B^A},\ \frac{1-\mu/\sigma}{1-\mu/\sigma+2\alpha}\right\} \tag{47}$$

The left-hand side of (47) defines the border between the domain A-mp and the domain mp, whereas the right-hand side of (47) defines the borders between the domain A-mp and the domain A and between the domain A-mp and the domain A-B in Figure 2. When $\frac{1+\mu/\sigma}{2} \geq \alpha$ (which is the case for Figure 2), the lower boundary of the domain A-mp is apart from the horizontal axis. Whereas, when $\frac{1+\mu/\sigma}{2} < \alpha < 1$, the domain A-mp locates around the origin.

3.2.5 Pattern B-mp

In terms of the shares of the three types of firms defined in (24a), Pattern *B-mp* means $\theta_A^A = 0$, $0 < \theta_B^A < 1$ and $0 < \theta_{mp}^A = 1 - \theta_B^A < 1$. Setting $\pi_B^{A*} = \pi_{mp}^{A*} = 0$ in (29) and (30), again, we obtain exactly the same wage rate of skilled labor as (39) (See Appendix G for the derivation). We also have the following share of firms whose plants are located in region B (See Appendix G for the derivation):

$$\theta_B^A = -\frac{1 - \alpha + \mu/\sigma + \alpha\mu/\sigma - (1+\alpha)(1+\mu/\sigma)\xi_B^A}{\alpha(1-\mu/\sigma)(1-\xi_B^A)} \equiv \check{\theta}_B^A \tag{48}$$

The following lemma gives the equilibrium condition for Pattern *B-mp* (See Appendix G for the proof).

Lemma 3.6 *Suppose that (37) holds. Then, Pattern B-mp in which some firms have single plants in region B, whereas the rest are multi-plant firms with a single plant in each region, is a spatial equilibrium when the following condition holds:*

$$\frac{1 - \alpha + \mu/\sigma + \alpha\mu/\sigma}{1 + \alpha + \mu/\sigma + \alpha\mu/\sigma} < \xi_B^A < \min\left\{\frac{1+\mu/\sigma}{1+\mu/\sigma+2\alpha}, \frac{1-\xi_A^B-\alpha}{1-(1+\alpha)\xi_A^B}\right\} \tag{49}$$

The left-hand side of (49) defines the border between the domain B-mp and the domain mp in Figure 2. On the other hand, when $\frac{1-\mu/\sigma}{2} \geq \alpha$ (which is the case for Figure 2), the right-hand side of (49) gives the borders between the domain B-mp and the domain B and between the domain B-mp and the domain A-B in Figure 2, whereas, when $\frac{1-\mu/\sigma}{2} < \alpha$, only the border between the domain B-mp and the domain B is defined by the right-hand side of (49).

3.2.6 Pattern mp

Setting $\pi_{mp}^{A*} = 0$ in (30), again, we obtain exactly the same wage rate of skilled labor as (39) (See Appendix G for calculation). The following lemma gives the equilibrium condition for Pattern *mp* (See Appendix G for the proof).

Lemma 3.7 *Suppose that (37) holds. Then, Pattern mp in which all firms are of multi-plant is a spatial equilibrium only when* $0 < \alpha < \frac{1-\mu/\sigma}{1+\mu/\sigma}$ *and the* *following two conditions hold:*

$$\xi_A^B \leq \frac{1 - \alpha - \mu/\sigma - \alpha\mu/\sigma}{1 + \alpha - \mu/\sigma - \alpha\mu/\sigma} \tag{50}$$

$$\xi_B^A \leq \frac{1 - \alpha + \mu/\sigma + \alpha\mu/\sigma}{1 + \alpha + \mu/\sigma + \alpha\mu/\sigma} \tag{51}$$

Conditions (50) and (51) define the domain mp shown in Figure 2. By (50) and (51), we can see that the domain mp in Figure 2 shrinks with a increase in the additional fixed costs α.

We may summarize the results obtained in this section as follows:

Proposition 3.1 *Pattern mp, in which all firms have one plant in each region, emerges under a strong relative cost advantage of region A over region B when serving to the market A and a strong relative cost advantage of region B over region A when serving to the market B. As region A loses a relative cost advantage over region B when serving to the market A, some plants located in region A shift to region B. Whereas, as region B loses a relative cost advantage over region A when serving to the market B, some plants located in region B shift to region A.*

4 The impact of economic integration on the distribution of plants

In this section, we explore the impact of decreasing communication costs between HQs and plants (ϕ_H increases) and decreasing transportation costs of differentiated products (ϕ_{BA} and ϕ_{AB} increase), assuming that Marshallian externalities are strong enough for (37) to hold.

4.1 Reducing communication costs

In this subsection, we examine the impact of decreasing communication costs on the location pattern of plants (i.e. increasing ϕ_H [4]). From (31) and (32), ξ_B^A increases and ξ_A^B decreases with a decrease in communication costs T_H. This means that locating plants in region B becomes more attractive to serve

[4]The increase of ϕ_H may also arise from the decrease in the difference of productivity between region A and region B.

region A and locating plants in region A becomes less desirable to serve region B. Thus the number of plants in region A decreases whereas that in region B increases.

To illustrate the shift of location pattern with decreasing communication costs, observe that when the value of $T_{AB}T_{BA}$ is fixed, equation (33) defines a hyperbola. In Figure 3, two hyperbolas are depicted under different value of $T_{AB}T_{BA}$. This hyperbola shifts away from the origin as $T_{AB}T_{BA}$ becomes smaller. We can see by (31) and (32) that as the value of T_H/a_B decreases, the point (ξ_B^A,ξ_A^B) moves on each hyperbola from the upper left to the lower right.

Figure 3

Overlapping Figures 2 and 3, we obtain Figure 4. We can see that (34) defines the line whose slope is the right-hand side of (34). In Figure 4, the line is depicted under the smallest communication costs. The point (ξ_B^A, ξ_A^B) does not move over the line with decreasing communication costs. We can see in Figure 4 that, when transportation costs of products are high like the automobile industry, the location pattern of plants shifts in the following order as communication costs decrease: Pattern A → Pattern A-*mp* → Pattern *mp*. Whereas, when transportation costs of products are low like the hard disc drive industry, the location pattern of plants shifts in the following order with decreasing communication costs: Pattern A → Pattern A-B → Pattern B. We can interpret the shifts of location pattern above in the following way: multi-plants increase in the automobile firms with decreasing communication costs, whereas single plants in region B increase in hard disc drive firms with decreasing communication costs.

Figure 4

First, to show these results precisely, we focus on the case where the location pattern shifts in the following order: Pattern A → Pattern A-*mp* → Pattern *mp* → Pattern B-*mp* → Pattern B. Using (40) and (47), we can see that the shift from Pattern A to Pattern A-*mp* happens by an increase in ξ_B^A and a decrease in ξ_A^B. Assuming Pattern A-*mp* to hold, we obtain the following result from (46):

$$\frac{\partial \hat{\theta}_A^A}{\partial \phi_H} = -\frac{2\phi_{AB}}{(1+\mu/\sigma)(\phi_{AB}-\phi_H)^2} < 0 \tag{52}$$

This shows that the share of firms which locate single plants in region A decreases and the share of firms which locate multi-plants increases gradually with decreasing communication costs. Using (47) and (51), we can see that the shift from Pattern *A-mp* to Pattern *mp* happens by an increase in ξ_B^A and a decrease in ξ_A^B. Likewise, we can see that the location pattern of plants shifts from Pattern *mp* to Pattern *B-mp* by an increase in ξ_B^A and a decrease in ξ_A^B, using (49) and (51). Assuming that Pattern *B-mp* to hold and considering a decrease in communication costs between HQs and plants (ϕ_H increases), we can obtain the following result from (48):

$$\frac{\partial \check{\theta}_B^A}{\partial \phi_H} = \frac{2\phi_{BA}}{(1-\mu/\sigma)(1-\phi_{BA}\phi_H)^2} > 0 \tag{53}$$

This shows that the share of firms which locate single plants in region B increases and the share of firms which have multi-plants decreases with a decrease in communication costs. Using (43) and (49), we can see that the shift from Pattern *B-mp* to Pattern B happens by a increase of ξ_B^A and a decrease of ξ_A^B.

Furthermore, we need to examine which pattern emerges when the communication costs are the smallest. Setting the smallest communication costs $T_H = 1$, we obtain the following result from (31) and (32):

$$\xi_B^A = \left(\frac{a_B}{T_{BA}}\right)^{\sigma-1} \qquad \xi_A^B = \left(\frac{1}{a_B T_{AB}}\right)^{\sigma-1} \tag{54}$$

Using (50), (51) and (54), we can see that Pattern *mp* emerges under the smallest communication costs when transportation costs are large and the productivity difference of the unskilled between regions is small. Therefore, when transportation costs are large and the productivity difference of the unskilled between the regions is small, the location pattern shifts with decreasing communication costs in the following order: Pattern A → Pattern *A-mp* → Pattern *mp*. This result imply that multi-plants in automobile firms, which involve large transportation costs, increase with decreasing communication costs. Whereas, using (42), (49) and (54), when both of transportation costs and the productivity difference of the unskilled are large, Pattern B or Pattern *B-mp* emerge under the smallest communication costs. Thus, when transportation costs and the productivity difference of the unskilled between the regions are large, the location pattern shifts with decreasing communication costs in the following order: Pattern A → Pattern *A-mp* → Pattern *mp* → Pattern *B-mp* → Pattern B.

Next, we focus on the case where the location pattern of plants shifts in the following order with decreasing communication costs: Pattern A $\rightarrow$ Pattern A-B $\rightarrow$ Pattern B with a decrease of communication costs. Using (40) and (45), we can see that the shift from Pattern A to Pattern A-B happens by an increase in ξ_B^A and a decrease in ξ_A^B when transportation costs are small or when the additional fixed costs are rather large. Assuming Pattern A-B to hold and considering a decrease in communication costs between HQs and plants (ϕ_H increases), we can obtain the following result from (44):

$$\frac{\partial \tilde{\theta}_B^A}{\partial \phi_H} = \frac{1}{\phi_{AB}} \frac{1 + \mu/\sigma}{2(1 - \phi_H/\phi_{AB})^2} + \phi_{BA} \frac{1 - \mu/\sigma}{2(1 - \phi_{BA}\phi_H)^2} > 0 \tag{55}$$

This shows that the share of firms which have single plants in region B increases and the share of firms which have single plants in region A decreases gradually with decreasing communication costs. The shift from Pattern A-B to Pattern B happens by an increase in ξ_B^A and a decrease in ξ_A^B, using (42) and (45). Furthermore, using (42) and (54), we can see that Pattern B emerges under the smallest communication costs when transportation costs are small. Therefore, when transportation costs are small, the location pattern shifts with decreasing communication costs in the following order: Pattern A $\rightarrow$ Pattern A-B $\rightarrow$ Pattern B. This results implies that the hard disc drive firms, which involve small transportation costs of their products, have single plants in low wage countries with decreasing communication costs.

In addition, we examine the shift of location patterns on Pattern A-B. Assuming that Pattern A-*mp* adjoins Pattern A-B on (ξ_B^A,ξ_A^B) space, we can see that the location pattern shifts from Pattern A-*mp* to Pattern A-B with decreasing communication costs when the following conditions are satisfied: 1) $\alpha \leq \mu/\sigma$ or 2) $\alpha > \mu/\sigma$, $\xi_B^A > \frac{1-\alpha}{1+\alpha}$ and $\xi_A^B < \frac{1-\alpha}{1+\alpha}$ (See Appendix G for the proof). Next, assuming that Pattern B-*mp* adjoins Pattern A-B on (ξ_B^A, ξ_A^B) space, we can see that the location pattern shifts from Pattern B-*mp* to Pattern A-B with decreasing communication costs (See Appendix H for the proof).

The discussion above may then be summarized as follows.

Proposition 4.1 *When transportation costs are large and the wage difference is small, the location pattern of plants shifts with decreasing communication costs in the following order: Pattern A $\rightarrow$ Pattern A-mp $\rightarrow$ Pattern mp.*

Whereas, when transportation costs are small, the location pattern of plants shifts with decreasing communication costs in the following order: Pattern A → Pattern A-B → Pattern B.

4.2 Reducing transportation costs

In this subsection, we examine the impact of decreasing transportation costs (i.e., increasing ϕ_{AB} and ϕ_{BA}) on the location pattern of plants. From (31) and (32), we have $\partial \xi_B^A / \partial \phi_{BA} = \phi_H$ and $\partial \xi_A^B / \partial \phi_{AB} = \phi_H^{-1}$. These mean that, when $\phi_H > 1$ (or $T_H/a_B > 1$), the relative cost advantage of region B over region A when serving to the market A decreases more with decreasing transportation costs, whereas the relative cost advantage of region A over region B when serving to the market B decreases less with decreasing transportation costs. Onthe other hand, when $\phi_H < 1$ (or $T_H/a_B > 1$), the relative cost advantage of region B over region A when serving to the market A decreases less with decreasing transportation costs, whereas the relative cost advantage of region A over region B when serving to the market B decreases more with decreasing transportation costs. Therefore, multi-plant firms become single-plant firms with decreasing transportation costs. Furthermore, firms locating single plants in region A increase when communication costs are high with decreasing transportation costs, whereas firms locating single plants in region B increase when communication costs are low with decreasing transportation costs.

To illustrate the shift of location pattern with decreasing transportation costs in Figures, observe that when the value $(T_H/a_B)^2$ is fixed and transportation costs from region A and from region B are the same value, equation (34) defines a line through the origin in Figure 5. As transportation costs increase, the location pattern of plants shifts away from the origin along this line. Since the slope of this line is T_H^2/a_B^2, when communication costs are high, the location pattern shifts in Figure 5 with decreasing transportation costs in the following order: Pattern *mp* → Pattern *A*-*mp* → Pattern *A*. Whereas, when communication costs are low, the location pattern shifts in Figure 5 with decreasing transportation costs in the following order: Pattern *mp* → Pattern *B*-*mp* → Pattern*B*.

Figure 5

We examine the shift of location pattern when we set transportation costs from region A and from region B take the same value. First, assuming that Pattern *mp* is held and using (47) and (50), we can see that, when communication costs are large, the location pattern of plants shifts from Pattern *mp* to Pattern *A-mp* with decreasing transportation costs, that is an increase of ξ_B^A and ξ_A^B. Whereas, using (49) and (51), we can see that the location pattern of plants shifts from Pattern *mp* to Pattern *B-mp* with decreasing transportation costs when communication costs are small.

Second, we examine Pattern *A-mp*. Assuming that Pattern *A-mp* to hold and considering a decrease in transportation costs (ξ_B^A and ξ_A^B increase), we can derive the following results from (46):

$$\frac{\partial \hat{\theta}_A^A}{\partial \phi_{AB}} = \frac{2\phi_H}{(1+\mu/\sigma)(\phi_{AB}-\phi_H)^2} > 0 \qquad \frac{\partial \hat{\theta}_A^A}{\partial \phi_{BA}} = 0 \tag{56}$$

These results show that the share of firms which have multi-plants decreases and the share of firms which have single plants only in region A increases when transportation costs from region A to region B decrease. Whereas the share of multi-plants firms and that of firms which have single plants in region A do not change when transportation costs from region B to region A decrease. The pace of the relocation of plants to region A becomes slower as the difference of market size (μ/σ) increases. Furthermore, assuming that Pattern *A-mp* adjoins Pattern *A-B* on (ξ_B^A,ξ_A^B)-space, we can see that the shift from Pattern *A-mp* to Pattern *A-B* happens with decreasing transportation costs (See Appendix I for the proof). Whereas, from (40) and (47), we can see that the location pattern of plants shifts from Pattern *A-mp* to Pattern A with decreasing transportation costs, that is an increase in ξ_B^A and ξ_A^B.

Third, we examine Pattern *B-mp*. Assuming that Pattern *B-mp* to hold and considering a decrease in transportation costs (ξ_B^A and ξ_A^B increase), we have the following results from (48):

$$\frac{\partial \check{\theta}_B^A}{\partial \phi_{BA}} = \frac{2\phi_H}{(1-\mu/\sigma)(1-\phi_{BA}\phi_H)^2} > 0 \qquad \frac{\partial \check{\theta}_B^A}{\partial \phi_{AB}} = 0 \tag{57}$$

which shows that the share of firms which have multi-plants decreases and the share of firms which have single plants in region B increases when transportation costs from region B to region A decrease. Whereas the share of firms which have multi-plants does not change when transportation costs from region A to region B decrease. The relocation of multi-plants becomes faster pace when the difference of market size (μ/σ) is large. From (42) and

(49), we can see that the location pattern of plants shifts from Pattern *B-mp* to Pattern *B* with decreasing transportation costs, that is an increase in ξ_B^A and ξ_A^B. Whereas we can see that the location pattern of plants shifts from Pattern *B-mp* to Pattern *A-B* with decreasing transportation costs (See Appendix I for the proof).

Forth, we examine Pattern A-B. Setting $d\phi_{AB} = d\phi_{BA} \equiv d\phi_T$ and $d\phi_H = 0$, we have

$$\frac{d\tilde{\theta}_B^A}{d\phi_T} \lesseqqgtr 0 \quad \Leftrightarrow -(1-\xi_B^A)^2 + \frac{1-\mu/\sigma}{1+\mu/\sigma}\phi_H^2 \left(1-\xi_A^B\right)^2 \lesseqqgtr 0 \tag{58}$$

From this expression, we can see that the share of firms which have single plants in region A decreases and the share of firms which have single plants in region B increases when 1) ϕ_H is large, 2)ξ_B^A is large and 3) ξ_A^B is small, that is small communication costs. Whereas the share of firms which have single plants in region A increases and the share of firms which have single plants in region B decreases when 1) ϕ_H is small, 2)ξ_B^A is small and 3) ξ_A^B is large, that is large communication costs. Furthermore, with decreasing transportation costs, the location pattern shifts from Pattern *A-B* to Pattern *A* when $\xi_B^A < \frac{\sigma}{\sigma+\mu}$, whereas the location pattern shifts from Pattern *A* to Pattern *A-B* when $\xi_B^A > \frac{\sigma}{\sigma+\mu}$ (See Appendix J for the proof). In addition, the location pattern shifts from Pattern *A-B* to Pattern *B* with decreasing transportation costs (See Appendix K for the proof).

The discussion above may be summarized as follows.

Proposition 4.2 *Suppose that transportation costs from region A and from region B takes the same value. Then, the number of the firms having plants in both regions decreases with decrease transportation costs. When communication costs are small, the number of plants located in region A increases and that of plants located in region B decreases with decreasing transportation costs.*

5 The welfare analysis

In this section, we examine the impact of decreasing communication costs on the welfare of workers in the core and the periphery. Since the nominal wages of the unskilled and the skilled are independent of communication costs, the impact of falling communication costs on the welfare is determined by the change in the price index of manufactured goods in each region.

First, we examine the price index in region A. Using (25), we have

$$\frac{\partial P_A}{\partial \phi_H} = -\frac{P_A}{\sigma - 1}\frac{\theta_B^A \phi_{BA} - (1 - \phi_H \phi_{BA})\partial \theta_B^A / \partial \phi_H}{(1 - \theta_B^A) + \theta_B^A \phi_H \phi_{BA}}$$

under either Pattern A, Pattern *mp* or Pattern A-*mp*, since $\theta_B^A = 0$ and $\partial \theta_B^A / \partial \phi_H = 0$, we have $\partial P_A / \partial \phi_H = 0$. Thus, the welfare in region A does not change with decreasing communication costs under either pattern, since all varieties are produced in region A. Under Pattern A-B ($0 < \theta_B^A < 1$), using (44) and (55), we have:

$$\theta_B^A \phi_{BA} - (1 - \phi_H \phi_{BA})\partial \theta_B^A / \partial \phi_H = -\frac{(\mu + \sigma)\phi_{AB}(1 - \phi_{AB}\phi_H)}{2\sigma(\phi_{AB} - \phi_H)^2} < 0$$

implying that $\partial P_A / \partial \phi_H > 0$. Likewise, under Pattern B-*mp* ($0 < \theta_B^A < 1$), using (48) and (53), we have:

$$\theta_B^A \phi_{BA} - (1 - \phi_H \phi_{BA})\partial \theta_B^A / \partial \phi_H = -\frac{(1 + \alpha)(\sigma + \mu)\phi_{BA}}{\alpha(\sigma - \mu)} < 0$$

implying that $\partial P_A / \partial \phi_H > 0$. In either pattern, two opposing effects work. First, the marginal cost of differentiated goods produced in region B decreases, which tends to increase P_A. Second, the number of plants increases in region B and decreases in region A, which tends to increase P_A. However, the second effects dominates the first, and hence the welfare in region A decreases under either Pattern A-B and Pattern B-*mp*.

Under Pattern B, since $\theta_B^A = 1$ and $\partial \theta_B^A / \partial \phi_H = 0$, we have $\partial P_A / \partial \phi_H < 0$. Thus, under Pattern B, the welfare in region A increases with decreasing communication costs. This is because the varieties made in region B are produced at lower marginal cost due to lower communication costs.

Next, concerning the price index in region B, using (26), we have

$$\frac{\partial P_B}{\partial \phi_H} = -\frac{P_B}{\sigma - 1}\frac{(1 - \theta_A^A) - (\phi_H - \phi_{AB})\partial \theta_A^A / \partial \phi_H}{(1 - \theta_A^A)\phi_H + \theta_A^A \phi_{AB}} \tag{59}$$

Under either Pattern B, Pattern *mp* or Pattern B-*mp*, since $\theta_A^A = 0$ and $\partial \theta_A^A / \partial \phi_H = 0$, we have $\partial P_B / \partial \phi_H < 0$. Thus, the welfare in region B increases. This is because varieties made in region B are produced at lower marginal cost with a lower communication costs.

Under Pattern A-B ($0 < \theta_A^A < 1$), using (44) and (55), we have:

$$(1-\theta_A^A) - (\phi_H - \phi_{AB})\partial\theta_A^A/\partial\phi_H = \frac{1}{\phi_H(1-\phi_H\phi_{BA})} > 0$$

implying that $\partial P_B/\partial\phi_H < 0$. Likewise, under Pattern A-mp ($0 < \theta_A^A < 1$), we have:

$$(1-\theta_A^A) - (\phi_H - \phi_{AB})\partial\theta_A^A/\partial\phi_H = \frac{\sigma-\mu}{\alpha(\sigma+\mu)} > 0$$

implying that $\partial P_B/\partial\phi_H < 0$. In either case, two effects work. First, the marginal cost of differentiated goods produced in region B decreases. Second, plants increase in region B and decrease in region A. Both effects reduce P_B, and hence increases the welfare in region B. Finally, under Pattern A, since $\theta_A^A = 1$ and $\partial\theta_A^A/\partial\phi_H = 0$, we have $\partial P_B/\partial\phi_H = 0$, implying that the welfare in region B does not change when Pattern A emerges.

We may summarize the result above as follows:

Proposition 5.1 *When communication costs are rather large, all varieties are produced in the core (=region A). In this case, all workers are unaffected from the decrease in communication costs. By more decrease in communication costs, some varieties are produced in the periphery (=region B). In this case, the unskilled living in the periphery are better off and the workers in the core are worse off with decreasing communication costs. Finally, when communication costs are small enough, all plants are located in the periphery. In this case, all workers in both regions benefit from further lowering communication costs.*

6 Conclusion

In this paper, globalization is characterized by lower communication costs between headquarters and plants and lower transportation costs of products. Each firm has the headquarter and chooses either to have a single plant in a region, or to have one plant in each region. Under the assumption that all headquarters are agglomerated in the core and that the productivity of unskilled workers in the traditional sector is higher in the core than in the periphery, we have examined the impact of globalization on the location pattern of plants between the core and the periphery.

From our analysis, we understand that multi-plants increase with decreasing communication costs when transportation costs of products are large due to the government regulation and the cultural differences and when the productivity difference of the skilled are small. This explains the fragmentation of the production by the automobile industry. On the other hand, single plants in the periphery increase with decreasing communication costs when transportation costs are small. This is suited to the globalization of the production by consumer electronics or the outsourcing of call centre. On the welfare, with decreasing communication costs, we could see that the workers in the core worse off and these in the periphery better off when the varieties are produced in both regions under medium communication costs. When communication costs are small enough, all plants are located in the periphery. In this case, all workers in both regions benefit from further lowering communication costs.

For further research, it is desirable to consider on the location of plants producing intermediate goods as well as plants producing final goods. Recently, the share of intermediate goods in trade has been increasing. By introducing the plants which produce intermediate goods, the forward and backward linkages would arise between the two types of plants, and we could explain the overseas expansion of a company producing intermediate goods as a factor of a fragmentation.

Appendix

A. The profit of firms whose HQs are in region B

Using (7), (16), (17), (18), (19), (21) and (27), we obtain the profit of firms whose HQs are in region B as follows:

$$\begin{aligned}\pi_B^{B*} &= \frac{\mu f(1+\alpha-\alpha\theta_A^A-\alpha\theta_B^A)}{\sigma S} \\ &\quad \times \left[\frac{(Sw_A^H+L/2)\phi_{BA}}{(1-\theta_B^A)+\theta_B^A\phi_H\phi_{BA}}+\frac{L/2}{(1-\theta_A^A)\phi_H+\theta_A^A\phi_{AB}}\right]-w_B^H f \quad (60)\end{aligned}$$

$$\begin{aligned}\pi_A^{B*} &= \frac{\mu f(1+\alpha-\alpha\theta_A^A-\alpha\theta_B^A)}{\sigma S}\phi_H \\ &\quad \times \left[\frac{Sw_A^H+L/2}{(1-\theta_B^A)+\theta_B^A\phi_H\phi_{BA}}+\frac{L/2\phi_{AB}}{(1-\theta_A^A)\phi_H+\theta_A^A\phi_{AB}}\right]-w_B^H f \quad (61)\end{aligned}$$

$$\pi_{mp}^{B*} = \frac{\mu f(1+\alpha-\alpha\theta_A^A-\alpha\theta_B^A)}{\sigma S} \times \left[\frac{(Sw_A^H+L/2)\phi_H}{(1-\theta_B^A)+\theta_B^A\phi_H\phi_{BA}} + \frac{L/2}{(1-\theta_A^A)\phi_H+\theta_A^A\phi_{AB}}\right] - (1+\alpha)w_B^H f \tag{62}$$

B. Proof of Lemma 3.1

Let us determine when the equilibrium conditions $\pi_A^{B*} \leq 0$, $\pi_B^{B*} \leq 0$, and $\pi_{mp}^{B*} \leq 0$ hold. Since all skilled workers are to be in region A, it must be that $\omega_A^H \geq \omega_B^H$. Without loss of generality, we may assume that $\omega_A^H = \omega_B^H$, which means

$$w_A^H = \frac{P_B^\mu}{P_A^\mu} w_B^H \tag{63}$$

From the free entry condition (20), it must hold that $\pi_B^{A*} \leq 0$, $\pi_A^{A*} \leq 0$, and $\pi_{mp}^{A*} \leq 0$. Using (60), (63) and $\pi_B^{A*} \leq 0$, it is readily verified that $\pi_B^{B*} \leq 0$ holds if and only if

$$\left[\frac{c(0)}{c(m)}\right]^{\sigma-1} \geq \left[\frac{(1-\theta_A^{A*})\phi_H+\theta_A^{A*}\phi_{AB}}{(1-\theta_B^{A*})+\theta_B^{A*}\phi_H\phi_{BA}}\right]^{\mu/(\sigma-1)} T_H^{\sigma-1}. \tag{64}$$

Using (61), (63) and $\pi_A^{A*} \leq 0$, it is then readily verified that $\pi_A^{B*} \leq 0$ holds if and only if

$$\left[\frac{c(0)}{c(m)}\right]^{\sigma-1} \geq \left[\frac{(1-\theta_A^{A*})\phi_H+\theta_A^{A*}\phi_{AB}}{(1-\theta_B^{A*})+\theta_B^{A*}\phi_H\phi_{BA}}\right]^{\mu/(\sigma-1)} T_H^{-(\sigma-1)}. \tag{65}$$

Using (62), (63) and $\pi_{mp}^{A*} \leq 0$, it is then readily verified that $\pi_{mp}^{B*} \leq 0$ holds if and only if (64) and (65) hold. Condition (65) is always satisfied when (64) holds. Note that the right-hand side of (64) is strictly decreasing in θ_A^A and strictly increasing in θ_B^A so that $\pi_A^{B*} \leq 0$, $\pi_B^{B*} \leq 0$, and $\pi_{mp}^{B*} \leq 0$ hold as long as (64) is satisfied for $\theta_A^{A*} = 1$ and $\theta_B^{A*} = 0$, that is, when condition (37) holds. Therefore, conditions $\pi_B^{B*} \leq 0$, $\pi_A^{B*} \leq 0$ and $\pi_{mp}^{B*} \leq 0$ hold if and only if condition (37) holds.

C. For Pattern A

Pattern A means $\theta_A^A = 1$ and $\theta_B^A = 0$. From (20), under Pattern A, the equilibrium conditions are: $\pi_A^{A*} = 0, \pi_B^{A*} \leq 0$, $\pi_{mp}^{A*} \leq 0$, $\pi_A^{B*} \leq 0$, $\pi_B^{B*} \leq 0$

and $\pi_{mp}^{B*} \leq 0$. Supposing (37) to hold, we determine when the conditions $\pi_A^{A*} = 0, \pi_B^{A*} \leq 0$, $\pi_{mp}^{A*} \leq 0$ is satisfied under Pattern A. First, substituting $\theta_A^A = 1$ and $\theta_B^A = 0$ into (28) and setting $\pi_A^{A*} = 0$ yields the wage of skilled labor in region A which turns out to be exactly the same as (39). Next, substituting $\theta_A^A = 1$, $\theta_B^A = 0$ and (39) into (29) and setting $\pi_B^{A*} \leq 0$ yields

$$\xi_A^B \geq \frac{1-\mu/\sigma}{2-(1+\mu/\sigma)\xi_B^A}. \tag{66}$$

On the other hand, substituting $\theta_A^A = 1$, $\theta_B^A = 0$ and (39) into (30) and setting $\pi_{mp}^{A*} \leq 0$ yields

$$\xi_A^B \geq \frac{1-\mu/\sigma}{1-\mu/\sigma+2\alpha} \tag{67}$$

Therefore, conditions $\pi_A^{A*} = 0$, $\pi_B^{A*} \leq 0$ and $\pi_{mp}^{A*} \leq 0$ are satisfied when (66) and (67) hold. Conditions (66) and (66) can be expressed together as (40).

D. For Pattern B

Pattern B means $\theta_A^A = 0$ and $\theta_B^A = 1$. From (20), under Pattern B, the equilibrium conditions are: $\pi_A^{A*} \leq 0, \pi_B^{A*} = 0$, $\pi_{mp}^{A*} \leq 0$, $\pi_A^{B*} \leq 0$, $\pi_B^{B*} \leq 0$ and $\pi_{mp}^{B*} \leq 0$. Supposing (37) to hold, we determine when the conditions $\pi_A^{A*} \leq 0, \pi_B^{A*} = 0$ and $\pi_{mp}^{A*} \leq 0$ are satisfied under Pattern B. First, substituting $\theta_A^A = 0$ and $\theta_B^A = 1$ into (29) and setting $\pi_B^{A*} = 0$ yield the wage of skilled labor in region A which turns out to be exactly the same as (39). Next, substituting $\theta_A^A = 0$, $\theta_B^A = 1$ and (39) into (28) and setting $\pi_A^{A*} \leq 0$ yield

$$\xi_B^A \geq \frac{1+\mu/\sigma}{2-(1+\mu/\sigma)\xi_A^B} \tag{68}$$

On the other hand, substituting $\theta_A^A = 0$, $\theta_B^A = 1$ and (39) into (30) and setting $\pi_{mp}^{A*} \leq 0$ yield

$$\xi_B^A \geq \frac{1+\mu/\sigma}{1+\mu/\sigma+2\alpha} \tag{69}$$

Therefore, conditions $\pi_A^{A*} \leq 0$, $\pi_B^{A*} = 0$ and $\pi_{mp}^{A*} \leq 0$ are satisfied when (68) and (69) hold. Condition (68) and (69) can be expressed together as (42).

E. For Pattern A-B

Pattern A-B means $\theta_A^A + \theta_B^A = 1$, $0 < \theta_B^A < 1$ and $0 < \theta_A^B < 1$. From (20), under Pattern A-B, the equilibrium conditions are: $\pi_A^{A*} = 0, \pi_B^{A*} = 0$, $\pi_{mp}^{A*} \le 0$, $\pi_A^{B*} \le 0$, $\pi_B^{B*} \le 0$ and $\pi_{mp}^{B*} \le 0$. Supposing (37) to hold, we determine when the conditions $\pi_A^{A*} = 0, \pi_B^{A*} = 0$ and $\pi_{mp}^{A*} \le 0$ are satisfied under Pattern A-B. First, substituting $\theta_A^A = 1 - \theta_B^A$ into (28) and (29), and setting $\pi_A^{A*} = \pi_B^{A*} = 0$ yields the wage of skilled labor in region A which turns out to be exactly the same as (39). Using this wage function, the share of firms whose plants are located in region B can be obtained as (44). Next, substituting $\theta_A^A = 1 - \theta_B^A$, (39) and (44) into (30) and setting $\pi_{mp}^{A*} \le 0$ yield

$$\xi_A^B > \frac{1 - \xi_B^A - \alpha}{1 - (1+\alpha)\xi_B^A} \tag{70}$$

Setting $\theta_B^A > 0$ in (44) yield

$$\xi_A^B > \frac{2\xi_B^A - 1 - \mu/\sigma}{(1 - \mu/\sigma)\xi_B^A} \tag{71}$$

Likewise, setting $\theta_B^A < 1$ in (44) yields

$$\xi_A^B \le \frac{1 - \mu/\sigma}{2 - (1 + \mu/\sigma)\xi_B^A} \tag{72}$$

Therefore, conditions $\pi_A^{A*} = 0$, $\pi_B^{A*} = 0$ and $\pi_{mp}^{A*} \le 0$ are satisfied when (70), (71) and (72) hold. Considering that ξ_A^B is positive by definition, conditions (70), (71) and (72) can be expressed together as (45).

F. For Pattern A-mp

Pattern A-mp means $0 < \theta_A^A = 1 - \theta_{mp}^A < 1$ and $\theta_B^A = 0$. From (20), under Pattern A-mp, the equilibrium conditions are: $\pi_A^{A*} = 0, \pi_B^{A*} \le 0$, $\pi_{mp}^{A*} = 0$, $\pi_A^{B*} \le 0$, $\pi_B^{B*} \le 0$ and $\pi_{mp}^{B*} \le 0$. Supposing (37) to hold, we determine when the conditions $\pi_A^{A*} = 0, \pi_B^{A*} \le 0$ and $\pi_{mp}^{A*} = 0$ are satisfied under Pattern A-mp. First, substituting $\theta_B^A = 0$ into (28) and (30), and setting $\pi_A^{A*} = \pi_{mp}^{A*} = 0$ yields the wage of skilled labor in region A which turns out to be exactly the same as (39). Using this wage function, the share of firms whose plants are located in region A can be obtained as (46).Next, substituting $\theta_B^A = 0$, (39) and (46) into (29) and setting $\pi_B^{A*} \leq 0$ yield

$$\xi_A^B \leq \frac{1 - \xi_B^A - \alpha}{1 - (1 + \alpha)\xi_B^A} \tag{73}$$

Setting $\theta_A^A > 0$ in (46) yields

$$\xi_A^B < \frac{1 - \mu/\sigma}{1 - \mu/\sigma + 2\alpha} \tag{74}$$

Likewise, setting $\theta_A^A < 1$ in (46) yields

$$\xi_A^B > \frac{1 - \alpha - \mu/\sigma - \alpha\mu/\sigma}{1 + \alpha - \mu/\sigma - \alpha\mu/\sigma} \tag{75}$$

Therefore, $\pi_A^{A*} = 0$, $\pi_B^{A*} \leq 0$ and $\pi_{mp}^{A*} = 0$ are satisfied when (73), (74) and (75) hold. Considering that ξ_A^B is positive by definition, conditions (73), (74) and (75) can be expressed together as (47).

G. For Pattern B-mp

Pattern B-mp means $0 < \theta_B^A = 1 - \theta_{mp}^A < 1$ and $\theta_A^A = 0$. From (20), under Pattern *B-mp*, the equilibrium conditions are: $\pi_A^{A*} \leq 0, \pi_B^{A*} = 0$, $\pi_{mp}^{A*} = 0$, $\pi_A^{B*} \leq 0$, $\pi_B^{B*} \leq 0$ and $\pi_{mp}^{B*} \leq 0$. Supposing (37) to hold, we determine when the conditions $\pi_A^{A*} \leq 0, \pi_B^{A*} = 0$ and $\pi_{mp}^{A*} = 0$ are satisfied under Pattern *B-mp*. First, substituting $\theta_A^A = 0$ into (29) and (30), and setting $\pi_B^{A*} = \pi_{mp}^{A*} = 0$ yield the wage of skilled labor in region A which turns out to be exactly the same as (39). Using this wage function, the share of firms whose plants are located in region B can be obtained as (48).Next, substituting $\theta_B^A = 0$, (39) and (48) into (28) and setting $\pi_A^{A*} \leq 0$ yields

$$\xi_A^B \leq \frac{1 - \xi_B^A - \alpha}{1 - (1 + \alpha)\xi_B^A} \tag{76}$$

Setting $\theta_B^A > 0$ in (48) yields

$$\xi_B^A < \frac{1 + \mu/\sigma}{1 + \mu/\sigma + 2\alpha} \tag{77}$$

Likewise, setting $\theta_B^A < 1$ in (48) yields

$$\xi_A^B > \frac{1 - \alpha + \mu/\sigma + \alpha\mu/\sigma}{1 + \alpha + \mu/\sigma + \alpha\mu/\sigma} \tag{78}$$

Therefore, $\pi_A^{A*} \le 0$, $\pi_B^{A*} = 0$ and $\pi_{mp}^{A*} = 0$ are satisfied when (76), (77) and (78) hold. Considering that ξ_A^B is positive by definition, conditions (76), (77) and (78) can be expressed together as (49).

H. For Pattern mp

Pattern mp means $\theta_A^A = \theta_B^A = 0$ and $\theta_{mp}^A = 1$. From (20), under Pattern *mp*, the equilibrium conditions are $\pi_A^{A*} \le 0, \pi_B^{A*} \le 0$, $\pi_{mp}^{A*} = 0$, $\pi_A^{B*} \le 0$, $\pi_B^{B*} \le 0$ and $\pi_{mp}^{B*} \le 0$. Supposing (37) to hold, we determine when the conditions $\pi_A^{A*} \le 0, \pi_B^{A*} \le 0$ and $\pi_{mp}^{A*} = 0$ are satisfied under Pattern *mp*. First, substituting $\theta_A^A = \theta_B^A = 0$ into (30) and setting $\pi_{mp}^{A*} = 0$ yields the wage of skilled labor in region A which turns out to be exactly the same as (39). Next, substituting $\theta_A^A = \theta_B^A = 0$ and (39) into (28) and setting $\pi_A^{A*} \le 0$ yields (50). On the contrary, substituting $\theta_A^A = \theta_B^A = 0$ and (39) into (29) and setting $\pi_B^{A*} \le 0$ yields (51). Therefore, $\pi_A^{A*} \le 0$, $\pi_B^{A*} \le 0$ and $\pi_{mp}^{A*} = 0$ are satisfied when (50) and (51) hold. Considering that ξ_A^B is positive by definition, Lemma 3.7 is verified.

I. For the shift of location pattern between Pattern A-mp and Pattern A-B when communication costs fall

The equilibrium condition for Pattern *A-B* (70) is rewritten as follows:

$$(-1 + \alpha + \xi_B^A) - \xi_A^B(-1 + (1 + \alpha)\xi_B^A) \ge 0 \tag{79}$$

Whereas, the equilibrium condition for Pattern *A-mp* (73) is rewritten as follows:

$$(-1 + \alpha + \xi_B^A) - \xi_A^B(-1 + (1 + \alpha)\xi_B^A) \le 0 \tag{80}$$

Using the first derivative of the left-hand side of (79) and (80) with ϕ_H, it is verified that the location pattern of plants shifts from Pattern *A-mp* to Pattern *A-B* with a decrease of communication costs when $\frac{1-\alpha}{2}\frac{1}{\xi_B^A} + \frac{1+\alpha}{2}\xi_A^B < 1$. Whereas the location pattern of plants shifts from Pattern *A-B* to Pattern

A-mp with a decrease of communication costs when $\frac{1-\alpha}{2}\frac{1}{\xi_B^A}+\frac{1+\alpha}{2}\xi_A^B > 1$. From (70) and (73), $\xi_A^B = \frac{1-\xi_B^A-\alpha}{1-(1+\alpha)\xi_B^A}$ which divides Pattern A-mp from Pattern A-B in (ξ_B^A, ξ_A^B)-space intersects $\frac{1-\alpha}{2}\frac{1}{\xi_B^A}+\frac{1+\alpha}{2}\xi_A^B = 1$ at $\xi_B^A = \xi_A^B = \frac{1-\alpha}{1+\alpha}$. Thus, the location pattern of plants shifts from Pattern A-mp to Pattern A-B when $\xi_B^A > \frac{1-\alpha}{1+\alpha}$ and $\xi_A^B < \frac{1-\alpha}{1+\alpha}$. Whereas the location pattern of plants shifts from Pattern A-B to Pattern A-mp when $\xi_B^A < \frac{1-\alpha}{1+\alpha}$ and $\xi_A^B > \frac{1-\alpha}{1+\alpha}$. From (47), $\frac{\sigma-\alpha\sigma-\mu-\alpha\mu}{\sigma+\alpha\sigma-\mu-\alpha\mu} < \frac{1-\alpha}{1+\alpha} < \frac{\sigma-\mu}{\sigma-\mu+2\alpha\sigma}$ holds when $\alpha > \mu/\sigma$ and $\frac{\sigma-\mu}{\sigma-\mu+2\alpha\sigma} \leq \frac{1-\alpha}{1+\alpha}$ holds when $\alpha \leq \mu/\sigma$. Therefore, the location pattern shifts from Pattern A-mp to Pattern A-B with a decrease of communication costs when the following conditions are satisfied: 1) $\alpha \leq \mu/\sigma$ or 2) $\alpha > \mu/\sigma$, $\xi_B^A > \frac{1-\alpha}{1+\alpha}$ and $\xi_A^B < \frac{1-\alpha}{1+\alpha}$. Whereas the location pattern shifts from Pattern A-B to Pattern A-mp when $\mu/\sigma < \alpha$, $\xi_B^A < \frac{1-\alpha}{1+\alpha}$ and $\xi_A^B > \frac{1-\alpha}{1+\alpha}$.

J. For the shift of location pattern from Pattern B-mp to Pattern A-B when the communication costs fall

We can rewrite (70) as (79), whereas, (76) as (80). From the first derivative of the left-hand side of (79) and (80) with ϕ_H, the location pattern of plants shifts from Pattern B-mp to Pattern A-B with a decrease of communication costs when $\frac{1-\alpha}{2}\frac{1}{\xi_B^A}+\frac{1+\alpha}{2}\xi_A^B < 1$. The border condition between Pattern B-mp and Pattern A-B $\xi_A^B = \frac{1-\xi_B^A-\alpha}{1-(1+\alpha)\xi_B^A}$ intersects $\frac{1-\alpha}{2}\frac{1}{\xi_B^A}+\frac{1+\alpha}{2}\xi_A^B = 1$ at $\xi_B^A = \xi_A^B = \frac{1-\alpha}{1+\alpha}$. Considering (49) and using $\frac{1-\alpha}{1+\alpha} < \frac{1-\alpha+\mu/\sigma+\alpha\mu/\sigma}{1+\alpha+\mu/\sigma+\alpha\mu/\sigma}$, the location pattern of plants shifts from Pattern B-mp to Pattern A-B when $\xi_B^A > \frac{1-\alpha}{1+\alpha}$ and $\xi_A^B < \frac{1-\alpha}{1+\alpha}$.

K. For the shift of location pattern to Pattern A-B when transportation costs fall

The equilibrium condition for Pattern A-B (70) is expressed as follows:

$$\xi_A^B\left(1-(1+\alpha)\xi_B^A\right)-(1-\xi_B^A-\alpha) \geq 0$$

Whereas the equilibrium condition for Pattern A-mp (73) and for Pattern B-mp (76) are expressed as follows:

$$\xi_A^B\left(1-(1+\alpha)\xi_B^A\right)-(1-\xi_B^A-\alpha) \leq 0$$

Setting $\phi_T \equiv \phi_{AB} = \phi_{BA}$, the first derivatives of the left-hand side of both equations with ϕ_T are derived as $(1-(1+\alpha)\xi_A^B)\frac{\partial \xi_B^A}{\partial \phi_T} + (1-(1+\alpha)\xi_B^A)\frac{\partial \xi_A^B}{\partial \phi_T}$. Using (47) and (49), this derivative is positive from $\frac{1}{1+\alpha} > \frac{\sigma-\mu}{\sigma-\mu+2\alpha\sigma}$ and $\frac{1}{1+\alpha} > \frac{\sigma+\mu}{\sigma+\mu+2\alpha\sigma}$. Therefore, the location pattern shifts from Pattern *A*-*mp* or from Pattern *B*-*mp* to Pattern *A*-*B* with decreasing transportation costs.

L. For the shift of location pattern about Pattern A-B and Pattern A when transportation costs fall

The equilibrium condition for Pattern *A*-*B* (72) is expressed as follows:

$$\xi_A^B(2\sigma - (\mu+\sigma)\xi_B^A) - \sigma + \mu \leq 0$$

Whereas the equilibrium condition for Pattern *A* (66) is expressed as follows:

$$\xi_A^B(2\sigma - (\mu+\sigma)\xi_B^A) - \sigma + \mu \geq 0$$

Setting $\phi_T \equiv \phi_{AB} = \phi_{BA}$, the first derivative of the left-hand side of both equations with ϕ_T is $(-(\mu+\sigma)\xi_A^B)\frac{\partial \xi_B^A}{\partial \phi_T} + (2\sigma - (\mu+\sigma)\xi_B^A)\frac{\partial \xi_A^B}{\partial \phi_T} \gtreqless 0 \Leftrightarrow \xi_B^A \lesseqgtr \frac{\sigma}{\sigma+\mu}$. Therefore, the location pattern shifts from Pattern *A*-*B* to Pattern *A* when $\xi_B^A < \frac{\sigma}{\sigma+\mu}$, whereas the location pattern shifts from Pattern *A* to Pattern *A*-*B* when $\xi_B^A > \frac{\sigma}{\sigma+\mu}$.

M. For the shift of location pattern about Pattern A-B and Pattern B when transportation costs fall

The equilibrium condition for Pattern *B* (68) is expressed as follows:

$$\xi_B^A(2\sigma - (\sigma-\mu)\xi_A^B) - \sigma - \mu \geq 0$$

Whereas the equilibrium condition for Pattern *A*-*B* (72) is expressed as follows:

$$\xi_B^A(2\sigma - (\sigma-\mu)\xi_A^B) - \sigma - \mu \leq 0$$

Setting $\phi_T \equiv \phi_{AB} = \phi_{BA}$, the first derivative of the left-hand side of both equations with ϕ_T is positive when $\xi_B^A < \frac{\sigma}{\sigma-\mu}$. Therefore, the location pattern shifts from Pattern *A*-*B* to Pattern *B* with decreasing transportation costs.

References

Bernstein, J.I. (2000) “Canadian Manufacturing, U.S. R&D Spillovers, and Communication Infrastructure”, *The Review of Economics and Statistics*, 82(4), 608-615

Fujita, M., P. Krugman and A.J. Venables (1999) *The Spatial Economy. Cities, Regions and International Trade.* Cambridge, MA:MIT Press.

Fujita, M. and J.-F. Thisse (2002) “ Globalization and the Evolution of the Supply Chain: who gain and who lose?”, Discussion Paper No.571, Institute of Economic Research, Kyoto University, Kyoto, Japan.

Gourevitch, P., R. Bohn and D. Mckendrick (1997) “Who is Us?–The Nationality of Production in the Hard Disk Drive Industry”, Report 97-01, The Information Storage Industry Center, University of California, San Diego, USA.

Gourevitch, P., R. Bohn and D. Mckendrick (2000) “Globalization of Production: Insights from the Hard Disk Drive Industry”, *World Development*, 28(2), 301-317

Grossman, G.M. and E. Helpman (2004) “Managerial Incentives and the International Organization of Production”, *Journal of International Economics*, 63, 237-262

Kim, S. (1999) “The Rise of Multinational Firms in U.S. Manufacturing”, *Explorations in Economic History*, 36, 360-386

Leamer, E.E. and M. Storper (2001) “The Economic Geography of the Internet Age”, *Journal of Economic Perspectives*, 9, Spring, 169-189

Makusen, J.R. and A.J. Venables (2000) “ The Theory of Endowment, Intra-industry and Multi-national trade”, *Journal of International Economics*, 52, 209-234

Park, K.H. (2003) “Patterns and strategies of Foreign direct Investment: the case of Japanese Firms”, *Applied Economics*, 35, 1739-1746

Rugman, A. and R. Hodgetts (2001) “The end of global strategy”, *European Management Journal*, 19(4), 333-343

Zhou, C., A. Delios and J.Y. Yang (2002) “ Locational Determinants of Japanese Foreign Direct Investment in China”, *Asia Pacific Journal of Management*, 19, 63-86

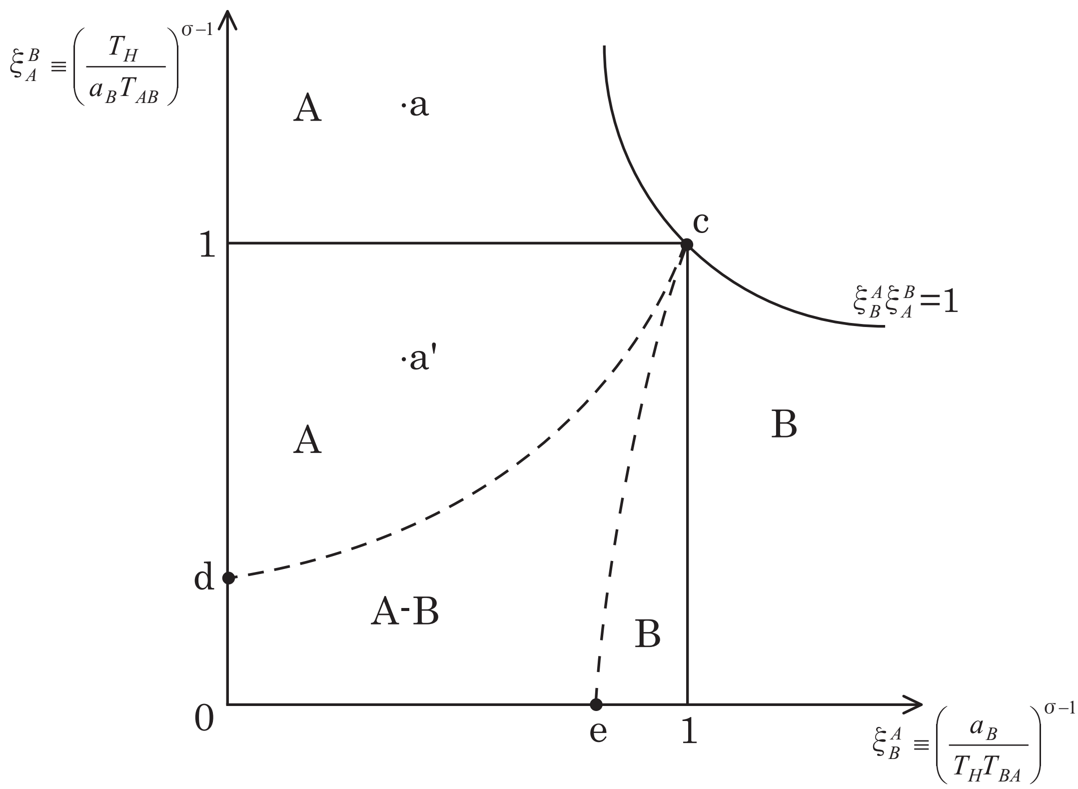

Fig.1 Equilibrium domains of three location patterns without multi-location firms (α =1 and μ / σ =0.5)

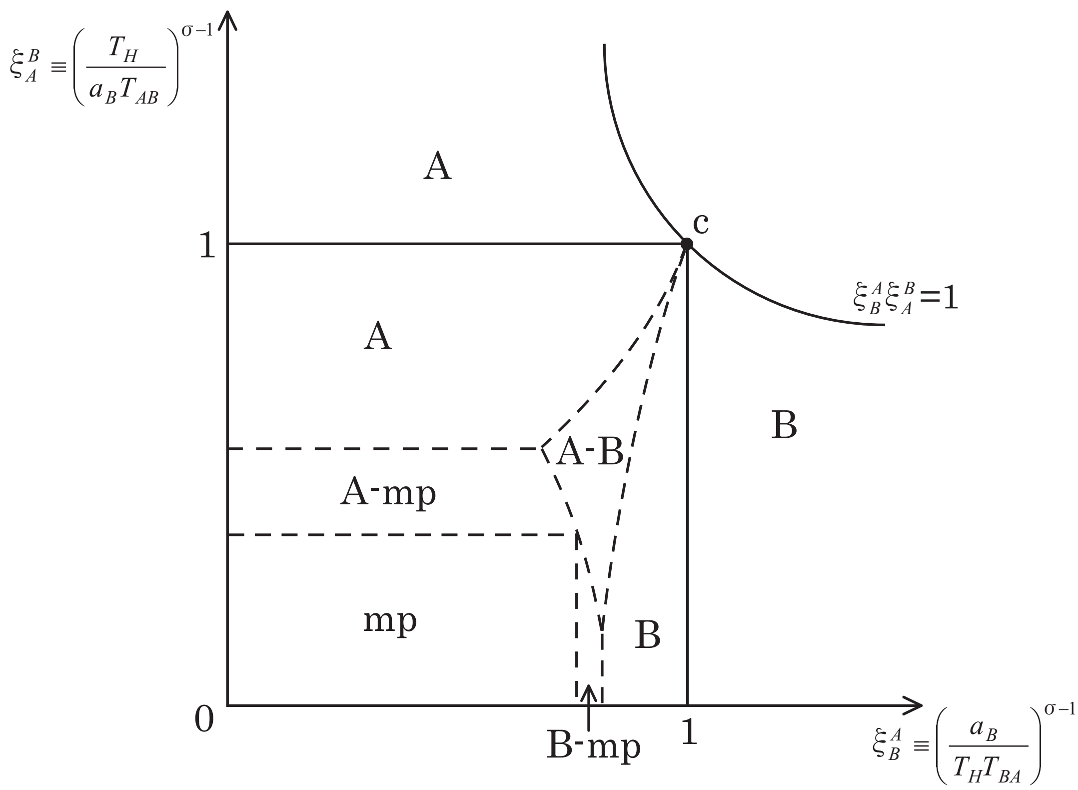

Fig.2 Equilibrium domains of six location patterns (α =0.2 and μ / σ =0.5)

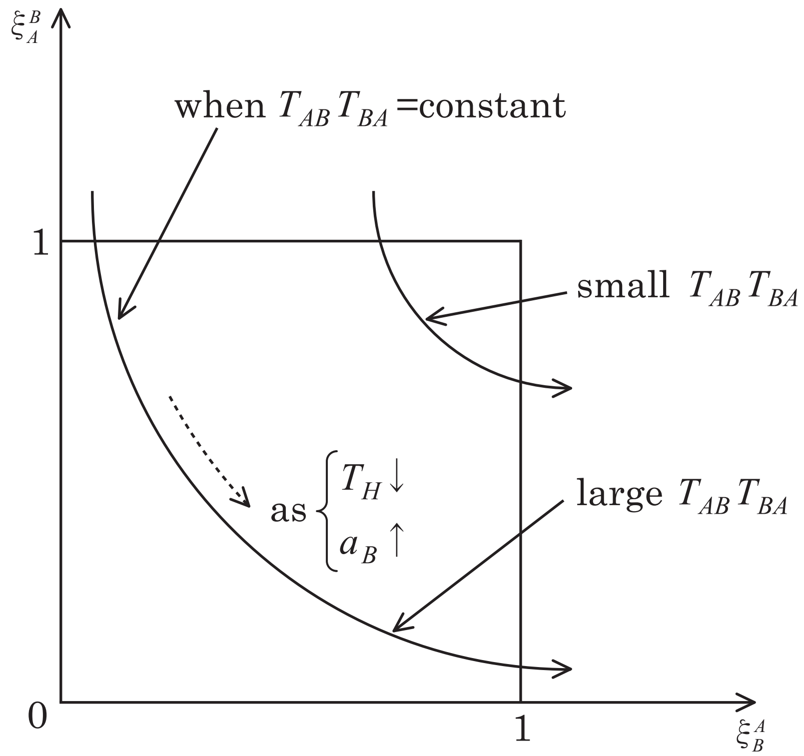

Fig.3　The shift of position (ξ_B^A, ξ_A^B) with changing parameters

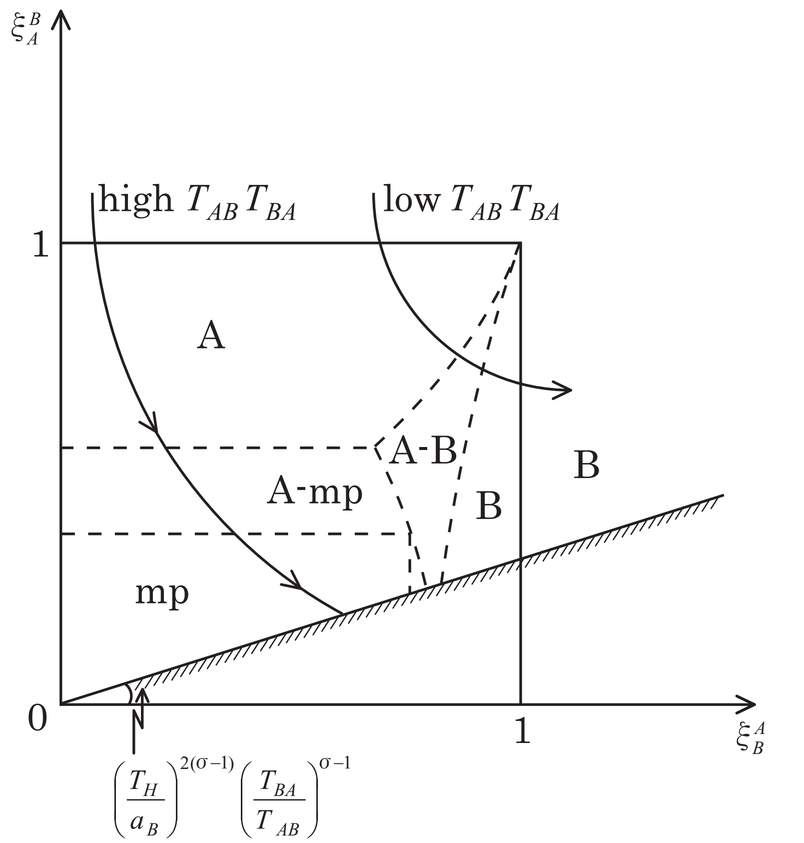

Fig.4　The shift of location pattern with decreasing communication costs
(α=0.2 and μ/σ=0.5)

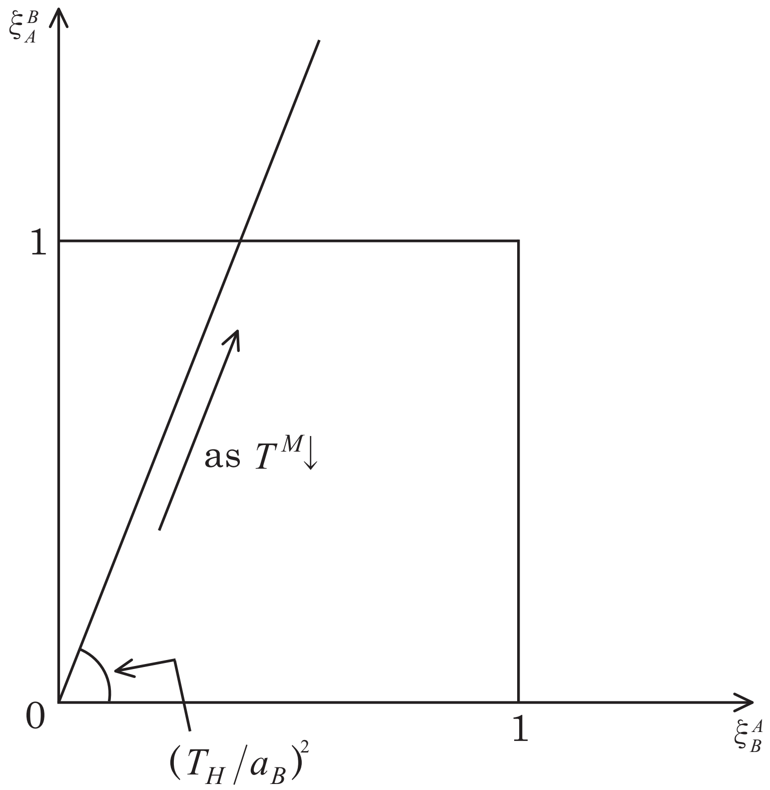

Fig.5 The impact of decreasing transportation costs when $T_{AB} = T_{BA} \equiv T^M$