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Brand Agriculture and Economic Geography: When Are Highly Differentiated Products Sustainable in the Remote Periphery?

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Brand Agriculture and Economic Geography:
When Are Highly Differentiated Products Sustainable in the Remote Periphery?*

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Abstract

This paper presents a general equilibrium model of new economic geography, incorporating brand agriculture that produces differentiated agricultural products. Focusing on the core-periphery space, we show that highly differentiated brand agriculture can be sustained in the periphery even when access to the core market is not particularly good. This result supports the promotion of innovative products in rural areas in order to avoid direct price competition in generic commodities markets under unfavorable conditions.

Keywords: product differentiation, new economic geography, core-periphery.
JEL Classification: O12, O18, R12.

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1. Introduction

In most existing models, economic development is led by the growth of modern industrial sector while the traditional agricultural sector takes a backseat playing the role of supplying food and excess labor force to the former. Agriculture is typically assumed with constant returns to scale technology and perfect competition market. Under such assumptions, as noted by Romer (1991, p.91), the total value of output is paid as compensation to variable inputs, and nothing is left for research and development. With the low capacity for innovation at each farm level, technological development in agriculture is possible only through external interventions, such as technology transfers from public research laboratories and the purchase of new inputs and equipment developed by manufactures. In this context, we cannot draw a picture of the endogenous development of the rural sector.

Moreover, product differentiation will not take place under the constant returns to scale and perfect competition paradigm. If farmers, especially those located in the far periphery with bad market access, were to continue producing only generic products, intensifying pressure from global trade liberalization will leave them no option but for surviving with subsidies[1]. While agricultural subsidies in developed countries may stall the multilateral and bilateral free trade negotiations, developing countries cannot afford such subsidies, and thus people in remote rural areas are often seen in a situation of mere subsistence.

In order to give a new turn to such a misguided agricultural policy, we need fresh thinking on agriculture. The first step should be to depart from conventional assumptions of constant returns to scale and perfect competition and to introduce product differentiation and scale economies at farm-level. In this regard, being one of the essential characteristics of agriculture, the attachedness to land has a particular role. Although scale economies induce the concentration of production, the agriculture cannot concentrate spatially near large markets because of the constraints of land; they need to be located dispersedly.

Therefore, the viability of innovative agriculture needs to be addressed in the context of the entire spatial structure of a national economy. The endogenous formation of a spatial structure has been extensively studied in the literature of new economic geography (NEG). However, to our knowledge, past studies of NEG have largely ignored the active role of agriculture in the formation of innovative regions. Given this situation, Fujita (2008) proposed a conceptual model that introduced product differentiation into the agricultural sector. He suggested that the appropriate location of each specific type of agricultural activity depend on the degree of product differentiation. Specifically, the less differentiated products

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[1]According to *Economist* (December 10, 2005), in 2003 all of the twenty poorest counties in the US are located in the eastern flank of the Rockies and on the western Great Plains where farmers mostly engage in the production of wheat, soybeans, and cattle receiving a substantial amount of federal agricultural subsidies (Not here, surely? pp.38-39). In Europe, about 40% of the total EU budget is allocated to CAP where agriculture accounts for less than 2% of the EU workforce. Some consider subsidies are emasculating farmers because they are not hardy producers but resemble rural park-keepers for town-dwellers who wish to visit the countryside occasionally (Europe's farm follies, p.27).

with high transport costs such as fresh vegetables should be grown near the metropolis. In contrast, the production of very unique farm products referred to as brand agriculture hereafter can take place profitably in remote villages because of low price elasticity.[2]. It entails high transport costs and fixed costs to develop local resources. Given the preference for consumption variety, consumers are willing to pay higher prices for differentiated products[3].

In practice, rural development based on brand agriculture is not new. In the remote regions of Japan today, for instance, there exist hundreds of small villages where unique agricultural goods are produced in innovative ways[4]. By brand agriculture, we do not mean the production of distinct agricultural products based on unique natural conditions. Local-specific agro-climatic conditions may affect the selection of crops, but they are not necessarily decisive factors of branding. Branding is instead based on the ingenuity and cooperation of local people, combined with distinctive approaches to the market to deal with particular types of demand with unfailing supply capability. Such conditions are what we call local resources; they are not the gifts of nature but are locally embedded as a fruit of local peoples' efforts that cannot be replicated easily elsewhere[5]. This implies that brand agriculture can be established potentially anywhere as an alternative to agricultural subsidy and migration to urban centers for people residing in remote rural areas. This view is supported by a broad range of international cases reported by OECD (2009).

In this article, we extend the idea of Fujita (2008) and present a NEG model to ask under what conditions brand agriculture can be sustained profitably in the periphery. Traditionally, the location of agricultural activity has been studied using the bid-rent

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[2]Behrens and Gaigné (2006) made a similar argument regarding the development of the outermost regions of Europe.

[3]According to the author's calculation based on the *organic price tables* published by Economic Research Service of United States Department of Agriculture, the wholesale price premium of organic products relative to conventional ones in Atlanta and San Francisco was 55.0% (4.6 points interval of 95% confidence) about fruits (apples, avocados, raspberries, strawberries, bananas, oranges, and pears) in 2010-13 and 110.0% (16.5 points interval of 95% confidence) about vegetables (artichoke, cabbage, carrots, cauliflower, greens, lettuce, mesclun mix, dry onions, spinach, potatoes, cherry tomatoes, sweet potatoes) in 2012-13.

[4]Also in Europe, there are numerous examples of brand agriculture that produces highly differentiated wine, cheese, and other typical agri-food products. There is a rich literature on this topic in the fields of rural sociology and rural geography. See, for example, Tregear (2007).

[5]Because of higher values inherent in local names, questions of authenticity are of grave concern for local producers. The European Union has introduced the legal framework for the protection of geographical indications and designations of origin by Regulation 2081/92. Producers also become focused on communicating the authenticity to the consumers using a special package and label.

approach originated by von Thünen[6] that assumes a constant return to scale and perfect competition for agriculture. Because we stipulate scale economies and product differentiation in brand agriculture, it is more appropriate to use the market potential function approach introduced by Fujita et al. (1999). Although this approach originally aims at studying of manufacturing firms' location patterns, it applies to the spatial problem of differentiated products in general, including brand agriculture.

We introduce explicitly land as an immobile input, which has an essential role in determining the location of brand agriculture[7]. As Tabuchi and Thisse (2006) and Pflüger and Tabuchi (2008) observe, few existing models of NEG explicitly consider land as an input for production. Such simplification causes the undesirable dismissal of a vital source of dispersion forces, primarily impacting the location decision for land-intensive production. We assume that abundant allocation of land represents a natural advantage of the periphery. In order to examine the real effect of transportation and product differentiation on the sustainability of brand agriculture, we assume that brand agriculture do not require a particular type of soil quality and all land in the economy is physically homogeneous.

In the next section, we present the basic model in a general setting. In Section 3, we reformulate the model in the context of the core-periphery economy with a hub-and-spoke transport system and derive market clearing outcomes in the factor (labor and land) markets and the product markets. Based on these results, Section 4 examines spatial equilibrium conditions, first assuming that workers cannot move across regions, then allowing the migration of workers in response to the real wage difference. Finally, we discuss some policy implications in Section 5.

2. Model

2.1 Utility and demand

We consider an economy with three types of products: the homogeneous generic agricultural product ($\mathbb{A}$-product), the differentiated agricultural products also called the brand agricultural products ($\mathbb{B}$-products), and the differentiated manufactured products ($\mathbb{M}$-products). Let A denote the consumption of $\mathbb{A}$-product, and B and M represent the consumption of varieties of $\mathbb{B}$-products and $\mathbb{M}$-products, respectively. All consumers in the economy share the same utility function given by

$$U = \Upsilon\left(A\right)^{\alpha^A}\left(B\right)^{\alpha^B}\left(M\right)^{\alpha^M}, \tag{1}$$

[6]For a detailed explanation of the bid-rent approach, see Fujita and Thisse (2013).
[7]In Fujita, et al. (1999) and Picard and Zeng (2005) that study the role of the agricultural sector in the formation of the spatial structure of an economy, the location of agriculture is given a priori.

where $\Upsilon = \left[\left(\alpha^A\right)^{\alpha^A} \left(\alpha^B\right)^{\alpha^B} \left(\alpha^M\right)^{\alpha^M} \right]^{-1}$, $\alpha^A + \alpha^B + \alpha^M = 1$, and

$$B = \left[\int_0^{n^B} x_i^{\rho^B} di \right]^{1/\rho^B} \qquad M = \left[\int_0^{n^M} q_j^{\rho^M} dj \right]^{1/\rho^M},$$

in which x_i represents the consumption of variety $i \in [0, n^B]$ of $\mathbb{B}$-products and q_j that of variety $j \in [0, n^M]$ of $\mathbb{M}$-products. The parameters ρ^B and ρ^M denote the substitutability of each variety over the differentiated products. When ρ^B is close to 1, for example, differentiated $\mathbb{B}$-products are nearly perfect substitutes for each other while as ρ^B decreases toward 0, the desire to consume a greater variety of $\mathbb{B}$-products increases. If we set $\sigma^B \equiv 1/\left(1-\rho^B\right)$ and $\sigma^M \equiv 1/\left(1-\rho^M\right)$, then σ^B represents the elasticity of substitution between any pair of varieties of $\mathbb{B}$-products, and σ^M that of $\mathbb{M}$-products, taking values between 1 and ∞.

Let Y denote the income of a consumer, p^A the price of $\mathbb{A}$-product, p_i^B the price of the *i*-th variety of $\mathbb{B}$-product, and p_j^M the price of the *j*-th variety of $\mathbb{M}$-product. Then, the demand functions are given by

$$A = \frac{\alpha^A Y}{p^A}, \tag{2}$$

$$x_i = \alpha^B Y \left(p_i^B\right)^{-\sigma^B} \left(P^B\right)^{\sigma^B - 1}, \tag{3}$$

$$q_j = \alpha^M Y \left(p_j^M\right)^{-\sigma^M} \left(P^M\right)^{\sigma^M - 1}, \tag{4}$$

where P^B and P^M are the price indices of $\mathbb{B}$-product and that of $\mathbb{M}$-product, respectively, given by

$$P^B = \left[\int_0^{n^B} {p_i^B}^{-\left(\sigma^B - 1\right)} di \right]^{-1/(\sigma^B - 1)}, \tag{5}$$

$$P^M = \left[\int_0^{n^M} {p_j^M}^{-\left(\sigma^M - 1\right)} dj \right]^{-1/(\sigma^M - 1)}. \tag{6}$$

2.2 Transport costs, price indices, and real wage

Let $r, s = 1, 2, \ldots, m$ index each region in the economy. In the following, we assume that all producers in each sector are symmetric in terms of production technology. Then, product indices *i* and *j* can be replaced by the regional indices because firms/farmers in the same region choose the same price and quantity. We assume the iceberg transport cost incurred in the inter-regional trade. Specifically, if a unit of any variety of $\mathbb{B}$-product is shipped from region r to region s, only a fraction $1/T_{rs}^B$ of the original unit actually arrives while the rest perishes away on the way. Likewise, we define the transport parameter for $\mathbb{A}$-product and $\mathbb{M}$-product by T_{rs}^A and T_{rs}^M respectively, where $T_{rs}^A > 1, T_{rs}^B > 1, T_{rs}^M > 1$ for $r \neq s$. Let p_r^A, p_r^B, and p_r^M be the f.o.b. price of $\mathbb{A}$-product, $\mathbb{B}$-product, and $\mathbb{M}$-product, respectively, in region r. Then, the transport technology implies that the delivered (c.i.f.) prices p_{rs}^A, p_{rs}^B, and p_{rs}^M in region s are given by

$$p_{rs}^A = p_r^A T_{rs}^A,\ p_{rs}^B = p_r^B T_{rs}^B,\ p_{rs}^M = p_r^M T_{rs}^M.$$

We assume no transport cost within the same region, i.e., $T_{rr}^A = T_{rr}^B = T_{rr}^M = 1$.

Let n_r^B be the size of the $\mathbb{B}$-product variety produced in region r (which equals the number of $\mathbb{B}$-farms in region r), and n_r^M the size of $\mathbb{M}$-product variety produced in region r (the number of $\mathbb{M}$-firms in region r). Then, (5) and (6) become

$$P_r^B = \left[\sum_{s=1}^{m} \left(T_{sr}^B \right)^{-(\sigma^B - 1)} n_s^B \left(p_s^B \right)^{-(\sigma^B - 1)} \right]^{-1/(\sigma^B - 1)}, \tag{7}$$

$$P_r^M = \left[\sum_{s=1}^{m} \left(T_{sr}^M \right)^{-(\sigma^M - 1)} n_s^M \left(p_s^M \right)^{-(\sigma^M - 1)} \right]^{-1/(\sigma^M - 1)}. \tag{8}$$

Substituting (2) - (4) into (1) and using (7) and (8), we obtain the indirect utility (real income), ω_r, of a worker earning nominal wage w_r:

$$\omega_r = w_r \left(p_r^A \right)^{-\alpha^A} \left(P_r^B \right)^{-\alpha^B} \left(P_r^M \right)^{-\alpha^M}. \tag{9}$$

The real wage may differ across regions when the population in each region is assumed to be immobile. When labor is freely mobile, the real wage should be equalized in any location where workers reside.

2.3 Production

2.3.1 Generic agriculture

Each $\mathbb{A}$-farmer uses one unit of land and c^A units of labor per unit of output. Let R_r be the land rent in region r. Then the profit from a unit of $\mathbb{A}$-product in region r is $\pi_r^A = p_r^A - c^A w_r - R_r$. Because $\pi_r^A = 0$ in equilibrium, solving the profit function for R_r gives $\mathbb{A}$-farm's bid-rent (the maximum rent per unit of land an $\mathbb{A}$-farmer can pay exhausting his revenue) in region r as follows:

$$R_r^A = p_r^A - c^A w_r. \tag{10}$$

Assuming that $\mathbb{A}$-farmers are price-takers facing p_r^A and w_r, $\mathbb{A}$-production cannot be sustained at r where $R_r^A < 0$.

2.3.2 Brand agriculture

The production of one unit of $\mathbb{B}$-product requires one unit of the composite input consisting of one unit of land and c^B units of labor. In addition, as a fixed input, f^B units of the same composite are required. Thus, the profit of each $\mathbb{B}$-product in region r is

$$\pi_r^B = p_r^B x_r - \left(c^B w_r + R_r\right) x_r - \left(c^B w_r + R_r\right) f^B \tag{11}$$

where x_r is the total sales of a $\mathbb{B}$-product produced in region *r*. The first two terms in the right side express the operating profit and the last term the fixed cost. From our observation of actual production sites of brand agriculture in Japan, we learned that the maintenance of a brand requires constant efforts for improving products through field experiments. Thus, in the last term of (11), we added the fixed cost involving labor and land[8]. Using (3), the total supply of a $\mathbb{B}$-product produced in region r across m regions amounts to

$$x_r = \sum_{s=1}^{m} \alpha^B Y_s \left[p_r^B T_{rs}^B \right]^{-\sigma^B} \left(P_s^B \right)^{\sigma^B - 1} T_{rs}^B. \tag{12}$$

Assuming monopolistic competition in the $\mathbb{B}$-product market, each farm takes the price index P_s^B in each region as given. The first-order conditions for profit-maximization yields equilibrium f.o.b. price as a constant markup of the marginal cost:

$$p_r^B = \frac{c^B w_r + R_r}{\rho^B}. \tag{13}$$

Because $0 < \rho^B < 1$, (13) implies that the equilibrium price always exceeds the marginal cost, generating an operational profit. Competition from free entry drives individual output to the following equilibrium level,

$$x^* = (\sigma^B - 1) f^B, \tag{14}$$

implying that the operating profit equals the fixed cost in (11).

Let us define the *market potential function* of a $\mathbb{B}$-farmer in region *r*:

$$\Omega_r^B \equiv \frac{x_r}{x^*}. \tag{15}$$

By definition, it holds that $\Omega_r^B \underset{>}{\overset{<}{=}} 1 \Leftrightarrow x_r \underset{>}{\overset{<}{=}} x^* \Leftrightarrow \pi_r^B \underset{>}{\overset{<}{=}} 0$. This simply says that Ω_r^B is a normalized measure of the profitability of $\mathbb{B}$-production in region *r*; when it just breaks even, the value of Ω_r^B equals 1; when it yields a positive profit, Ω_r^B is greater than 1; and when it earns a negative profit, Ω_r^B is less than 1. The market potential function can be used to evaluate the sustainability of $\mathbb{B}$-production in region *r*.

2.3.3 Manufacturing

$\mathbb{M}$-products are produced using labor only[9]. The production of each $\mathbb{M}$-good requires a

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[8]The assumption of the same composite for variable input and fixed input is for the convenience of analysis.

[9]In reality, the manufactures use land in addition to labor. However, for simplifying the

marginal input of c^M units of labor in addition to $c^M f^M$ units of fixed labor. Thus, when an $\mathbb{M}$-firm in region r produces q_r, its profit is given by

$$\pi_r^M = p_r^M q_r - w_r c^M q_r - w_r c^M f^M. \tag{16}$$

Using (4), the total supply of an $\mathbb{M}$-product from region r to m regions is given by

$$\widehat{q}_r = \sum_{s=1}^{m} \alpha^M Y_s \left[p_r^M T_{rs}^M \right]^{-\sigma^M} \left(P_s^M \right)^{\sigma^M - 1} T_{rs}^M. \tag{17}$$

Assuming monopolistic competition in the $\mathbb{M}$-product market where each firm takes the price index in each region P_s^M as given, the first-order conditions for profit-maximization using (16) and (17) yields the equilibrium f.o.b. price:

$$p_r^M = \frac{c^M w_r}{\rho^M}. \tag{18}$$

Substituting (18) into (16), free entry equilibrium output of an $\mathbb{M}$-firm is given by

$$q^* = \left(\sigma^M - 1 \right) f^M. \tag{19}$$

The market potential function of a $\mathbb{M}$-firm in region r is defined as follows:

$$\Omega_r^M \equiv \frac{q_r}{q^*}. \tag{20}$$

Similarly to (15), it holds for Ω_r^M that $\Omega_r^M \overset{<}{\underset{>}{=}} 1 \Leftrightarrow q_r \overset{<}{\underset{>}{=}} q^* \Leftrightarrow \pi_r^M \overset{<}{\underset{>}{=}} 0$. Thus, $\Omega_r^M < 1$ implies that $\mathbb{M}$-product cannot be produced profitably in region *r*.

2.4 Factor markets

First, consider the land market. The land is used by both $\mathbb{A}$-sector and $\mathbb{B}$-sector in each region. Let G_r be the total amount of land in region r : and G_r^A and G_r^B respectively be the land utilized by the $\mathbb{A}$-sector and by the $\mathbb{B}$-sector. Since one unit of land is required per unit of $\mathbb{A}$-production, if Q_r^A is the total output of $\mathbb{A}$-product in region r , we have $G_r^A = Q_r^A$. In the $\mathbb{B}$-sector, we have $G_r^B = n_r^B \sigma^B f^B$ where $\sigma^B f^B$ is the land required for producing the equilibrium output, x^* given by (14).

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analysis, we follow the standard literature of spatial economics à la Fujita et al. (1999), and ignore the land consumption by manufacturers. In comparison to agricultural production, manufacturers use a relatively small amount of land per worker. Hence, given that the focus of this paper is on the location of brand agriculture and generic agriculture, it is expected that ignoring land consumption by manufacturers would not change the result substantially. The generalization of the model by considering land consumption of manufacturers is an important task left for the future.

We have $R_r > 0$ only when the land in region *r* is fully occupied, whereas $R_r = 0$ if the land is not fully occupied. Assuming a perfectly competitive land market in each region, the equilibrium land rent equals the highest bid-rent in region r ,

$$R_r = \max\left\{R_r^A,\ R_r^B,\ 0\right\}, \tag{21}$$

where R_r^A is given by (10), and R_r^B is the land rent that a $\mathbb{B}$ -farmer can pay at zero-profit (i.e., $\pi_r^B = 0$ in (11)), given by

$$R_r^B = \left(1 + \frac{f^B}{x_r}\right) p_r^B - c^B w_r.$$

Thus, we have

$$Q_r^A > 0 \Rightarrow R_r^A = R_r, \text{ and } R_r^A < R_r \Rightarrow Q_r^A = 0$$

$$n_r^B > 0 \Rightarrow R_r^B = R_r, \text{ and } R_r^B < R_r \Rightarrow n_r^B = 0.$$

This implies that if $Q_r^A > 0$ and $n_r^B > 0$, then $R_r^A = R_r^B = R_r$.

Turning to the labor market, provided that the total size of workers in region *r* is L_r , the labor demand for each sector, $\mathbb{A}$, $\mathbb{B}$, and $\mathbb{M}$ in region r is given respectively by:

$$L_r^A = c^A Q_r^A, \tag{22}$$

$$L_r^B = n_r^B c^B \sigma^B f^B, \tag{23}$$

$$L_r^M = n_r^M c^M \sigma^M f^M, \tag{24}$$

where $c^B \sigma^B f^B$ and $c^M \sigma^M f^M$ are respectively the labor required to produce x^* and q^* . Thus, full-employment of workers in each region *r* (i.e., $L_r^A + L_r^B + L_r^M = L_r$) means

$$c^A Q_r^A + n_r^B c^B \sigma^B f^B + n_r^M c^M \sigma^M f^M = L_r. \tag{25}$$

We assume that landlords live on their landholdings. That is, land rents are consumed where they are accrued. Landlords constitute a class of consumers having the same tastes given by (1). Then, the total factor income in region *r* denoted by Y_r, consists of the total wage income and the total land rent in region *r*:

$$Y_r = L_r w_r + G_r R_r. \tag{26}$$

3. The core-periphery economy with a hub-and-spoke transport system

3.1 Spatial structure of an economy

In the preceding section, we described the model and explained the equilibrium conditions in a general setting. In this section, in order to examine the spatial structure of the economy more concretely, we consider a specific form of a geographical system. Since we focus on the conditions for the viability of brand agriculture in the rural periphery, we assume a geographic system with the characteristic of the core-periphery economy.

Specifically, we consider the spatial structure of the core-periphery economy built on the hub-and-spoke transport system (CP-HS) as illustrated in Figure 1. In this context, let region 0 be the core where all firms of the $\mathbb{M}$-sector are assumed to locate. In the periphery, represented by subscript 1, there exist *m* sub-regions. Thus, there exist $m+1$ regions in the economy. For simplicity, we assume that transport costs between the core and the periphery are symmetrical in both directions, and we focus on the case where all *m* sub-regions in the periphery are symmetrical in all characteristics. In this configuration, region 0 is directly connected with *m* sub-regions which belong to the periphery, whereas the trade between any pair of sub-regions in the periphery, say *r* and *s*, necessarily passes through region 0. Thus, the transportation cost per unit of $\mathbb{M}$-product from region 0 to a sub-region *s* is T^M, whereas if they were to be transported from sub-region *r* to *s*, the transportation cost would be $(T^M)^2$. Hence, region 0 has a natural transportation cost advantage[10].

Figure 1 around here

3.2 Market clearing outcomes

3.2.1 General outcomes

While assuming that $\mathbb{A}$-product is always produced in both core and periphery, we distinguish two possible trading patterns for $\mathbb{A}$-product. *Pattern (a)* refers to the case in which region 0 and all m sub-regions in the periphery produce their own requirement of $\mathbb{A}$-product (i.e., $\mathbb{A}$-product is in self-sufficiency in each location). In contrast, in *pattern (b)*, $\mathbb{A}$-product is exported from each sub-region of the periphery to region 0.

Let L_0 be the size of the workforce and G_0 and the amount of land in region 0. Let L_1 and G_1 respectively be the *total* amount of labor and land in all sub-regions in the periphery. It implies that each sub-region of the periphery has L_1/m units of workers and G_1/m units of land. Let $\bar{L}$ be the given size of the total population of the economy; hence, the following always holds.

$$L_0 + L_1 = \bar{L}. \tag{27}$$

We assume that the land in region 0 is always fully used by $\mathbb{A}$-production, whereas the land in each sub-region of the periphery is so abundant that it cannot be fully occupied by $\mathbb{A}$-farmers and $\mathbb{B}$-farmers. This assumption implies that $R_0 > R_1 = 0$, where R_0

[10]Hence, our assumption of the concentration of $\mathbb{M}$-sector in region 0 can be justified based on Krugman (1993) which showed that stronger market potential makes a transportation hub be a preferred location for the production of goods subject to increasing returns to scale.

represents the land rent in region 0 and R_1 that in region 1.

The assumption of the CP-HS spatial structure gives specific forms of price indices for $\mathbb{B}$-products and $\mathbb{M}$-products in each region. Let n_0^M be the number of $\mathbb{M}$-products produced in the core and n_1^B be the number of $\mathbb{B}$-products produced *in each sub-region* in the periphery. We set $w_0 = 1$ for normalization. Using (7) and (8), we obtain:

$$P_0^B = T^B \left(mn_1^B\right)^{-1/(\sigma^B-1)} \frac{c^B w_1}{\rho^B} \tag{28}$$

$$P_1^B = \left[\left\{\left(T^B\right)^{-2\left(\sigma^B-1\right)}(m-1)+1\right\}n_1^B\right]^{-1/\left(\sigma^B-1\right)} \frac{c^B w_1}{\rho^B} \tag{29}$$

$$P_0^M = \left(n_0^M\right)^{-1/(\sigma^M-1)} \frac{c^M}{\rho^M} \tag{30}$$

$$P_1^M = T^M \left(n_0^M\right)^{-1/(\sigma^M-1)} \frac{c^M}{\rho^M}. \tag{31}$$

Using (9), the real wage in each region is given by

$$\omega_0 = \left(p_0^{A*}\right)^{-\alpha^A} \left(P_0^{B*}\right)^{-\alpha^B} \left(P_0^{M*}\right)^{-\alpha^M} \tag{32}$$

$$\omega_1 = w_1^* \left(p_1^{A*}\right)^{-\alpha^A} \left(P_1^{B*}\right)^{-\alpha^B} \left(P_1^{M*}\right)^{-\alpha^M} \tag{33}$$

For each pattern of (a) and (b), by solving the market clearing conditions for factor markets and product markets, we can obtain the equilibrium values of p_0^A, p_1^A, R_0, w_1, ω_0, and ω_1 as follows (for this derivation, refer Appendix 1 and Appendix 2).

3.2.2 Pattern (a)

$$p_0^{A^*} = \frac{\alpha^A}{1-\alpha^A} \frac{L_0 - c^A G_0}{G_0} \tag{34}$$

$$p_1^{A^*} = \frac{c^A \alpha^B}{\alpha^M \left(1-\alpha^A\right)} \frac{L_0 - c^A G_0}{L_1} \tag{35}$$

$$R_0^* = \frac{1}{1-\alpha^A} \left(\frac{\alpha^A L_0 - c^A G_0}{G_0}\right) \tag{36}$$

$$w_1^* = \frac{\alpha^B}{\alpha^M \left(1-\alpha^A\right)} \frac{L_0 - c^A G_0}{L_1}. \tag{37}$$

$$
\begin{aligned}
\omega_0 = {} & \left(\frac{\alpha^B}{\alpha^M}\right)^{-\alpha^B} \left(L_0 - c^A G_0\right)^{\alpha^M ? \rho^M - 1} \left\{\frac{\left(1-\alpha^A\right) G_0}{\alpha^A}\right\}^{\alpha^A} \left\{\left(1-\alpha^A\right) L_1\right\}^{\alpha^B ? \rho^B} \\
& \times \left\{\frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M - 1\right)} \left(c^M\right)^{1/\rho^M}}\right\}^{\alpha^M} \left\{\frac{\rho^B}{\left(\sigma^B f^B\right)^{1/\left(\sigma^B - 1\right)} \left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B} \left(T^B\right)^{-\alpha^B}
\end{aligned} \tag{38}
$$

$$
\begin{aligned}
\omega_1 = {} & \left(\frac{\alpha^B}{\alpha^M}\right)^{\alpha_M} \left(L_0 - c^A G_0\right)^{\alpha^M ? \rho^M} \left(c^A\right)^{-\alpha^A} \left\{\left(1-\alpha^A\right) L_1\right\}^{-\left(1-\alpha^A-\alpha^B ? \rho^B\right)} \\
& \times \left\{\frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M - 1\right)} \left(c^M\right)^{1/\rho^M}}\right\}^{\alpha^M} \left\{\frac{\rho^B}{\left(\sigma^B f^B\right)^{1/\left(\sigma^B - 1\right)} \left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B} \\
& \times \left(\frac{(m-1)\left(T^B\right)^{-2\left(\sigma^B-1\right)} + 1}{m}\right)^{\alpha^B/\left(\sigma^B-1\right)} \left(T^M\right)^{-\alpha^M}
\end{aligned} \tag{39}
$$

3.2.3 Pattern (b)

$$p_0^{A^*} = p_1^{A^*} T^A \tag{40}$$

$$p_1^{A^*} = c^A \frac{1-\alpha^M}{\alpha^M} \frac{L_0 - c^A G_0}{L_1 + c^A G_0 T^A} \tag{41}$$

$$R_0^* = c^A \left(\frac{1-\alpha^M}{\alpha^M} \frac{L_0 - c^A G_0}{L_1 + c^A G_0 T^A} T^A - 1\right) \tag{42}$$

$$w_1^* = \frac{1-\alpha^M}{\alpha^M} \frac{L_0 - c^A G_0}{L_1 + c^A G_0 T^A} \tag{43}$$

$$
\begin{aligned}
\omega_0 = {} & \left(\alpha^M\right)^{1-\alpha^M} \left(c^A\right)^{-\alpha^A} \left(L_0 - c^A G_0\right)^{\left(\alpha^M/\rho^M\right)-1} \left(\frac{L_1 + c^A G_0 T^A}{1-\alpha^M}\right)^{\alpha^A + \alpha^B/\rho^B} \\
& \times \left\{\frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M - 1\right)} \left(c^M\right)^{1/\rho^M}}\right\}^{\alpha^M} \left\{\left(\frac{\alpha^B}{\sigma^B f^B}\right)^{1/\left(\sigma^B-1\right)} \frac{\rho^B}{\left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B} \\
& \times \left(T^A\right)^{-\alpha^A} \left(T^B\right)^{-\alpha^B}
\end{aligned} \tag{44}
$$

$$
\omega_1 = \left(\alpha^M\right)^{-\alpha^M} \left(c^A\right)^{-\alpha^A} \left(L_0 - c^A G_0\right)^{\alpha^M/\rho^M} \left(\frac{L_1 + c^A G_0 T^A}{1-\alpha^M}\right)^{\alpha^B/\left(\sigma^B - 1\right) - \alpha^M}
$$

$$
\times \left\{ \frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M - 1\right)} \left(c^M\right)^{1/\rho^M}} \right\}^{\alpha^M} \left\{ \left(\frac{\alpha^B}{\sigma^B f^B}\right)^{1/\left(\sigma^B - 1\right)} \frac{\rho^B}{\left(c^B\right)^{1/\rho^B}} \right\}^{\alpha^B} \tag{45}
$$

$$
\times \left(T^B\right)^{-2\alpha^B} \left(T^M\right)^{-\alpha^M}
$$

Under both patterns, the $\mathbb{A}$-production must be able to pay positive land rent in region 0, whereas we assume that the land rent in region 1 is zero. Thus, it must hold for pattern (a) from (36)

$$
\alpha^A L_0 > c^A G_0,
$$

and for pattern (b) from (42)

$$
\left(1-\alpha^M\right) L_0 > c^A G_0 + \frac{\alpha^M L_1}{T^A}.
$$

4. Spatial equilibrium conditions

4.1 Location equilibrium conditions of production activities

Given the market outcomes above, we proceed to examine the *location equilibrium conditions* for each type of production activity. We state that a production activity is in location equilibrium if firms and farmers are not able to increase their profit by changing a location. In this subsection, it is assumed that workers are immobile and hence, the size of labor in each region is fixed respectively at L_0 and L_1. In other words, here we consider a short-run equilibrium. In order to claim that the CP-HS spatial structure is in *spatial equilibrium*, none of the individual producers in the three production sectors should have the incentive to change the present locations.

In $\mathbb{A}$-sector, we distinguished two trade patterns. It is straightforward to see that the self-sufficiency of $\mathbb{A}$-product under pattern (a) will occur when T^A is so high that the delivered price is always higher than the local price. This condition is given by

$$
\frac{1}{T^A} < \frac{p_0^{A^*}}{p_1^{A^*}} < T^A.
$$

Using (34) and (35), we can specify this condition as follows:

$$
\frac{1}{T^A} < \frac{\alpha^A \alpha^M}{\alpha^B} \frac{L_1}{c^A G_0} < T^A. \tag{46}
$$

When T^A is sufficiently small such that

$$T^A < \frac{\alpha^A \alpha^M}{\alpha^B} \frac{L_1}{c^A G_0}, \tag{47}$$

meaning that the delivered price of $\mathbb{A}$-product import from region 1 in region 0 undercuts the autarky price (34). This condition applies for location equilibrium of $\mathbb{A}$-sector in pattern (b).

The location equilibrium of $\mathbb{B}$-sector requires that to produce $\mathbb{B}$-product is not profitable in region 0. To examine this condition, we obtain the market potential function of a $\mathbb{B}$-farmer in region 0 using (15) as follows (refer to Appendix 3 for the derivation):

$$\Omega_0^B = \left(\frac{c^B w_1^*}{c^B + R_0^*} \right)^{\sigma^B} \left(T^B \right)^{\sigma^B - 1} \frac{Y_0^* + Y_1^* m \left[\left(T^B \right)^{2(\sigma^B - 1)} + (m-1) \right]^{-1}}{Y_0^* + Y_1^*}$$

In this expression, the first term captures the *fixed-cost advantage* of region 0 against region 1 to maintain $\mathbb{B}$-production. The second term indicates region 0's *operating-cost advantage* in supplying a unit of $\mathbb{B}$-product to the core market or to any other regions in the periphery[11]; and the last term the *effective demand size advantage*. Here, let us focus on the case where the periphery is divided into such a large number of regions that *the local demand for its own* $\mathbb{B}$*-product is negligibly small in comparison with the total demand for the same product by the whole economy*. In this context, setting $m \to \infty$ in the equation above, we obtain

$$\Omega_0^B = \left(\frac{c^B w_1^*}{c^B + R_0^*} \right)^{\sigma^B} \left(T^B \right)^{\sigma^B - 1}.$$

As discussed in section 2.3.2, the location equilibrium condition of $\mathbb{B}$-sector is

$$\Omega_0^B < 1, \text{ i.e., } \frac{c^B + R_0^*}{c^B w_1^*} > \left(T^B \right)^{(\sigma^B - 1)/\sigma^B} \tag{48}$$

meaning that region 0's cost disadvantage (i.e., higher land rent in region 0 and lower nominal wage in region 1) exceeds the operating cost advantage in supplying $\mathbb{B}$-product to the core market. Notice that the utility function (1) implies that $\mathbb{B}$-products must be produced somewhere in the economy. Hence, in equilibrium, if $\Omega_0^B < 1$, then it must be that $\Omega_1^B = 1$.

We also apply the potential function to the $\mathbb{M}$-sector. Suppose that a firm intends to produce an $\mathbb{M}$-product in a region in the periphery. Then, its market potential function is given as follows (see Appendix 4 for the derivation):

---

[11]Note that serving cost of one unit of $\mathbb{B}$-product from one sub-region to another in the periphery is $\rho^{-1} c_B w_1 \left(T_B \right)^2$ while that from the core to one sub-region in the periphery is $\rho^{-1} \left(c_B + R_0 \right) T_B$. Hence the ratio of these serving costs is the same as the one related to the serving cost to the core market from the core and that from a sub-region in the periphery.

$$\Omega_1^M = \left(w_1^*\right)^{-\sigma^M} \left(T^M\right)^{-\left(\sigma^M - 1\right)} \frac{Y_0^* + Y_1^* \left[\left(T^M\right)^{2\left(\sigma^M - 1\right)} + \left(m-1\right)\right] \Big/ m}{Y_0^* + Y_1^*}.$$

In this expression, the first term captures the *fixed-cost advantage* of region 1 against region 0 in $\mathbb{M}$-production, namely, the lower the nominal wage in region 1 relative to that in region 0, which is set to be unity, the more advantageous for a $\mathbb{M}$-firm to produce in region 1. The second term expresses region 1's *operating-cost disadvantage* relative to other firms remaining in region 0 in supplying a unit of $\mathbb{M}$-product to the core market or to any other regions in the periphery with transport cost, and the last term *effective demand size disadvantage* for producing in region 1 for being in the periphery of the CP-HS spatial structure. As before, assuming that m is sufficiently large so that each $\mathbb{M}$-firm entrant ignores the local demand in the region where it produces, we obtain

$$\Omega_1^M = \left(w_1^*\right)^{-\sigma^M} \left(T^M\right)^{-\left(\sigma^M - 1\right)}.$$

In order to claim that $\mathbb{M}$-production is location equilibrium, it must hold as follows:

$$\Omega_1^M < 1, \text{ i.e., } w_1^* > \left(T^M\right)^{-\left(\sigma^M - 1\right)/\sigma^M}. \tag{49}$$

implying that the labor cost in region 1 is not sufficiently low to overcome the high transport cost of $\mathbb{M}$-product from region 1. Again, in equilibrium, if $\Omega_1^M < 1$, then it must be that $\Omega_0^M = 1$.

In summary, (48) and (49) together represent location equilibrium conditions of $\mathbb{B}$-farmers and $\mathbb{M}$-firms in the CP-HS. If (46) is satisfied, the spatial structure is pattern (a), while (40) means pattern (b). For both patterns, $R_0^* > 0$ also must hold.

Using the equilibrium solutions obtained in the previous section, we can specify that location equilibrium conditions of pattern (a) given by (46), (48), (49), and $R_0^* > 0$ are respectively

$$\frac{1}{T^A} \frac{\alpha^B}{\alpha^A \alpha^M} c^A G_0 < L_1 < T^A \frac{\alpha^B}{\alpha^A \alpha^M} c^A G_0. \tag{50}$$

$$L_1 \geq \left(T^B\right)^{\left(\sigma^B - 1\right)/\sigma^B} \frac{\alpha^B}{\alpha^M} \frac{c^B G_0}{1 - \left(1 - \alpha^A\right)\left(L_0 - c^B G_0\right)\left(L_0 - c^A G_0\right)^{-1}}, \tag{51}$$

$$L_1 \leq \left(T^M\right)^{\left(\sigma^M - 1\right)/\sigma^M} \frac{\alpha^B}{\left(1 - \alpha^A\right)\alpha^M} \left(L_0 - c^A G_0\right) \tag{52}$$

$$0 < \alpha^A L_0 - c^A G_0. \tag{53}$$

Location equilibrium conditions of pattern (b) given by (47), (48), (49), and $R_0^* > 0$ are respectively

$$L_1 > T^A \frac{\alpha^B}{\alpha^A \alpha^M} c^A G_0. \tag{54}$$

$$L_1 \geq \frac{\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} c^B - T^A c^A}{c^B - c^A} \frac{1-\alpha^M}{\alpha^M}\left(L_0 - c^A G_0\right) - T^A c^A G_0, \tag{55}$$

$$L_1 \leq \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M} \frac{1-\alpha^M}{\alpha^M}\left(L_0 - c^A G_0\right) - T^A c^A G_0. \tag{56}$$

$$L_1 < T^A \frac{\left(1-\alpha^M\right) L_0 - c^A G_0}{\alpha^M}. \tag{57}$$

The foregone results are summarized in the following proposition:

Proposition 1 *Suppose that workers are immobile among regions. The core-periphery economy with the hub-and-spoke transport system of pattern (a) is in equilibrium if population size in the core,* L_0*, and that in the periphery,* L_1*, satisfy conditions (50) to (53). It is in equilibrium with pattern (b) if conditions (54) to (57) are satisfied.*

4.2 Spatial equilibrium with immobile workers

Based on Proposition 1 we can show graphically the conditions under which the CP-HS is sustained in either pattern (a) or pattern (b). For the convenience of the presentation, let us define the following functions of L_0 respectively from (51), (52), (55), (56), (53) and (57):

$$F^{B(a)}\left(L_0\right) \equiv \left(T^B\right)^{\left(\sigma^B-1\right)?\sigma^B} \frac{\alpha^B}{\alpha^M} \frac{c^B G_0}{1-\left(1-\alpha^A\right)\left(L_0 - c^B G_0\right)/\left(L_0 - c^A G_0\right)}, \tag{58}$$

$$F^{M(a)}\left(L_0\right) \equiv \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M} \frac{\alpha^B}{\alpha^M} \frac{L_0 - c^A G_0}{1-\alpha^A}, \tag{59}$$

$$F^{R(a)}\left(L_0\right) \equiv \frac{c^A G_0}{\alpha^A} - L_0, \tag{60}$$

$$F^{B(b)}\left(L_0\right) \equiv \frac{c^B \left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} - c^A T^A}{c^B - c^A} \frac{1-\alpha^M}{\alpha^M}\left(L_0 - c^A G_0\right) - T^A c^A G_0, \tag{61}$$

$$F^{M(b)}\left(L_0\right) \equiv \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M} \frac{1-\alpha^M}{\alpha^M}\left(L_0 - c^A G_0\right) - T^A c^A G_0, \tag{62}$$

$$F^{R(b)}\left(L_0\right) \equiv T^A \frac{\left(1-\alpha^M\right) L_0 - c^A G_0}{\alpha^M}. \tag{63}$$

Note that (50) and (54) are not functions of L_0. Proposition 1 requires that (50), $F^{B(a)} \leq L_1$, $F^{M(a)} \geq L_1$, and $F^{R(a)} < 0$ for pattern (a); and (54), $F^{B(b)} \leq L_1$, $F^{M(b)} \geq L_1$, and $F^{R(b)} < L_1$ for pattern (b).

We can depict the shaded areas in Figure 2 as combinations of L_0 and L_1 that establishes either pattern (a) and (b)[12]. Four different cases (i)-(iv) are drawn according to the relative size of T^A , T^B, and T^M. Case I and II (respectively Figure 2(i) and 2(ii)) are when $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}\left[\alpha^B/\left(\alpha^A\alpha^M\right)\right]c^B G_0 < T^A\left[\alpha^B/\left(\alpha^A\alpha^M\right)\right]c^A G_0$, hence, $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} < \left(c^A/c^B\right)T^A$. Namely, they express the situation in which: T^B is sufficiently lower than T^A; σ^B is closer to 1 implying that $\mathbb{B}$-product is highly differentiated; and/or c^A/c^B is sufficiently large implying that $\mathbb{B}$-product is produced with much less labor per unit of land. These conditions describe well what we characterize $\mathbb{B}$-product as *brand agriculture*. Case III and IV (respectively Figure 2(iii) and 2(iv)) are when $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} > \left(c^A/c^B\right)T^A$, meaning the opposite situation where $\mathbb{B}$-product is not highly differentiated and transportation is costly and/or per unit of land labor requirement for production is high.

The condition that differs case I from II and case III from IV is $T^A < \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$, derived from $\left\{a^A + \left(1-a^A\right)T^A\left(T^M\right)^{-\left(\sigma^M-1\right)/\sigma^M}\right\}c^A G_0/\alpha^A < c^A G_0/\alpha^A$. Thus, case II describes the situation where transportation of $\mathbb{A}$-product is the most costly; therefore the periphery is not advantageous in producing generic food despite having abundant lands. Note that if $T^A < \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$ (cases II and IV), the location equilibrium condition of $\mathbb{M}$-firms $F^{M(a)} \geq L_1$ and $F^{M(b)} \geq L_1$ always hold if $F^{R(a)} < 0$ and $F^{R(b)} < L_1$ (the positive rent condition in region 0) are met, implying that the labor cost can never be sufficiently low to overcome the high operating cost of supplying $\mathbb{M}$-product from region 1.

Figure 2 around here

Because $L_0 + L_1 = \overline{L}$, population distribution between region 0 and region 1 for a given $\overline{L}$ is given on $L_1 = \overline{L} - L_0$ line. We are able to find $\overline{L}^1$, $\overline{L}^2$ (and $\overline{L}^{2'}$), and $\overline{L}^3$ that characterize boundaries:

- If $\overline{L} < \overline{L}^1$, the CP--HS spatial structure is not feasible;
- If $\overline{L}^1 \leq \overline{L} \leq \overline{L}^2$ in case I and III and $\overline{L}^1 \leq \overline{L} \leq \overline{L}^{2'}$ in case II and IV, only pattern (a) is feasible;

[12]Detailed explanations of the construction of Figure 2 are given in Appendix 5

- If $\overline{L}^2 < \overline{L}$ in case I, $\overline{L}^{2'} < \overline{L}$ in case II, $\overline{L}^2 < \overline{L} \leq \overline{L}^3$ in case III and IV, both patterns (a) and (b) are feasible; and
- If $\overline{L}^3 < \overline{L}$ in case III and IV, only pattern (b) is feasible.

Based on the foregone analysis, the following observations are in order. First, for a population size $\overline{L}^1 \leq \overline{L},$ the CP-HS spatial structure with $\mathbb{B}$-production in the periphery is in spatial equilibrium in either pattern (a) or (b) for a much wider range of L_0 - L_1 combination if parameters satisfy cases I and II (i.e., $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} < \left(c^A/c^B\right)T^A$). In these cases, the operating cost advantage of supplying $\mathbb{B}$-products from region 0 do not compensate for higher production cost in labor and land. In other words, $\mathbb{B}$-product is viable in region 1 because of lower production cost and also because the operating cost disadvantage is not high owing to the lower T^B and the strong product differentiation (i.e., lower σ^B). If these conditions are not met, we still may have the same spatial structure in equilibrium in cases III and IV, yet the possible L_0 - L_1 combinations are more limited because the condition of $F^{B(b)} < L_1$ becomes binding. Specifically, the equilibrium does not hold if the population is highly concentrated in the core (the lower-right area of Figure 2). It means that the production of $\mathbb{B}$-product in region 0 becomes viable if L_0 is sufficiently large because operating cost advantage and effective demand size advantage exceed the production cost disadvantage in region 0.

Secondly, if $T^A > \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$, conditions $F^{M(a)} \geq L_1$ and $F^{M(b)} \geq L_1$ become binding as shown in cases II and IV. Due to high T^A and amply large L_1, wage in region 1 becomes sufficiently lower than that of region 0. Despite the effective demand advantage in region 0, $\mathbb{M}$-firms find it attractive to produce in region 1 taking advantage of lower production cost.

From the viewpoint of policy-making, the first point suggests that in order to develop brand agriculture as an alternative mean of the rural economy, farmers should be supported by the reduction of physical transport cost (lower T^B) and, more importantly, promotion of higher degree of product differentiation (lower σ^B). The latter should be achieved by the combination of proper use of the locally abundant resource (represented by the land in the model), local cooperation in product development, and effective marketing to cultivate consumers' interest in the core market. This approach presents a different view from the conventional thinking in agricultural development where new technologies for staple food production to reduce production cost is developed in the core region and disseminated to the rural area, such as the case of genetically modified organisms (GMO) food products. Importantly, the agricultural development emphasizing brand agriculture is suitable to a rural area facing high transport cost (in broad sense) of generic agricultural product.

4.3 Spatial equilibrium with mobile workers

So far, we have assumed that workers are immobile between regions. Now we relax this assumption and examine the spatial equilibrium with mobile workers. This represents the case of a long-run equilibrium of the national economy, where the real wage is equalized in all regions. We keep the assumption of the symmetry of sub-regions in region 1. Using (32) and (33), the spatial equilibrium condition of mobile workers is given by

$$\frac{\omega_0}{\omega_1}=\left(\frac{p_1^A}{p_0^A}\right)^{\alpha^A}\left(\frac{P_1^B}{P_0^B}\right)^{\alpha^B}\left(\frac{P_1^M}{P_0^M}\right)^{\alpha^M}\frac{1}{w_1}=1. \tag{64}$$

4.3.1 Pattern (a)

Substituting equilibrium solutions of pattern (a) given in Appendix 1 and (27) into (64), if m is sufficiently large, we obtain

$$\frac{\alpha^M\left(1-\alpha^A\right)}{\alpha^B K_a}\frac{\left(L_1\right)^{1-\alpha^A}}{\bar{L}-c^A G_0-L_1}=1. \tag{65}$$

where $K_a\equiv\left[\left(\alpha^M/\alpha^B\right)\alpha^A/\left(c^A G_0\right)\right]^{\alpha^A}\left(T^B\right)^{-\alpha^B}\left(T^M\right)^{-\alpha^M}$ is a positive constant. As depicted in Figure 3, the left side of (65) increases continuously from 0 toward ∞ as L_1 increases from 0 to $\bar{L}-c^A G_0$. Hence, for given $\bar{L}$ and K_a, the equilibrium population in region 1, L_1^*, is uniquely determined. In this figure, the equilibrium population in region 0, L_0^*, the equilibrium size of $\mathbb{M}$-workers, $L_0^{M^*}$ and that of $\mathbb{A}$-workers in region 0, $c^A G_0$, are also shown.

Figure 3 around here

4.3.2 Pattern (b)

Substituting equilibrium solutions of pattern (b) given in Appendix 2 and (27) into (64), if m is sufficiently large, we obtain

$$L_1^*=\frac{K_b\left(\bar{L}-c^A G_0\right)-\left[\alpha^M/\left(1-\alpha^M\right)\right]c^A G_0 T^A}{\alpha^M/\left(1-\alpha^M\right)+K_b}, \tag{66}$$

where $K_b\equiv\left(T^A\right)^{\alpha^A}\left(T^B\right)^{-\alpha^B}\left(T^M\right)^{-\alpha^M}$ is a positive constant. Thus, L_1^* and $L_0^*=\bar{L}-L_1^*$ are uniquely determined for a given $\bar{L}$.

4.3.3 Consistency and stability

In order to claim that CP-HS is in spatial equilibrium with mobile workers, either in pattern (a) or pattern (b), condition (65) and equilibrium periphery population (66) must be consistent with propositions 1. To examine these conditions graphically, it is convenient to define the following as functions of L_0 from (27), (65) and (66):

$$F^{*(a)}(L_0) \equiv \left[\frac{\alpha^B K_a}{\alpha^M (1-\alpha^A)}\right]^{1/(1-\alpha^A)} (L_0 - c^A G_0)^{1/(1-\alpha^A)}$$

$$F^{*(b)}(L_0) \equiv \frac{(1-\alpha^M)K_b}{\alpha^M}(L_0 - c^A G_0) - c^A G_0 T^A.$$

Then, $L_1 = F^{*(a)}(L_0)$ and $L_1 = F^{*(b)}(L_0)$ represent the equilibrium population distribution of patterns (a) and (b), respectively when workers are mobile. The $F^{*(a)}(L_0)$ - $F^{*(b)}(L_0)$ locus can be depicted as Figure 4.

Figure 4 around here

Because $\omega_0/\omega_1 \gtreqless 1$ as $L_1 \gtreqless F^{*(a)}(L_0)$ and $L_1 \gtreqless F^{*(b)}(L_0)$, we can readily see that the response to perturbations will restore the equilibrium on $F^{*(a)}$ - $F^{*(b)}$ locus through migration along $\overline{L} = L_0 + L_1$ line. Hence the equilibrium population distribution is stable.

When workers are mobile, CP-HS is in location equilibrium on the $F^{*(a)}$ - $F^{*(b)}$ locus, which is positioned in the feasible area in Figure 2 (the shaded area). Because of the convex shape of $F^{*(a)}(L_0)$, pattern (a) always exists whenever $F^{*(b)}(L_0)$ passes through the feasibility area of pattern (b). Thus we can focus on pattern (b). Specifically, we first check whether the slope of $F^{*(b)}(L_0)$ is less than that of $F^{R(b)}(L_0)$ for cases I and III and $F^{M(b)}(L_0)$ for cases II and IV[13]. This yields the following condition:

$$K_b \le \min\left\{T^A, (T^M)^{(\sigma^M-1)?\sigma^M}\right\}.$$

Cases III and IV additionally call for that the slope of $F^{*(b)}(L_0)$ is greater than that of $F^{B(b)}(L_0)$. This yields the second condition:

[13]We get the same result by examining the condition for that the intersection of $L_1 = T^A(\alpha^B/\alpha^M)(c^A G_0/\alpha^A)$ with the $F^{*(a)} - F^{*(b)}$ line in Figure 4 should be located between that with $F^{R(a)} - F^{R(b)}$ or $F^{M(a)} - F^{M(b)}$ and that with $F^{B(a)} - F^{B(b)}$ in Figure 2.

$$\frac{c^B\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}-c^AT^A}{c^B-c^A}\leq K_b.$$

Hence, for cases III and IV to hold when workers are mobile, the following condition should be met:

$$\frac{c^B\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}-c^AT^A}{c^B-c^A}\leq K_b\leq\min\left\{T^A,\left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}\right\}. \tag{67}$$

In fact, the first inequality always hold for cases I and II because they presume $c^B\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}<c^AT^A$. Hence, (67) is generally applicable spatial equilibrium condition with mobile workers.

The results above can be summarized as follows:

Proposition 2 *Suppose that workers can migrate freely between regions as well as between sectors. If condition (67) is satisfied, the equilibrium population is uniquely determined as (65) and (66). Furthermore, the equilibrium population distribution is stable.*

4.4 Impact of lower T^B and lower σ^B on the equilibrium real wage

Having obtained the spatial equilibrium with mobile workers, we shall discuss some policy implications of our model. In section 4.2, we found that the spatial equilibrium with brand agriculture produced in the periphery holds for broader range of population distribution between the core and the periphery if the operating cost disadvantage of the periphery in supplying $\mathbb{B}$-products from the periphery is not very high owing to the lower transport cost and the stronger product differentiation of $\mathbb{B}$-goods. These results suggest that the reduction of physical transport cost and effective marketing of local brands (lower T^B) and, more importantly, promotion of higher degree of product differentiation (lower σ^B) are recommended to develop brand agriculture as an alternative mean of the rural economy.

In order to investigate whether such policies are desirable from the welfare point of view, we examine the impact of lower T^B and lower σ^B on the real wage. In this subsection, we only analyze the case of the pattern (b) because we can obtain the same result from pattern (a). Let ω_0^* and ω_1^* respectively denote the equilibrium real wage in region 0 and 1. Substituting $L_0=\bar{L}-L_1^*$ into (44) and (45), we have

$$\omega_0^*=\left(\alpha^M\right)^{1-\alpha^M}\left(c^A\right)^{-\alpha^A}\left(\bar{L}-L_1^*-c^AG_0\right)^{\left(\alpha^M/\rho^M\right)-1}\left(\frac{L_1^*+c^AG_0T^A}{1-\alpha^M}\right)^{\alpha^A+\alpha^B/\rho^B}$$
$$\times\left\{\frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M-1\right)}\left(c^M\right)^{1/\rho^M}}\right\}^{\alpha^M}\left\{\left(\frac{\alpha^B}{\sigma^B f^B}\right)^{1/\left(\sigma^B-1\right)}\frac{\rho^B}{\left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B} \tag{68}$$
$$\times\left(T^A\right)^{-\alpha^A}\left(T^B\right)^{-\alpha^B},$$

and

$$\omega_1^* = \left(\alpha^M\right)^{-\alpha^M} \left(c^A\right)^{-\alpha^A} \left(\overline{L} - L_1^* - c^A G_0\right)^{\alpha^M/\rho^M} \left(\frac{L_1^* + c^A G_0 T^A}{1-\alpha^M}\right)^{\alpha^B/\left(\sigma^B-1\right)-\alpha^M}$$
$$\times \left\{\frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M-1\right)} \left(c^M\right)^{1/\rho^M}}\right\}^{\alpha^M} \left\{\left(\frac{\alpha^B}{\sigma^B f^B}\right)^{1/\left(\sigma^B-1\right)} \frac{\rho^B}{\left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B} \tag{69}$$
$$\times \left(T^B\right)^{-2\alpha^B} \left(T^M\right)^{-\alpha^M}.$$

Since L_1^* has been obtained by setting $\omega_0 = \omega_1$, i.e., (44) = (45) in (66), it holds identically that

$$\omega^* \equiv \omega_0^* \equiv \omega_1^*.$$

Hence, in the following analysis of the impact of change in T^B and ρ^B , we use equation (69). More detailed calculations are provided in Appendix 6.

First, we examine the impact of T^B change on ω^* . Using (69), we can obtain that

$$\frac{\mathrm{d}\omega_1^*}{\mathrm{d}T^B} < 0 \text{ iff } K_b\left(\frac{\alpha^M}{\rho^M} - 2\right) - \frac{1+\alpha^M}{1-\alpha^M}\alpha^M - \frac{\alpha^B}{\sigma^B - 1} < 0 \tag{70}$$

In particular, it holds that

$$\frac{\mathrm{d}\omega_1^*}{\mathrm{d}T^B} < 0 \text{ if } \frac{\alpha^M}{\rho^M} < 2. \tag{71}$$

In the standard economic theory, e.g., Fujita et al. (1999), it is customarily assumed that the following *no-black-hole condition* prevails in the economy:

$$\frac{\alpha^M}{\rho^M} < 1.$$

In this case, of course, we have that $\mathrm{d}\omega_1^* / \mathrm{d}T^B < 0$.

Next, we examine the impact of σ^B change on ω^*. Using (69), we can obtain that

$$\frac{\mathrm{d}\omega_1^*}{\mathrm{d}\sigma^B} < 0 \text{ iff } \overline{L} > \frac{c^B \sigma^B f^B}{\alpha^B}\left(\frac{\alpha^M}{K_b} + 1 - \alpha^M\right) + c^A G_0\left(T^A - 1\right). \tag{72}$$

Hence, we can summarize the results as follows:

Proposition 3 *For pattern (b), transport cost reduction of $\mathbb{B}$-goods will increase the real income if (71) is met. Assuming the no-black-hole condition, this result always holds. Higher degree of product differentiation of $\mathbb{B}$-goods increases real income if the total population is sufficiently large such that (72) holds.*

5. Concluding remarks

In this paper, we extended the NEG model by introducing the brand agriculture characterized by product differentiation. We focused on the CP-HS spatial structure where manufacturing is concentrated in the core, and brand agricultural products are produced in the fragmented periphery. We found that brand agriculture is sustainable in the periphery provided that these products are highly differentiated. The production of brand agricultural is viable even in the periphery which faces high transportation cost in supplying staple food to major markets, meaning a remote rural area, if the products are differentiated enough to overcome the transport disadvantage. If farmers in such areas were to continue producing only generic agricultural products, they would have to endure low earnings to compete with those with more favorable conditions. Our results suggest that branding is an alternative strategy for them rather than surviving with subsidies.

In contrast to the general perception of development strategy where the industrialization occurs in cities first, and then income growth trickles down to the rural sector, the approach in this paper highlights the necessity of thinking backward: thinking first of the product differentiation and innovation in rural areas. The NEG literature has emphasized that the power of megacities will increase in the era of globalization. It also refers to the increasing development potential of well-connected medium-sized, or near periphery, cities, as the congestion in megacities grows. In the meantime, the agricultural hinterland, or far periphery, has received little attention in the literature, although the widening income gap between the core and the periphery has been recognized as a severe social problem. The NEG approach has not been able to provide meaningful policy implications for this critical question due to the simplistic assumptions of perfect competition in the homogeneous product about the rural sector. Our approach suggests a promising research direction to fill that gap.

That much said, however, another critical question remains: Is it possible to develop highly differentiated agricultural products in the far periphery? We indeed have many observations such as some essential anecdotes from Japan in Fujita (2008), the growth of organic agriculture in the United States, and trade promotion based on geographical indication scheme in European Union. This observation suggests that it is possible to develop such very distinctive products sustainably in remote regions successfully, provided that appropriate support is given initially and suitable learning networks are formed locally to promote the innovative capacity in each area. To pursue this question formally, however, we need to extend our static model into a dynamic model by combining the new economic geography with endogenous growth theory such as Fujita and Thisse (2013). We hope to be able to report such a development in the not-too-distant future.

Appendix 1: Derivation of the market clearing solutions for pattern (a)

In pattern (a), $\mathbb{A}$-product is self-sufficient at each location. Provided that the land in region 0 is fully occupied by $\mathbb{A}$-sector and each $\mathbb{A}$-farmer uses one unit of land, the total $\mathbb{A}$-product in region 0 is $Q_0^A = G_0$. Given that $w_0 = 1$, (10) yields $R_0 = p_0^A - c^A$. Using (26), total factor income in region 0 is $Y_0 = L_0 + G_0(p_0^A - c^A)$. In region 2, because $R_1 = 0$ by assumption, we have $Y_1 = L_1 w_1$. Using (2), market clearing of $\mathbb{A}$-product in region 0 becomes

$$G_0 = \frac{\alpha^A \left(L_0 - c^A G_0\right)}{p_0^A} + \alpha^A G_0.$$

Solving this equation for p_0^A, we obtain

$$p_0^{A^*} = \frac{\alpha^A}{1-\alpha^A}\frac{L_0 - c^A G_0}{G_0}.$$

Substituting $p_0^{A^*}$ in (10), equilibrium land rent in region 0 is

$$R_0^* = \frac{1}{1-\alpha^A}\left(\alpha^A \frac{L_0}{G_0} - c^A\right).$$

Workers in region 0 denoted as L_0 are employed in either $\mathbb{A}$-sector or $\mathbb{M}$-sector. Using (22) and (24), the labor market clears at $c^A Q_0^A + n_0^M c^M \sigma^M f^M = L_0$. Substituting G_0 for Q_0^A, we obtain the equilibrium size of $\mathbb{M}$-product variety produced in region 0:

$$n_0^{M^*} = \frac{L_0 - c^A G_0}{c^M \sigma^M f^M}.$$

Using (8), (12), (13), (19), and Y_0 and Y_1 as specified above, the market clearing of $\mathbb{M}$-product becomes

$$\frac{c^M \sigma^M f^M}{\alpha^M} n_0^{M^*} = L_0 + G_0(p_0^{A^*} - c^A) + L_1 w_1.$$

Substituting $p_0^{A^*}$ and $n_0^{M^*}$, we obtain

$$w_1^* = \frac{\alpha^B}{\alpha^M\left(1-\alpha^A\right)}\frac{L_0 - c^A G_0}{L_1}.$$

Given these results, Y_0 and Y_1 are specified as

$$Y_0^* = \frac{L_0 - c^A G_0}{1-\alpha^A},\ Y_1^* = \frac{\alpha^B}{\alpha^M}\frac{L_0 - c^A G_0}{1-\alpha^A}.$$

Because $R_1 = 0$ by assumption, $p_1^{A^*} = c^A w_1^*$ in zero-profit. Using this for (2) we get the equilibrium production of $\mathbb{A}$-product in each sub-region of region 1 as

$$Q_1^{A^*} = \frac{\alpha^A L_1}{mc^A}$$

The labor market in each sub-region in region 1 clears at

$$c^A Q_1^A + n_1^B c^B \sigma^B f^B = \frac{L_1}{m}.$$

By substituting $Q_1^{A^*}$, we get the equilibrium size of $\mathbb{B}$-product variety produced in each sub-region of region 1:

$$n_1^{B^*} = \frac{\left(1-\alpha^A\right) L_1}{mc^B \sigma^B f^B}.$$

Using the foregone results, price indices given by (28) - (31) are specified as follows:

$$P_0^B = T^B \frac{\alpha^B}{\alpha^M} \frac{\left(\sigma^B f^B\right)^{1/\left(\sigma^B-1\right)}}{\rho^B} \left(L_0 - c^A G_0\right) \left(\frac{c^B}{\left(1-\alpha^A\right) L_1}\right)^{1/\rho^B},$$

$$P_1^B = \left(\frac{(m-1)\left(T^B\right)^{-2\left(\sigma^B-1\right)}+1}{m}\right)^{-1/\left(\sigma^B-1\right)} \frac{\alpha^B}{\alpha^M} \frac{\left(\sigma^B f^B\right)^{1/\left(\sigma^B-1\right)}}{\rho^B} \left(L_0 - c^A G_0\right) \left(\frac{c^B}{\left(1-\alpha^A\right) L_1}\right)^{1/\rho^B},$$

$$P_0^M = \left(\frac{L_0 - c^M G_0}{c^M \sigma^M f^M}\right)^{-1/\left(\sigma^M-1\right)} \frac{c^M}{\rho^M},$$

$$P_1^M = T^M \left(\frac{L_0 - c^A G_0}{c^M \sigma^M f^M}\right)^{-1/\left(\sigma^M-1\right)} \frac{c^M}{\rho^M}.$$

Finally, using (32) and (33), we obtain respectively (38), the real wage in the core, and (39), that in the periphery.

Appendix 2: Derivation of the market clearing solutions for pattern (b)

Agricultural trade of pattern (b) and the assumption of $R_1 = 0$ imply that $p_0^A = p_1^A T^A = c^A w_1 T^A$. Using this in the market clearing condition of $\mathbb{M}$-product with $n_0^{M^*}$ obtained in Appendix 1, we get

$$w_1^* = \frac{1-\alpha^M}{\alpha^M} \frac{L_0 - c^A G_0}{L_1 + c^A G_0 T^A}.$$

Thus, we can specify

$$p_0^{A^*} = c^A \frac{1-\alpha^M}{\alpha^M} \frac{L_0 - c^A G_0}{L_1 + c^A G_0 T^A} T^A,\ p_1^{A^*} = c^A \frac{1-\alpha^M}{\alpha^M} \frac{L_0 - c^A G_0}{L_1 + c^A G_0 T^A}.$$

Substituting this into (10), we obtain the equilibrium rent in region 0:

$$R_0^* = c^A\left(\frac{1-\alpha^M}{\alpha^M}\frac{L_0 - c^A G_0}{L_1 + c^A G_0 T^A}T^A - 1\right).$$

In pattern (b), agricultural demand given by (2) in region 0 is satisfied by the local production $Q_0^A = G_0$ and import of 𝔸-product from each sub-regions in region 1 denoted by Q_{10}^A. Provided that $Y_0 = L_0 + G_0 R_0$, the market clearing of 𝔸-product in region 0 becomes

$$G_0 + mQ_{10}^A = \frac{\alpha^A\left(L_0 - c^A G_0\right)}{p_0^A} + \alpha^A G_0.$$

Substituting $p_0^{A^*}$ into this, we obtain the import of 𝔸-product from region 1 to region 0:

$$mQ_{10}^A = \frac{1}{1-\alpha^M}\left[\left(\frac{\alpha^A \alpha^M L_1}{c^A T^A}\right) - \alpha^B G_0\right].$$

Provided that $Y_1 = L_1 w_1$, the 𝔸-product output in each sub-region of region 1 is either consumed locally or exported to region 0. This relationship yields the equilibrium output:

$$Q_1^{A^*} = \frac{\alpha^A\left(L_1/m\right)w_1}{p_1^A} + Q_{10}^A T^A = \frac{1}{\left(1-\alpha^M\right)m}\left(\alpha^A \frac{L_1}{c^A} - \alpha^B G_0 T^A\right)$$

Substituting w_1^*, $p_1^{A^*}$, and $Q_1^{A^*}$ into the labor market clearing condition (25), we get

$$n_1^{B^*} = \frac{\alpha^B}{1-\alpha^M}\frac{L_1 + c^A G_0 T^A}{mc^B \sigma^B f^B}.$$

Using R_0^* and w_1^*, we obtain Y_0 and Y_1:

$$Y_0 = \frac{\left(L_0 - c^A G_0\right)\left(\alpha^M L_1 + c^A G_0 T^A\right)}{\alpha^M\left(L_1 + c^A G_0 T^A\right)},$$

$$Y_1 = \frac{\left(L_0 - c^A G_0\right)\left(1-\alpha^M\right)L_1}{\alpha^M\left(L_1 + c^A G_0 T^A\right)}.$$

Using the foregone results, price indices given by (28) and (29) are specified as follows:

$$P_0^B = T^B \frac{L_0 - c^A G_0}{\alpha^M}\frac{\left(\sigma^B f^B ? \alpha^B\right)^{1/\left(\sigma^B - 1\right)}}{\rho^B}\left(\frac{\left(1-\alpha^M\right)c^B}{L_1 + c^A G_0 T^A}\right)^{1/\rho^B}$$

$$P_1^B = \left(\frac{(m-1)\left(T^B\right)^{-2\left(\sigma^B-1\right)} + 1}{m}\right)^{-1/\left(\sigma^B-1\right)}\frac{L_0 - c^A G_0}{\alpha^M}\frac{\left(\sigma^B f^B/\alpha^B\right)^{1/\left(\sigma^B-1\right)}}{\rho^B}\left(\frac{\left(1-\alpha^M\right)c^B}{L_1 + c^A G_0 T^A}\right)^{1/\rho^B}$$

Note that the price indices of $\mathbb{M}$-products are the same as those obtained in Annex 1 for pattern (a).

Finally, using (32) and (33), we obtain respectively (44), the real wage in the core; and

$$\omega_1 = \left(\alpha^M\right)^{-\alpha^M} \left(c^A\right)^{-\alpha^A} \left(L_0 - c^A G_0\right)^{\alpha^M/\rho^M} \left(\frac{L_1 + c^A G_0 T^A}{1-\alpha^M}\right)^{\alpha^B/\left(\sigma^B-1\right)-\alpha^M}$$
$$\times \left\{\frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M-1\right)}\left(c^M\right)^{1/\rho^M}}\right\}^{\alpha^M} \left\{\left(\frac{\alpha^B}{\sigma^B f^B}\right)^{1/\left(\sigma^B-1\right)} \frac{\rho^B}{\left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B}$$
$$\times \left\{\frac{(m-1)\left(T^B\right)^{-2\left(\sigma^B-1\right)}+1}{m}\right\}^{\alpha^B/\left(\sigma^B-1\right)} \left(T^M\right)^{-\alpha^M}$$

for the periphery. Setting $m \to \infty$, we obtain (45).

Appendix 3: Derivation of the market potential function of $\mathbb{B}$-sector in region 0

Define $\Omega_0^B \equiv x_0 / x^*$. Using (12) and (13), the total sales is

$$x_0 = \frac{\left(\rho^B\right)^{\sigma^B}}{c^B + R_0}\left[\frac{\alpha^B Y_0\left(P_0^B\right)^{\sigma^B-1}}{\left(c^B+R_0\right)^{\sigma^B-1}} + \frac{\alpha^B Y_1\left(P_1^B\right)^{\sigma^B-1}}{\left[\left(c^B+R_0\right)T^B\right]^{\sigma^B-1}}\right].$$

where Y_0 is the income of the core and Y_1 the total income of m sub-regions in the periphery. Substitution of (14) yields

$$\Omega_0^B = \frac{\left(\rho^B\right)^{\sigma^B}}{\left(c^B+R_0\right) f^B\left(\sigma^B-1\right)}\left[\frac{\alpha^B Y_0\left(P_0^B\right)^{\sigma^B-1}}{\left(c^B+R_0\right)^{\sigma^B-1}} + \frac{\alpha^B Y_1\left(P_1^B\right)^{\sigma^B-1}}{\left[\left(c^B+R_0\right)T^B\right]^{\sigma^B-1}}\right].$$

Using (7), we obtain

$$\Omega_0^B = \frac{\alpha^B}{n_1^B \sigma^B f^B (c^B + R_0)}\left(\frac{c^B w_1}{c^B+R_0}\right)^{\sigma^B-1}\left[Y_0 + \frac{m}{\left(T^B\right)^{2\left(\sigma^B-1\right)}+(m-1)}Y_1\right]\frac{\left(T^B\right)^{\sigma^B-1}}{m}.$$

Next, the potential function of $\mathbb{B}$-sector in region 1 is given by

$$\Omega_1^B \equiv \frac{x_1}{x^*} = \frac{\alpha^B}{n_1^B \sigma^B f^B (c^B w_1)}\frac{Y_0+Y_1}{m}.$$

Since it must always hold that $\Omega_1^B = 1$ in equilibrium, we have $\Omega_0^B = \Omega_0^B / \Omega_1^B$. Substitution of the results above yields

$$\Omega_0^B = \frac{f^B(c^B w_1)}{f^B(c^B+R_0)}\left(\frac{c^B w_1 T^B}{c^B+R_0}\right)^{\sigma^B-1} \frac{Y_0 + mY_1 \Big/ \left[\left(T^B\right)^{2\left(\sigma^B-1\right)} + (m-1)\right]}{Y_0+Y_1}.$$

Appendix 4: Derivation of the potential function of $\mathbb{M}$-sector in region 1

Define $\Omega_1^M \equiv q_1 / q^*$. Using (17) and (18), the total sales of the $\mathbb{M}$-product produced in region 1 is given by

$$\widehat{q}_1 = \frac{\left(\rho^M\right)^{\sigma^N}}{w_1 c^M}\left[\frac{\alpha^M Y_0 \left(P_0^M\right)^{\sigma^M-1}}{\left(w_1 c^M T^M\right)^{\sigma^M-1}} + \frac{\left(\alpha^M Y_1/m\right)\left(P_1^M\right)^{\sigma^M-1}}{\left(w_1 c^M\right)^{\sigma^M-1}} + \frac{(m-1)\left(\alpha^M Y_1/m\right)\left(P_1^M\right)^{\sigma^M-1}}{\left[w_1 c^M \left(T^M\right)^2\right]^{\sigma^M-1}}\right].$$

Substitution of this for q_1 and (19) for q^* yields

$$\Omega_1^M = \frac{\left(\rho^M\right)^{\sigma^M}}{w_1 c^M f^M \left(\sigma^M-1\right)}\left[\frac{\alpha^M Y_0 \left(P_0^M\right)^{\sigma^M-1}}{\left(w_1 c^M T^M\right)^{\sigma^M-1}}\right.$$

$$\left. + \frac{\alpha^M \left(Y_1/m\right)\left(P_1^M\right)^{\sigma^M-1}}{\left(w_1 c^M\right)^{\sigma^M-1}} + \frac{(m-1)\alpha^M \left(Y_1/m\right)\left(P_1^M\right)^{\sigma^M-1}}{\left(w_1 c^M \left(T^M\right)^2\right)^{\sigma^M-1}}\right]$$

Using (8), we get

$$\Omega_1^M = \frac{\alpha^M}{n_0^M \sigma^M f^M c^M w_1}\left(\frac{c^M}{w_1 c^M T^M}\right)^{\sigma^M-1}\left[Y_0 + Y_1 \frac{\left(T^M\right)^{2\left(\sigma^M-1\right)} + (m-1)}{m}\right]$$

The potential function of $\mathbb{M}$-sector in region 0 is given by

$$\Omega_0^M = \frac{\left(\rho^M\right)^{\sigma^M}}{c^M f^M \left(\sigma^M-1\right)}\left[\frac{\alpha^M Y_0 \left(P_0^M\right)^{\sigma^M-1}}{\left(c^M\right)^{\sigma^M-1}} + \frac{\alpha^M Y_1 \left(P_1^M\right)^{\sigma^M-1}}{\left(c^M T^M\right)^{\sigma^M-1}}\right]$$

$$= \frac{\alpha^M \left(Y_0+Y_1\right)}{n_0^M \sigma^M c^M f^M}.$$

Because it must always hold that $\Omega_0^M = 1$ in equilibrium, we have $\Omega_1^M = \Omega_1^M / \Omega_0^M$. Substitution of above results yields

$$\Omega_1^M = \left(w_1\right)^{-\sigma^M} \left(T^M\right)^{-\left(\sigma^M-1\right)} \frac{Y_0 + Y_1\left[\left(T^M\right)^{2\left(\sigma^M-1\right)} - 1 + m\right]\Big/ m}{Y_0 + Y_1}.$$

Appendix 5: Description of Figure 2

In (58), as $\lim_{L_0\to\infty}\left\{\left(L_0 - c^B G_0\right)\Big/\left(L_0 - c^A G_0\right)\right\} = 1$, we get

$$\lim_{L_0\to\infty} F^{B(a)}\left(L_0\right) = \left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} \frac{\alpha^B}{\alpha^A\alpha^M} c^B G_0.$$

Thus, $F^{B(a)}\left(L_0\right)$ asymptotically approaches $L_1 = \left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}\left[\alpha^B\Big/\left(\alpha^A\alpha^M\right)\right]c^B G_0$. We also depict the line $L_1 = T^A\left[\alpha^B\Big/\left(\alpha^A\alpha^M\right)\right]c^A G_0$, which delimits pattern (a) and (b) as indicated by (50) and (54). Note that the intersection of $F^{B(a)}\left(L_0\right)$ and $L_0 = c^A G_0\big/\alpha^A$ is given at

$$L_1 = \left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} \frac{\alpha^B}{\alpha^A\alpha^M} c^A G_0 > \left(T^A\right)^{-1} \frac{\alpha^B}{\alpha^A\alpha^M} c^A G_0.$$

Thus, hereafter, we drop the first inequality in (50). All loci of $F^{M(a)}\left(L_0\right)$ - $F^{M(b)}\left(L_0\right)$, $F^{B(b)}\left(L_0\right)$ - $F^{B(b)}\left(L_0\right)$, $F^{R(a)}\left(L_0\right)$ - $F^{R(b)}\left(L_0\right)$ have intersections on this line. The line of $F^{B(b)}\left(L_0\right)$ is not drawn in case I and II because of $F^{B(b)}\left(L_0\right) < 0$ for all L_0 if $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} < \left(c^A/c^B\right)T^A$. Figure 2 depicts location equilibrium conditions (51), (52), (55), (56), and (57), respectively corresponding to $F^{B(a)}\left(L_0\right)$, $F^{M(a)}\left(L_0\right)$, $F^{B(b)}\left(L_0\right)$, $F^{M(b)}\left(L_0\right)$ and $F^{R(b)}\left(L_0\right)$. Furthermore, we have (53), which assures full use of land in region 0 under pattern (a).

The graph of $F^{R(b)}\left(L_0\right)$ is characterized by

$$F^{R(b)\,\prime} = T^A \frac{1-\alpha^M}{\alpha^M} > 0,\ F^{R(b)}\left(L_0 = c^A G_0\right) = -c^A G_0 T^A, \text{ and}$$

$$F^{R(b)}\left(L_0 = \frac{c^A G_0}{\alpha^A}\right) = T^A \frac{\alpha^B}{\alpha^M}\frac{c^A G_0}{\alpha^A}$$

The graph of $F^{B(a)}\left(L_0\right)$ is characterized by

$$F^{B(a)\,\prime} > 0,\ F^{B(a)\,\prime\prime} < 0,\ F^{B(a)\,\prime}\left(L_0 = c_A G_0\right) = \left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} \frac{\alpha^B}{\alpha^M\left(1-\alpha^A\right)}\frac{c^B}{c^B - c^A},$$

$$F^{B(a)}\left(L_0 = c^A G_0\right) = 0,\ F^{B(a)}\left(L_0 = \infty\right) = \left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} \frac{\alpha^B}{\alpha^A\alpha^M} c^B G_0.$$

The graph of $F^{B(b)}\left(L_0\right)$ is characterized by

$$F^{B(b)\prime}=\frac{c^B}{c^B-c^A}\frac{1-\alpha^M}{\alpha^M}\left[\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}-\frac{c^A}{c^B}T^A\right],\ F^{B(b)}\left(L_0=c^AG_0\right)=-c^AG_0T^A,\ \text{and}$$

$$F^{B(b)\prime}\overset{<}{\underset{>}{=}}0 \iff \left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}\overset{<}{\underset{>}{=}}\frac{c^A}{c^B}T^A.$$

This implies that $F^{B(b)}\left(L_0\right)<0$ for all $L_0>c^AG_0$ if $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}<\left(c^A/c^B\right)T^A$. Hence, $F^{B(b)}$ is not drawn in cases I and II of Figure 2 because it is not binding. For a given T^A, cases I and II (III and IV) represent relatively low (high) T^B. In cases III and IV, i.e., $\left(c^A/c^B\right)T^A<\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}$, we have the intersection of $F^{B(a)}\left(L_0\right)$ and $F^{B(b)}\left(L_0\right)$ at

$$L_0=\left\{1+\frac{1-\alpha^A}{\alpha^A}\frac{c^B-c^A}{c^B\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}\left(T^A\right)^{-1}-c^A}\right\}c^AG_0.$$

Thus, for cases III and IV to hold in location equilibrium (73) must be larger than c^AG_0/α^A. This yields

$$\frac{c^A}{c^B}T^A<\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}<T^A$$

The graphs of both $F^{M(a)}\left(L_0\right)$ and $F^{M(b)}\left(L_0\right)$ are positive lines characterized by

$$F^{M(a)\prime}=\left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}\frac{\alpha^B}{\alpha^M\left(1-\alpha^A\right)}>0,\ F^{M(a)}\left(c^AG_0\right)=0,\ \text{and}$$

$$F^{M(b)\prime}=\left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}\frac{1-\alpha^M}{\alpha^M}>F^{M(a)\prime}\left(L_0\right),\ F^{M(b)}\left(c^AG_0\right)=-c^AG_0T^A.$$

We have the intersection of $F^{M(a)}\left(L_0\right)$ and $F^{M(b)}\left(L_0\right)$ at

$$L_0=\left\{1+\frac{1-\alpha^A}{\alpha^A}T^A\left(T^M\right)^{-\left(\sigma^M-1\right)/\sigma^M}\right\}c^AG_0.$$

It follows that (74) is greater than c^AG_0/α^A and $F^{M(b)}$ is located below $F^{R(b)}\left(L_0\right)$ as illustrated by cases II and IV if $T^A>\left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$. For a given T^A, cases I and III (resp., II and IV) represent relatively high (resp., low) T^M. Particularly in case IV, (74) must be less than (73) for the existence of spatial equilibrium (shaded areas), which requires

$$\left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}>\frac{c^B\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B}-c^AT^A}{c^B-c^A}.$$

Appendix 6: Proof of Proposition 3

First, we examine the impact of T^B change on ω_1^*. Equation (69) can be rewritten as

$$\omega_1^* = C_1\left(\bar{L} - L_1^* - c^A G_0\right)^{\alpha^M/\rho^M}\left(L_1^* + c^A G_0 T^A\right)^{\alpha^B/\left(\sigma^B-1\right)-\alpha^M}\left(T^B\right)^{-2\alpha^B},$$

where C_1 represents all terms in (69) that are independent of T^B:

$$C_1 = \left(\alpha^M\right)^{-\alpha^M}\left(c^A\right)^{-\alpha^A}\left(\frac{1}{1-\alpha^M}\right)^{\alpha^B/\left(\sigma^B-1\right)-\alpha^M}\left\{\frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M-1\right)}\left(c^M\right)^{1/\rho^M}}\right\}^{\alpha^M}$$

$$\times\left\{\left(\frac{\alpha^B}{\sigma^B f^B}\right)^{1/\left(\sigma^B-1\right)}\frac{\rho^B}{\left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B}\left(T^M\right)^{-\alpha^M}.$$

Hence, using (66), we can obtain that

$$\frac{\mathrm{d}\ln\omega_1^*}{\mathrm{d}T^B} = -\frac{\alpha^B}{T^B}\left\{2 - \frac{K_b}{\alpha^M/\left(1-\alpha^M\right)+K_b}\left[\frac{\alpha^M}{\rho^M} + \frac{L^{M^*}}{L_1^* + c^A G_0 T^A}\left(\alpha^M - \frac{\alpha^B}{\sigma^B-1}\right)\right]\right\}.$$

where K_b is given in (66). Since $L^{M^*} \equiv \bar{L} - L_1^* - c^A G_0$, using (66), we obtain

$$L^{M^*} = \left(1 + \left[\left(1-\alpha^M\right)/\alpha^M\right]K_b\right)^{-1}\left(\bar{L} - \left(T^A - 1\right)c^A G_0\right)$$

and

$$\frac{L^{M^*}}{L_1^* + c^A G_0 T^A} = \frac{1}{K_b}$$

Notice that the left-hand side is independent of $\bar{L}$. Substituting (76) into (75), we can see that

$$\frac{\mathrm{d}\ln\omega_1^*}{\mathrm{d}T^B} < 0 \text{ iff } 2 > \frac{K_b}{\alpha^M/\left(1-\alpha^M\right)+K_b}\left[\frac{\alpha^M}{\rho^M} + \frac{1}{K_b}\left(\alpha^M - \frac{\alpha^B}{\sigma^B-1}\right)\right].$$

or

$$\frac{\mathrm{d}\ln\omega_1^*}{\mathrm{d}T^B} < 0 \text{ iff } 0 > K_b\left(\frac{\alpha^M}{\rho^M} - 2\right) - \frac{1+\alpha^M}{1-\alpha^M}\alpha^M - \frac{\alpha^B}{\sigma^B-1}.$$

Since $\frac{\mathrm{d}\ln\omega_1^*}{\mathrm{d}T^B} = \frac{1}{\omega_1^*}\cdot\frac{\mathrm{d}\omega_1^*}{\mathrm{d}T^B}$, we can conclude that (70) holds for pattern (b).

Next, we examine the impact of σ^B change on ω^*. Notice that L_1^* given by (66) is independent of parameters σ^B and ρ^B. Hence, we can rewrite (69) as follows:

$$\omega_1^* = C_2\left(\frac{L_1^* + c^A G_0 T^A}{1-\alpha^M}\right)^{\alpha^B/\left(\sigma^B-1\right)-\alpha^M}\left\{\left(\frac{\alpha^B}{\sigma^B f^B}\right)^{1/\left(\sigma^B-1\right)}\frac{\rho^B}{\left(c^B\right)^{1/\rho^B}}\right\}^{\alpha^B},$$

where C_2 represents all terms in (69) that are independent of parameters σ^B and ρ^B:

$$C_2 = \left(\alpha^M\right)^{-\alpha^M} \left(c^A\right)^{-\alpha^A} \left(L_0 - c^A G_0\right)^{\alpha^M/\rho^M} \left\{ \frac{\rho^M}{\left(\sigma^M f^M\right)^{1/\left(\sigma^M - 1\right)} \left(c^M\right)^{1/\rho^M}} \right\}^{\alpha^M}$$

$$\times \left(T^B\right)^{-2\alpha^B} \left(T^M\right)^{-\alpha^M} .$$

The impact of σ^B change on ω_1^* is given by that

$$\frac{\mathrm{d}\ln\omega_1^*}{\mathrm{d}\sigma^B} = -\frac{\alpha^B}{\left(\sigma^B - 1\right)^2} \cdot \ln\left[\frac{\alpha^B\left(L_1^* + c^A G_0 T^A\right)}{\left(1-\alpha^M\right) c^B \sigma^B f^B}\right]$$

$$= -\frac{\alpha^B}{\left(\sigma^B - 1\right)^2} \cdot \ln\left[\frac{\alpha^B}{c^B \sigma^B f^B} \frac{K_b\left(\overline{L} - c^A G_0\left(T^A - 1\right)\right)}{\alpha^M + \left(1-\alpha^M\right) K_b}\right].$$

Since $\frac{\mathrm{d}\ln\omega_1^*}{\mathrm{d}\sigma^B} = \frac{1}{\omega_1^*} \cdot \frac{\mathrm{d}\omega_1^*}{\mathrm{d}\sigma^B}$, we can conclude for pattern (b) that

$$\frac{\mathrm{d}\omega_1^*}{\mathrm{d}\sigma^B} < 0 \text{ iff } \frac{\alpha^B}{c^B \sigma^B f^B} \frac{K_b\left(\overline{L} - c^A G_0\left(T^A - 1\right)\right)}{\alpha^M + \left(1-\alpha^M\right) K_b} > 1.$$

Hence, rearranging terms, we obtain (72).

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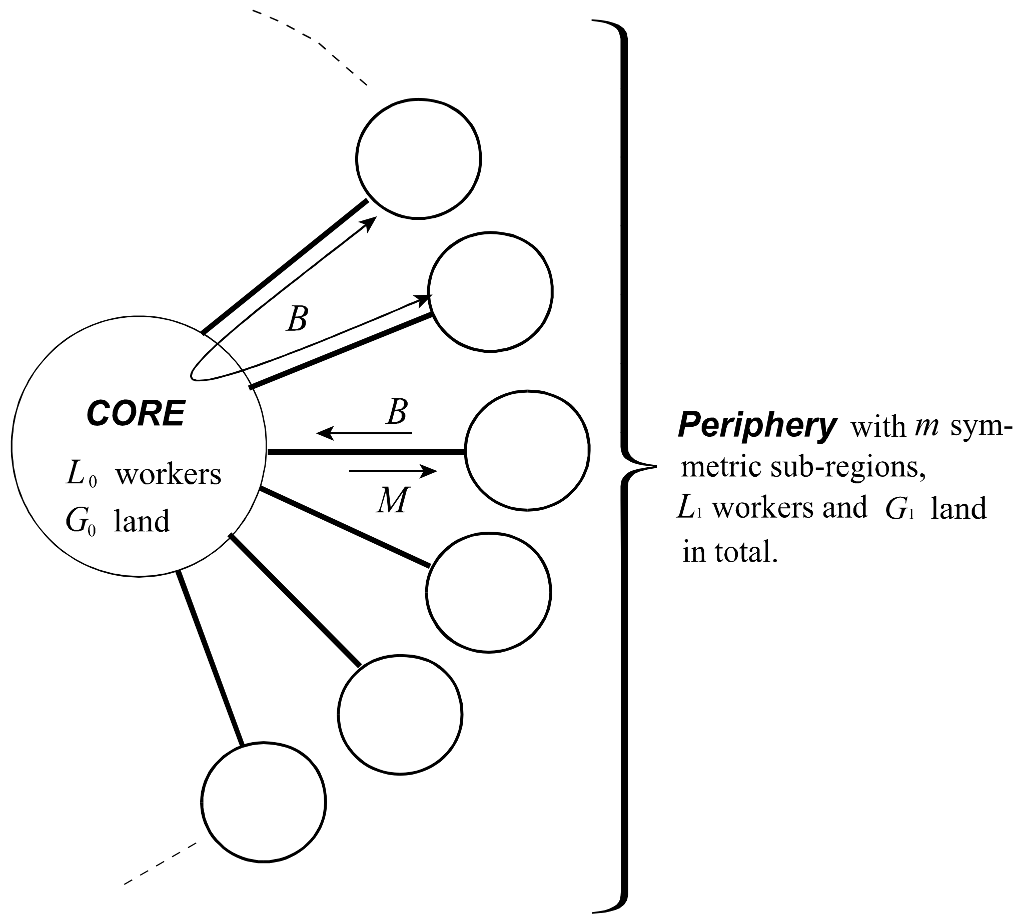
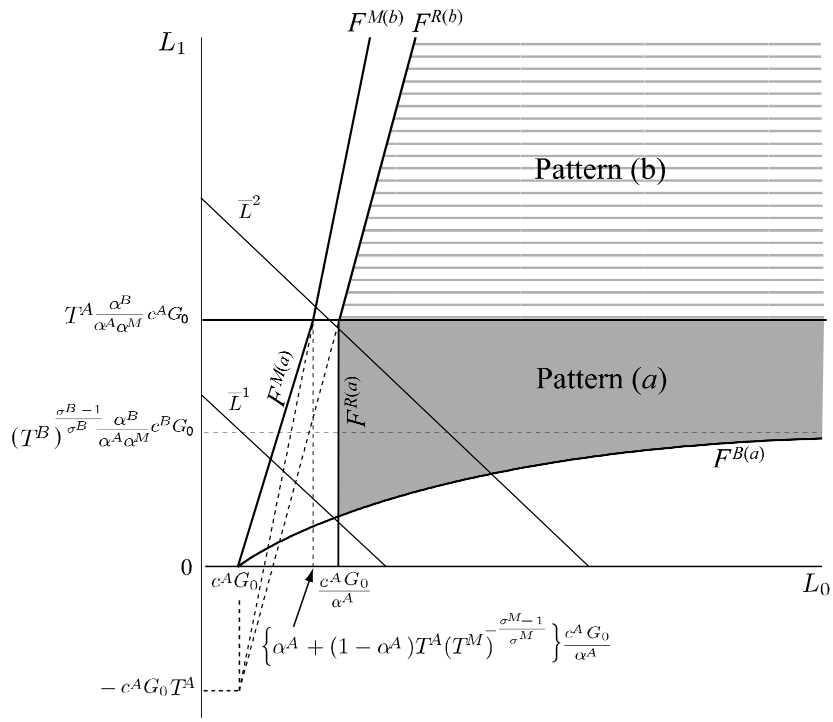
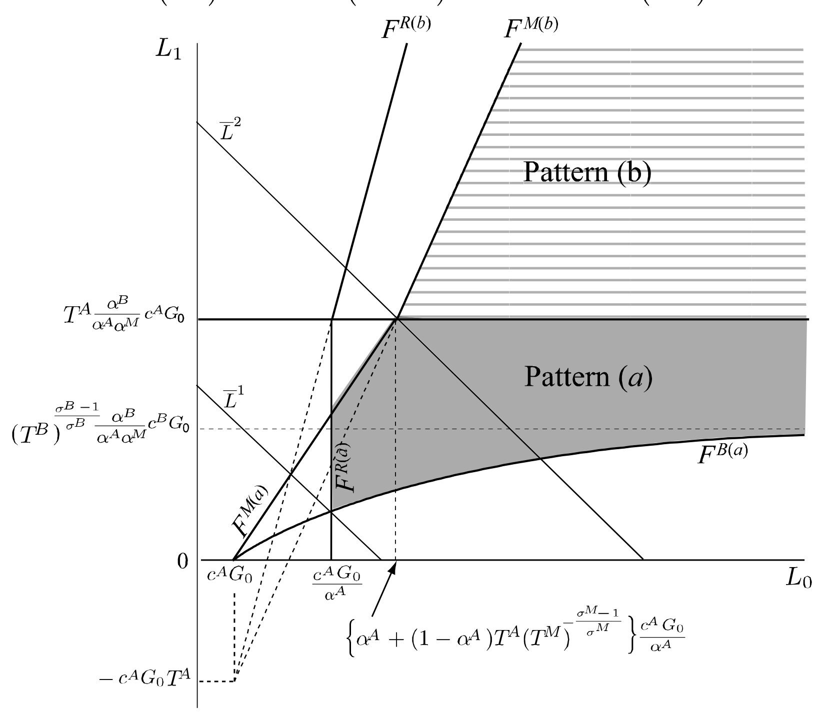


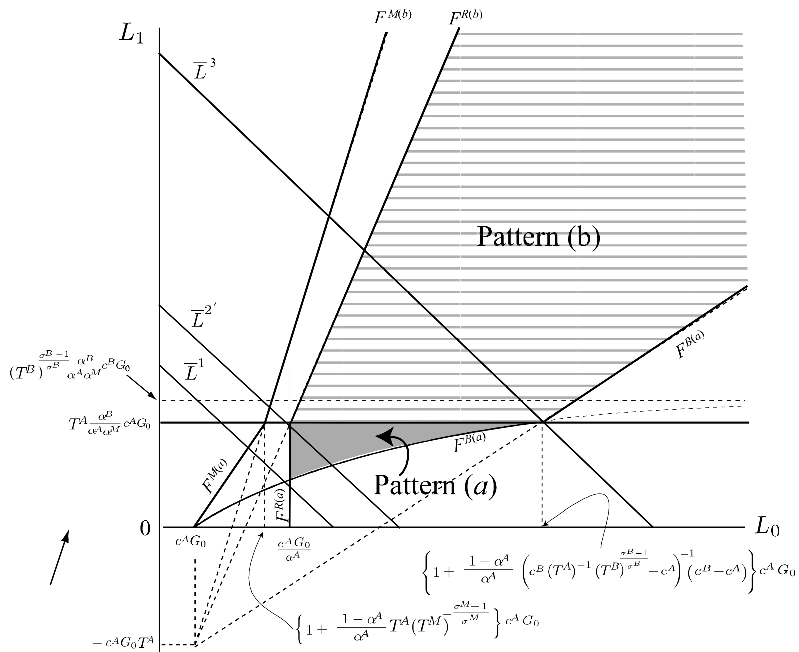
Figure 1: Core-periphery economy with the hub-and-spoke transport system



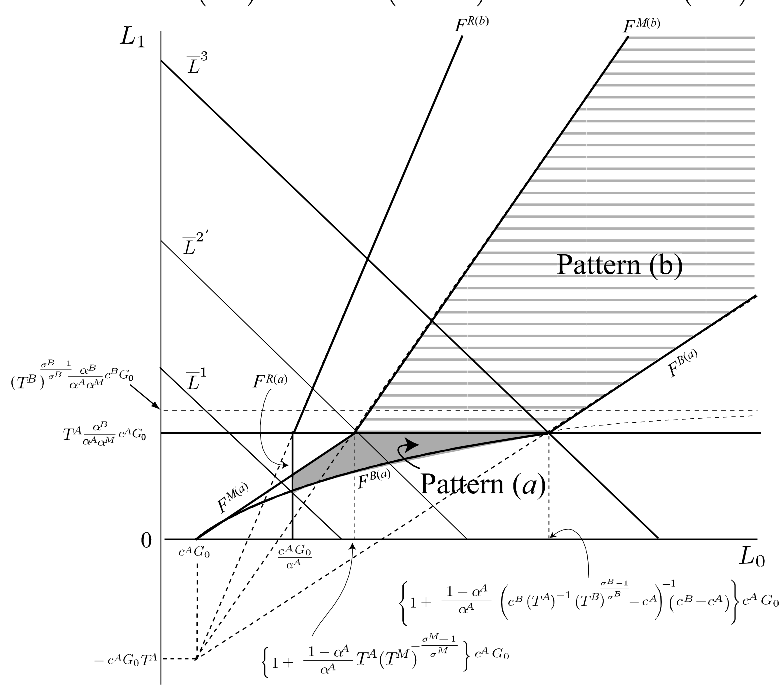
(i) Case I. $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} < \left(c^A/c^B\right)T^A$ and $T^A < \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$



(ii) Case II. $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} < \left(c^A/c^B\right)T^A$ and $T^A > \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$



(iii) Case III. $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} > \left(c^A/c^B\right)T^A$ and $T^A < \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$



(iv) Case IV. $\left(T^B\right)^{\left(\sigma^B-1\right)/\sigma^B} > \left(c^A/c^B\right)T^A$ and $T^A > \left(T^M\right)^{\left(\sigma^M-1\right)/\sigma^M}$

Figure 2: Spatial equilibrium with immobile workers

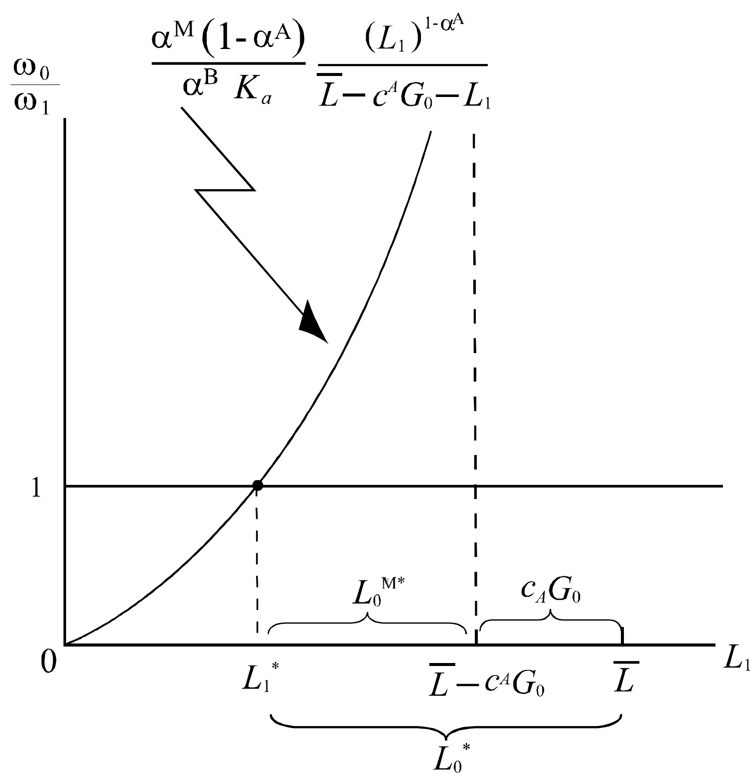


Figure 3. Population distribution in spatial equilibrium of pattern(a) with mobile workers

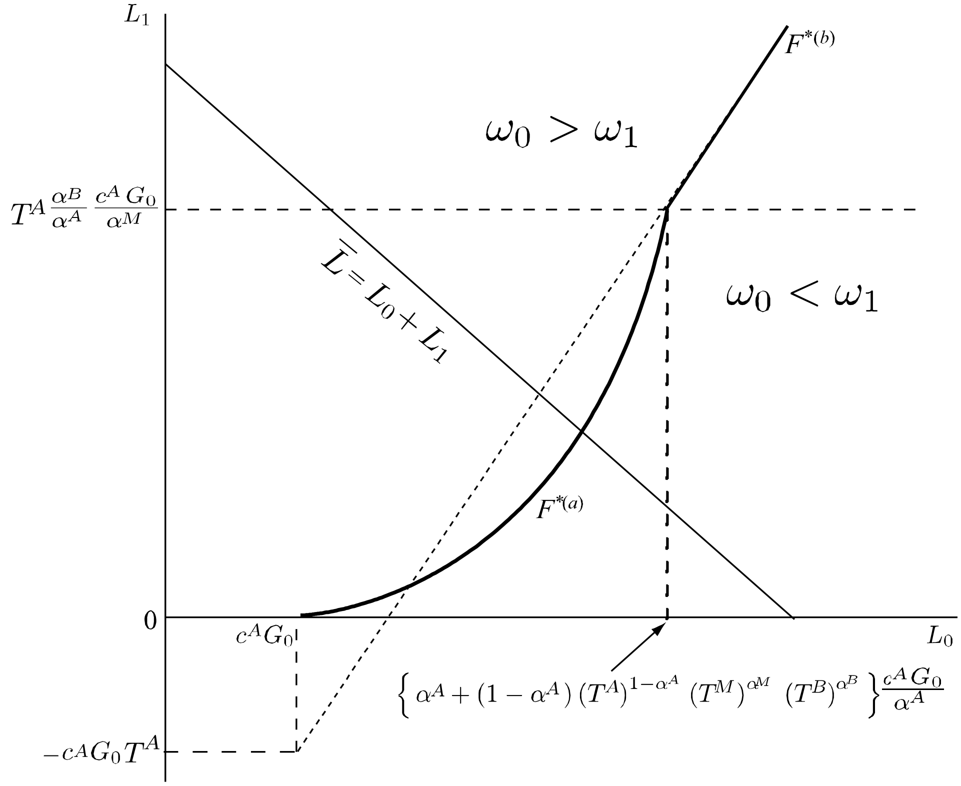


Figure 4. Spatial equilibrium with mobile workers