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**The location of manufacturing firms
and imperfect information in
transport market**

Toshitaka GOKAN*

Abstract

It is well known that transport charges are not symmetric: fronthaul and backhaul costs on a route may differ, because they are affected by the distribution of economic activities. This paper develops a two-regional general equilibrium model in which transport costs are determined endogenously as a result of a search and matching process. It is shown that economies or diseconomies of transport density emerge, depending on the search costs of transport firms and the relative importance of the possibility of backhaul transportation. It is found that the symmetry of the distribution of economic activity may break owing to economies of transport density when the additional search costs are small enough.

Keywords: transport sector, new economic geography, imperfect competition, imperfect information

JEL classification: F12, R12, R49

* Researcher, IDE (toshitaka_gokan@ide.go.jp)

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INSTITUTE OF DEVELOPING ECONOMIES (IDE), JETRO
3-2-2, WAKABA, MIHAMA-KU, CHIBA-SHI
CHIBA 261-8545, JAPAN

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1. Introduction

North (1958) pointed out that “When one focuses on freight rates and their immediate effect upon economic change, it is all too easy to lose sight of the larger context of which the costs of ocean transportation were only a part. The fall in freight rates, it is true, was essential to an international economy, but the fall itself was a result of the expansion of trade...”. In the overall framework of New Economic Geography (NEG), it has been shown that the spatial configuration of economic activity depends on the balance between agglomeration forces and dispersion forces. To avoid complication, typical NEG models utilize exogenous and symmetric transport costs over a route to determine the balance between two forces. However, some analysis in NEG have used endogenous or asymmetric transport costs. Mori and Nishikimi (2002) examined the effect of economies of transport density on the interdependence between industrial location behavior and the transport network, while Behrens and Gaigne (2006) and Behrens, Gaigne, Ottaviano and Thisse (2006) examined the effect of (dis) economies of transport density. In these analyses, the relationship between transport costs and transport quantity is given exogenously. Behrens (2006) examined the effects of asymmetric but exogenous transport costs between two regions. Takahashi (2006) explicitly incorporated an endogenous transport sector and analyzed the adoption of modern transport technologies, such as highways or a high-speed train system. Behrens, Gaigne and Thisse (2009) considered profit-maximizing carriers and examined the relationships between transport costs, industry location and welfare. Their model is an extension of the model of Ottaviano, Tabuchi and Thisse (2002) in which quasi-linear utility is used. Takahashi (2011) also explicitly introduced carriers into a Krugman-Dixit-Stiglitz type model. Transport costs became higher in the binding direction (Takahashi 2011) or under the asymmetry of the distribution of manufacturing firms (Behrens, Gaigne and Thisse 2009).

In a different approach from that of NEG, some analyses have considered equilibrium transport charges, given the distribution of economic activity or peak and off-peak transport flow. Our paper is very close to the analysis of De Vany and Saving (1977) which built a model of a two-region competitive trucking industry with the greatest traffic flow in a region and derived equilibrium transport charges such that the full price of shipping a unit load for the fronthaul market is the marginal hauling cost plus the inventory holding costs in the fronthaul minus the inventory holding costs in the backhaul. De Vany and Saving (1977) counted the waiting time as a cost, so large traffic flow in a region lowered the cost of transport from the region. Furthermore, the imbalance of transport flow over a route was included in the transport charges from a region with a larger traffic flow. From historical cases, North (1958) pointed out that the existence of backhaul freight reduces freight rates. These points are well studied in empirical works and it is natural to incorporate these phenomena into an NEG model.

The purpose of this paper is to provide a micro foundation for both a transport market with imperfect information and the spatial distribution of manufacturing firms. That is, the distribution of manufacturing firms affects transport charges in transport markets and the transport charges affects the price of manufactured goods and also the distribution of manufacturing firms. Our setup is a combination of two existing models. For describing a transport market with imperfect information, we use monopolistic competition models

with search and matching process, such as those of Wolinsky (1983) and Anderson and Renault (1999), instead of directly adopting the model of De Vany and Saving (1977). The other model we use is a footloose capital model (Baldwin et.al. 2003 Ch. 5 and Ottaviano and Thisse 2004 Ch.58) in which the repatriation of capital returns to the owner is allowed. The original footloose capital model shows that, assuming symmetric regions, a symmetric distribution of firms is always an equilibrium but a core-periphery structure is not an equilibrium. This is only because the agglomeration of manufacturing firms causes harsh price competition. In our setting, endogenized transport costs lead to agglomeration forces or dispersion forces, depending on the circumstances of the transport market.

The rest of the paper is organized as follows. In Section 2 the model is described. In Section 3 the properties of variables for a given distribution of capital are examined. In Section 4 the spatial equilibrium is established and characterized. Finally, in Section 5 some concludes are given.

2. Model

The economy involves three sectors (agriculture, manufacturing and transport), two production factors (labor and capital) and two regions (1 and 2). The world population is perfectly inelastic and equal to L ; the world supply of capital is also perfectly inelastic and equal to K . Owners of capital provide labor inputs. Half of the labor and half of the capital are in each region. Consumers are immobile but, in contrast, capital is mobile between regions. More precisely, the distribution of the owners of capital is exogenously given, but capital returns are repatriated to the owner when the distribution of the demand of capital is asymmetric between regions. Hence, the size of regional income is the same for both regions. Let s represent the share of capital used by manufacturing firms in region 1.

2.1. Preferences

Preferences over a homogeneous good and horizontally differentiated goods are shared among consumers, which is supposed to be symmetric in all varieties of manufactured goods. We assume that there is a continuum of firms so that an unknown manufacturing firm can be described by a density function. We also assume that the utility is quasi-linear and the subutility is quadratic. A consumer solves the following problem:

$$\max_{q_1(i), q_0} U \equiv \alpha \int_0^N q_1(i) di - \frac{\beta - \gamma}{2} \int_0^N [q_1(i)]^2 di - \frac{\gamma}{2} \left[\int_0^N q_1(i) di \right]^2 + q_0, \quad (1)$$

$$s.t. \quad \int_0^N p_1(i) q_1(i) di + p_0 q_0 = y_1 + \bar{q}_0 \quad (2)$$

where $q_1(i)$ and $p_1(i)$ represent the quantity and price of the consumption of variety $i \in [0, N]$ of manufactured goods, q_0 and p_0 the quantity and price of the consumption of the numéraire, y_1 is the individual income in region 1 and \bar{q}_0 is the initial endowment supposed to be sufficiently large for the equilibrium consumption of the numéraire to be positive. The restrictions of parameters in (1) are $\alpha > 0$, $\beta > \gamma > 0$. For a given value

of β , the parameter γ represents the substitutability between varieties: the higher γ , the closer the substitution.

In the following, we focus on region 1. Results for region 2 can be derived by symmetry. We focus on the case where individuals consume both the agricultural good and manufactured goods.

Each consumer inelastically supplies one unit of labor and earns the wage prevailing in her regional labor market. She also supplies one unit of capital in the country where she resides. The capital return she receives stems from competition among national entrepreneurs who want to launch a manufacturing firm.

From (1) and (2), we obtain the demand for variety $i \in [0, N]$ of manufactured goods in region 1:

$$q_1(i) = a - bp_1(i) + c \int_0^N [p_1(j) - p_1(i)] dj, \quad i \in [0, N] \quad (3)$$

where $a \equiv \alpha/[\beta + (N-1)\gamma]$, $b \equiv 1/[\beta + (N-1)\gamma]$, and $c \equiv \gamma/(\beta - \gamma)[\beta + (N-1)\gamma]$. Since we suppose the demand functions are symmetric for each variety, the prices of manufactured goods are also symmetric. Using this assumption and (3), the individual demand in region 1 faced by a representative manufacturing firm located in region 1 is

$$q_{11} = a - (b + cN)p_{11} + c[sp_{11} + (1 - s)p_{21}]N, \quad (4)$$

and the individual demand in region 2 faced by a manufacturing firm located in region 1 is

$$q_{12} = a - (b + cN)p_{12} + c[sp_{12} + (1 - s)p_{22}]N, \quad (5)$$

where p_{11} is the price in region 1 of manufactured goods produced locally, whereas p_{12} is the price of manufactured goods exported from region 1 to region 2. In all cases, if there are two subscripts, the former indicates the region where the goods are produced and the latter the region where the goods are consumed.

2.2. Consumption goods sector

There are two types of consumption goods. The first good is a homogenous agricultural good produced using a constant-returns technology under perfect competition. One unit of the agricultural good is produced by one unit of labor input. The agricultural good is assumed to be traded costlessly between regions. Assuming the agricultural good is produced in both regions, the choice of this good as the numéraire implies that, in equilibrium, the wage rates of agricultural workers and the prices of the agricultural good in both regions are one.

The second consumption goods consists of horizontally differentiated products by manufacturing firms. Each manufacturing product is produced with the increasing returns to scale technology under imperfect competition. A fixed m units of capital inputs are required to produce any quantity of a variety of manufactured goods and the marginal capital input is zero. Because of increasing returns to scale technology and no scope economies, there is a one-to-one relationship between manufacturing firms and varieties of manufactured goods.

Preferences of economic agents and the technology of firms in each sector are supposed to be identical across each variety. Manufacturing firms are able to segment markets, that is, each manufacturing firm has the ability to set a price specific to the market in which the product is sold. Since there is free entry and exit, the expected profits of a manufacturing firm are zero. We assume that there is a continuum N of manufacturing firms so that an unknown firm can be described by a density function. Given the foregoing assumptions, clearing of the capital market for manufactured goods in each region implies that

$$n_1^M = sK/m \quad n_2^M = (1 - s)K/m \quad (6)$$

where n_1^M is the number of manufacturing firm s in region 1 and s is the share of capital used by manufacturing firm s in region 1. To transport manufactured goods to the remote region, manufacturing firm s pay transport charge to transport firms, whereas transport within a region is assumed to be costless for simplicity. The profit of a manufacturing firm located in region 1, π_1^M , is

$$\pi_1^M = p_{11}q_{11}(p_{11})L/2 + (p_{12} - t_{12}) q_{12}(p_{12})L/2 - mr_1^M \quad (7)$$

where t_{12} is the charges for transportation of manufactured goods from region 1 to region 2 and r_1^M is the capital return used by manufacturing firms in region 1.

2.3. Transport sector

The transport sector consists of services horizontally differentiated by transport firms. Each service is provided using increasing returns to scale technology under imperfect competition. Because of increasing return to scale technology and no scope economies, there is also a one-to-one relationship between transport firms and varieties of transport services. Each transport firm requires a fixed one unit of numéraire inputs and some variable numéraire inputs. Transport firms are able to segment markets, that is, each transport firm has the ability to set a transport charge specific to the market in which the product is loaded onto transport equipment. Because there is free entry and exit, the profits of a transport firm are zero.

We assume non-strategic behavior by transport firms, which is implied by our assumption that a transport firm takes the total amount of transported goods to be given as they solve their profit maximization problem. We assume that transport firms load all amounts which manufacturing firms need to have transported. We may consider that this assumption express the case when all amount of load is in a unit of a container. Then, we may say that transport firms decide transport charges per container. Furthermore, manufacturing firms do not try to change the amount to be sent during their contact with transport firms. Hence, transport firms decide on their transport charge pre load, given the total number of loads. Owing to the law of large numbers, manufacturing firms and transport firms use expected transport costs in their profit function. Based on the expected value, manufacturing firms maximize their profits.

The interaction between transport firms and manufacturing firm s is expressed by applying the mechanism rigorously examined in Anderson and Renault (1999). Transport firms need to bear different additional adjustments costs, depending on the requests of each manufacturing firm and transport demand. Each manufacturing firm has specific

requests, such as time of collection and time of delivery. When transport firms can adjust to each manufacturing firm's specific requests easily or when they do not need to wait to start their transport, the match between a transport firm and a manufacturing firm is better and the transport firm can save additional costs such as inventory holding costs. Furthermore, transport firms may adjust transport charges to reduce the difference of costs between fronthaul transportation and backhaul transportation. Hence, we suppose that the sum of additional costs and hauling costs is given by $h - \mu\epsilon_{1i} - v\epsilon_{2i}$ where μ is a scale parameter for fronthaul that expresses the heterogeneity of the match between manufacturing firms and transport firms, and v is the corresponding scale parameter for backhaul. The parameter $\epsilon_{1i} \in [0, n_1^M]$ are a random variables for fronthaul that are independent and identically distributed across manufacturing firms and transport firms, with a common density function f and the corresponding distribution function F . Similarly, $\epsilon_{2i} \in [0, n_2^M]$ are random variables for backhaul. Larger values of ϵ_{1i} or ϵ_{2i} mean smaller adjustment costs. We suppose that h is large enough that $h - \mu\epsilon_{1i} - v\epsilon_{2i} > 0$. The conditional profit function for transport firms for transporting a unit of manufactured goods can be described by:

$$T_{12i}(t_{12i}) = t_{12i} - (h - \mu\epsilon_{1i} - v\epsilon_{2i}) \quad (8)$$

where t_{12i} is the full price of transport charge.¹ Higher T_{12i} implies larger t_{12i} and lower $h - \mu\epsilon_{1i} - v\epsilon_{2i}$.² The term ϵ_{2i} is replaced with the same expected value for all transport firms which decide transport charges in region 1. Andersen and Renoult (1999) explained that an equilibrium exists under monopolistic competition if the density f is log concave. The uniform distribution has this property over a convex set. Suppose that a transport firm holds a best offer with conditional profit $T_{12j}(t_{12j})$. If it contacts another manufacturing firm i , at which it expects transport charge t^* , it will prefer to accept the request for transportation if $t^* - (h - \mu\epsilon_{1i}) > t_j - (h - \mu\epsilon_{1j})$, which is equivalent to $\epsilon_{1i} > x \equiv \epsilon_{1j} - (t^* - t_j)/\mu$. We suppose a uniform distribution as follows:

$$f_1(x_1) = 1/n_1^M \text{ for } x_1 \in [0, n_1^M] \quad (9)$$

where $x_1 \equiv \epsilon_{1j} - (t^* - t_j)/\mu$. Added conditional profits can be expressed as $t^* - h + \mu\epsilon_{1i} - (t_j - h + \mu\epsilon_{1j}) = \mu(\epsilon_{1i} - x)$. When transport firms do not accept the request of manufacturing firm s , the transport firms advertise, wait for new requests, waste the space on transport equipment, and try to contact manufacturing firms to find a load to be transported. We call these costs the search costs. If the costs for additional search per unit of transport are, ω , covered by the numéraire, the incremental conditional profit for finding one more manufacturing firm is $\mu g(x)$ and the value of x when transport firms stop searching, \hat{x} , is given by

$$\omega/\mu = g(\hat{x}) \text{ where } \mu g(x) = \mu \int_x^{n_1^M} (\epsilon - x)f(\epsilon)d\epsilon$$

¹Recall is costless.

²Lower $h - \mu\epsilon_{1i} - v\epsilon_{2i}$ means that manufacturing firms accept transport offers more easily when matching is good in region 1 and region 2.

where $\mu g(x)$ is the expected value of finding a better matching than x . The expected incremental conditional profit from a single extra search exceeds the search cost if $x < \hat{x}$, whereas a single extra search yields a non-positive expected benefit if $x \geq \hat{x}$.

The gross profits per unit of transport when a transport firm decide to transport a variety of manufactured goods at transport charges t_1 after contacting k_1 manufacturing firms is given by

$$T_{12}(t_{12}) - \omega k_1.$$

At equilibrium, all transport firms have the same charge per unit of goods transported, t^* . The profits of a transport firm located in region 1, π_1^T , are

$$\pi_1^T = (t_{12} - c_{12}) q_{12}(p_{12}) \frac{L n_1^M}{2 n^T} + (t_{21} - c_{21}) q_{21}(p_{21}) \frac{L n_2^M}{2 n^T} - 1, \quad (10)$$

where $c_{12} \equiv h - \mu\epsilon_1 - v\epsilon_2 + \omega k_1$ and $c_{21} \equiv h - \mu\epsilon_2 - v\epsilon_1 + \omega k_2$.

2.4. Capital flow

Capital moves between the two regions to equalize capital returns. The processes of capital flow are expressed as follows:

$$\dot{s} \equiv ds/dt = \begin{cases} \Delta r & \text{if } 0 < s_M < 1 \\ \max\{0, \Delta r\} & \text{if } s_M = 0 \\ \min\{0, \Delta r\} & \text{if } s_M = 1, \end{cases}$$

where $\Delta r \equiv r_1 - r_2$. We define the spatial equilibrium as the situation where capital owners cannot earn a strictly higher rental rate by changing regions serviced by his/her capital endowments. The spatial equilibrium condition for manufacturing firms is $\Delta r = 0$ if $0 < s < 1$, $\Delta r < 0$ if $s = 0$, or $\Delta r > 0$ if $s = 1$.

3. Transport charge, price of products and capital returns

Given the distribution of firms, we start by considering the number of additional contacts that a transport firm will make in order to clarify the properties of the search process. Then, we proceed to determine transport charges. Using these transport charges, the prices of manufactured goods are derived. Finally, we derive capital returns and the number of transport firms.

3.1. Number of additional contacts

A transport firm stops searching and accepts the requests of a manufacturing firm if it finds a manufacturing firm with requests such that $x \geq \hat{x}$. Otherwise, the transport firm continues searching. Supposing $0 < F(\hat{x}) < 1$, the transport firm stops searching at the first contact with a manufacturing firm with probability $1 - F(\hat{x})$, at the second contact with probability $F(\hat{x})[1 - F(\hat{x})]$, at the third contact with probability $F(\hat{x})^2[1 - F(\hat{x})]$ etc. Summing up the probabilities that a transport firm stops searching, we obtain the expected number of contacts as

$$k^e = [1 - F(\hat{x})] \sum_{n_1^M=1} n_1^M F(\hat{x})^{n_1^M-1}.$$

Solving $\omega/\mu = g(\hat{x})$ yields

$$\hat{x}_1 = n_1^M - \sqrt{2n_1^M \omega/\mu}, \quad (11)$$

which is a quadratic function of $\sqrt{n_1^M}$. Using (11), we obtain

$$\hat{x}_1 \gtrless 0 \Leftrightarrow \mu n_1^M / 2 \gtrless \omega. \quad (12)$$

The last inequality shows that the sign of the reservation value depends on the balance between the expected returns from additional matching and the additional search costs. When $\hat{x}_1 < 0$, which implies the number of manufacturing firms is small, transport firms stop searching at the first contact. Whereas, when $\hat{x}_1 \geq 0$, which implies the number of manufacturing firms is large, transport firms try to contact another manufacturing firm. Furthermore, if μ goes to infinity or ω goes to 0, we obtain $\hat{x}_1 = n_1^M$. In other words, transport firms never stop searching and never accept any request for transportation because adjustment entails huge costs, even if the adjustment is relatively easy and the cost for additional contact is very small. Whereas, if $\hat{x}_1 < 0$, transport firms always accept a request from a manufacturing firm at the first contact because the adjustment entails small costs, even if it is relatively difficult, and the cost for an additional contact is too high.³

Using (11), we obtain the probability when consumers do not accept a variety:

$$F(\hat{x}_1) = 1 - \sqrt{\frac{2}{n_1^M} \frac{\omega}{\mu}}. \quad (13)$$

If the number of manufacturing firms is large enough such that $n_1^M > 2\omega/\mu$, we obtain $F(\hat{x}_1) > 0$. Using (13), we find that we always obtain $|F(\hat{x}_1)| < 1$. Thus, we obtain the expected number of contacts before a transport firm accepts the request of a manufacturing firm:

$$k^e = \frac{1}{1 - F(\hat{x}_1)} = \sqrt{\frac{n_1^M}{2} \frac{\mu}{\omega}}. \quad (14)$$

This is the inverse of the probability that a transport firm finds a manufacturing firm with acceptable requests, $1 - F(\hat{x}_1)$. For example, if the probability is $1/3$, a transport firm expects to contact three manufacturing firms before agreeing to transport a load.

If the number of manufacturing firms is small enough that $n_1^M \leq 2\omega/\mu$, we obtain $F(\hat{x}_1) \leq 0$. That means, consumers accept any requests if $n_1^M \leq 2\omega/\mu$. Hence, we find that the number of additional contacts k_1^* is 0 if $n_1^M \leq 2\omega/\mu$.

3.2. Transport charges

We suppose all transport firms except transport firm i set price t^* , given the number of transport firms and manufacturing firms. Given that transport firm i is contacted,

³Note that the reservation value increases as the number of manufacturing firms becomes larger because we obtain $\partial \hat{x}_1 / \partial n_1^M \gtrless 0 \Leftrightarrow n_1^M \gtrless \omega/2\mu$.

the probability of transport firm i accepting the request and sending the load of the manufacturing firm is

$$\Pr(x < \hat{x}) = 1 - F(\hat{x} + \Delta),$$

where $\Delta \equiv (t^* - t_i)/\mu$ is the standardized transport return premium of transport firm i . To determine the probability that transport firm i is contacted, we use the distribution function for another transport firm being contacted first and not accepting, $F(\hat{x})$. Focusing on the case when $n_1^M > 2\omega/\mu$, the transport firm i is contacted first with probability $1/n_1^M$, second with probability $F(\hat{x})/n_1^M$, third with probability $F(\hat{x})^2/n_1^M$, etc. Summing, we obtain the probability as $1/n_1^M \cdot [1 - F(\hat{x})^{n_1^M}]/[1 - F(\hat{x})]$. If n_1^M is sufficiently large, we can rewrite the probability as $1/n_1^M \cdot 1/[1 - F(\hat{x})]$. Thus, the probability that firm i is contacted and accepted becomes $1/n_1^M \cdot [1 - F(\hat{x} + \Delta)]/[1 - F(\hat{x})]$. Since no transport firm can contact all manufacturing firms, transport firm i 's demand in region 1 is

$$D_1(t_i, t^*) = \frac{n_1^M Q_1}{n^T} [1 - F(\hat{x} + \Delta)] \frac{1 - F(\hat{x})^{n_1^M}}{1 - F(\hat{x})},$$

where Q_1 is the transport demand of a variety of manufactured goods in region 1 and n^T is the number of transport firms. The derivative of transport firm i 's demand in region 1 with respect to t_i , evaluated at $t_i = t^*$, is

$$\frac{\partial D_1(t^*, t^*)}{\partial t_i} = -\frac{n_1^M Q_1}{n^T} \frac{f(\hat{x})}{\mu} \frac{1 - F(\hat{x})^{n_1^M}}{1 - F(\hat{x})} < 0.$$

At the equilibrium in which all transport firms charge the same, the demand for transport services is $D_1(t^*, t^*) = n_1^M Q_1/n^T$. Thus, we obtain transport charges where marginal revenue equals marginal cost:

$$t_{12}^* = \mu[1 - F(\hat{x}_1)]/f(\hat{x}_1) + h - \mu\epsilon_{1i} - v\epsilon_2 + \omega k_1$$

which is the condition given for monopolistic competition in the appendix of Anderson and Renault (1999) if we set $h - \mu\epsilon_{1i} - v\epsilon_2 + \omega k_1 = 0$.

If $n_1^M \leq 2\omega/\mu$ and thus $F(\hat{x}_1) = 0$, setting $k_1 = 0$, we obtain $t_{12}^* = h - \mu\epsilon_{1i} - v\epsilon_2$, which is the competitive price. In other words, *not accepting all requests of manufacturing firms can be regarded as a source of imperfect competition*. Because we allow the case when transport firms to agree to transport products at the first contact with a manufacturing firms, the expected match value ϵ_1^E becomes $n_1^M/2$. The part of transport costs t^* corresponding to mark-up, $\mu[1 - F(\hat{x})]/f(\hat{x})$, can be written as $\sqrt{2\omega\mu n_1^M}$, which expresses mark-up. This part increases with the search cost, ω , and the scale parameter, μ (Propositions 1 and 2 of Anderson and Renault (1999)). It also increases with a rise in the number of manufacturing firms. This appears to be different from the result of Anderson and Renault (1999) in which the price falls with an increase in the number of firms. This difference is simply because we focus only on monopolistic competition but Anderson and Renault (1999) examined much wider cases. It possible to interpret our case as stating that mark-up increases if a transport firm has a chance of a better matching.

Using (14), the cost for contacting manufacturing firms, ωk_1 , can be written as $\sqrt{n_1^M \mu \omega / 2}$. Thus, substituting $n_2^M = K/m - n_1^M$, if $n_1^M > 2\omega/\mu$, transport costs can be written as

$$t_{12} = \sqrt{5\omega\mu n_1^M / 2} + h - vK/2m - (\mu - v)n_1^M / 2, \quad (15)$$

whereas if $n_1^M \leq 2\omega/\mu$, transport costs can be written as

$$t_{12} = h - vK/2m - (\mu - v)n_1^M / 2.$$

Proposition 1 *The transport charges are determined by imperfect competition if the number of manufacturing firms in the transport market is large enough that $n_1^M > 2\omega/\mu$, whereas transport charges are equal to the marginal cost of transport firms if the number of manufacturing firms are small enough that $n_1^M \leq 2\omega/\mu$.*

It is readily verified that the core-periphery pattern provides a competitive transport market in the periphery. However, an imperfect competitive transport market (a competitive transport market) emerges in the core if $K/m > 2\omega/\mu$ ($K/m \leq 2\omega/\mu$). With a symmetric pattern there is an imperfect competitive transport market (a competitive transport market) if $K/m > 4\omega/\mu$ ($K/m \leq 4\omega/\mu$). In summary, we obtain the following results. (1) If $0 < K/m \leq 2\omega/\mu$, marginal cost pricing in the transport market may exist in the core and the periphery, and with a symmetric distribution of capital. (2) If $2\omega/\mu < K/m \leq 4\omega/\mu$, marginal cost pricing in the transport market may exist in the periphery and with a symmetric distribution of capital, whereas transport firms are under imperfect competition in the core. (3) If $4\omega/\mu < K/m$, marginal cost pricing in the transport market may exist in the periphery, whereas transport firms are under imperfect competition in the core or with a symmetric distribution of capital.

Supposing $n_1^M > 2\omega/\mu$ and substituting capital constraint $n_2^M = K/m - n_1^M$ into (12), it is straightforward to obtain:

$$\frac{\partial t_{12}}{\partial n_1^M} \begin{matrix} \geq \\ \leq \end{matrix} 0 \Leftrightarrow \frac{5}{2} \frac{\omega\mu}{(\mu - v)^2} \begin{matrix} \geq \\ \leq \end{matrix} n_1^M \quad \text{if } \mu > v; \quad (16)$$

$$\frac{\partial t_{12}}{\partial n_1^M} > 0 \quad \text{if } \mu \leq v. \quad (17)$$

In other words, focusing on the case when a transport firm may not accept all requests, if the scale parameter of the cost for backhaul, v , is not smaller than that for fronthaul, μ , transport charges decrease as the number of manufacturing firms increases. Otherwise, transport charges increase (decrease) when the number of manufacturing firms are small (large) as the number of manufacturing firms increase in the transport market. Economies of density may emerge when transport firms do not care about backhaul and the number of manufacturing firms is large enough.

On the other hand, supposing $n_1^M \leq 2\omega/\mu$ and substituting capital constraint $n_2^M = K/m - n_1^M$ into transport charge $h - \mu n_1^M / 2 - v n_2^M / 2$ yields

$$\frac{\partial t_{12}}{\partial n_1^M} \begin{matrix} \geq \\ \leq \end{matrix} 0 \Leftrightarrow \mu \begin{matrix} \leq \\ \geq \end{matrix} v.$$

That is, if transport firms accept any requests and the scale parameter for fronthaul is larger than that for backhaul, transport charges decrease with an increase in the number of manufacturing firms.

Furthermore, it is straightforward to obtain $t_{12} = t_{21}$ if $n_1^M = n_2^M = K/2m$ and also

$$\frac{\partial t_{12}}{\partial n_1^M} = -\frac{\partial t_{21}}{\partial n_1^M}.$$

That is, transport costs become asymmetric between regions if the distribution of manufacturing firms is asymmetric. Furthermore, the size of marginal changes of transport costs are the same between transport markets. However, when transport costs from region 1 to region 2 increase (decrease), transport costs from region 2 to region 1 decrease (increase).

3.3. Prices of manufactured goods

Solving the first-order conditions for a manufacturing firm's profit maximization with respect to the prices of manufactured goods yields the prices of manufactured goods consumed in region 1:

$$p_{11}(\tau_{21}) = \frac{2a + t_{21}cn_2^M}{2(2b + cK/m)}, \quad (18)$$

$$p_{21}(\tau_{21}) = \frac{2a + t_{21}(2b + cK/m + cn_2^M)}{2(2b + cK/m)}. \quad (19)$$

Similarly, the price of the manufactured goods transported from region 1 to region 2 are

$$p_{12}(\tau_{12}) = \frac{2a + t_{12}(2b + cK/m + cn_1^M)}{2(2b + cK/m)}. \quad (20)$$

Substituting (15) into (20), we obtain the equilibrium price of the manufactured goods transported from region 1 to region 2:

$$p_{12} = \frac{2a + \left(\sqrt{5\omega\mu n_1^M/2} + h - \mu n_1^M/2 - \nu n_2^M/2\right)(2b + cK/m + cn_1^M)}{2(2b + cK/m)}. \quad (21)$$

Similarly, the equilibrium price of the manufactured goods produced and consumed in region 1 is

$$p_{11} = \frac{2a + \left(\sqrt{5\omega\mu n_2^M/2} + h - \mu n_2^M/2 - \nu n_1^M/2\right)cn_2^M}{2(2b + cK/m)}. \quad (22)$$

Using (4), (5) and the first-order conditions for a manufacturing firm's profit maximization with respect to the prices of manufactured goods, we obtain the quantities of individual consumption of each manufactured good:

$$q_{11} = (b + cK/m)p_{11} \text{ and} \quad (23)$$

$$q_{12} = (b + cK/m)(p_{12} - t_{12}). \quad (24)$$

To obtain the sufficient condition for manufactured goods produced in region 1 to be demanded in region 2, substituting (15), (21) and (24) into the condition $p_{12} - t_{12} > 0$ which gives

$$2a/(2b + cn_1^M) > t_{12} = \sqrt{5\omega\mu n_1^M/2} + h - \mu n_1^M/2 - vn_2^M/2. \quad (25)$$

The left-hand side of (25) takes its minimum value when $n_1^M = K/m$, whereas the right-hand side of (25) takes its maximum value when $n_1^M = 5/2 \cdot \omega\mu / (\mu - v)^2$. Requiring that the minimum value of the left-hand side is always larger than the maximum value of the right-hand side, we obtain the condition

$$a > \frac{2b + cK/m}{2} \left(\frac{5}{4} \frac{\omega\mu}{\mu - v} + h - v \frac{K/m}{2} \right). \quad (26)$$

We suppose that (26) is always satisfied.

The ambiguity about the effects of an increase in the number of manufacturing firms on the price of manufactured goods remains. As explained in Ottaviano, Tabuch and Thisse (2002), the prices of manufactured goods produced by both local and foreign manufacturing firms fall when the number of local firms rises and the number of foreign manufacturing firms falls, if the transport costs are fixed. However, the effects of an increase in the number of manufacturing firms on the transport costs may change the effects of that increase on the price of manufactured goods. Using (22), we obtain

$$\frac{\partial p_{11}}{\partial n_2^M} \geq 0 \Leftrightarrow (v - \mu) n_2^M + \frac{3}{2} \sqrt{\frac{5}{2} \omega\mu n_2^M} + h - v \frac{K}{2m} \geq 0,$$

which is simply a quadratic function of $\sqrt{n_2^M}$. Because $h - vK/2m > 0$, this model has the same effect of the number of manufacturing firms on the price of local products as in the model of Ottaviano, Tabuch and Thisse (2002) if the scale parameter for backhaul is not smaller than that for fronthaul ($v \geq \mu$), or if the number of local manufacturing firms is small and the scale parameter on backhaul is smaller than that on fronthaul ($v < \mu$). However, *if the number of local manufacturing firms is large enough and the scale parameter for backhaul is not small, an increase in local manufacturing firms increases the price of local products.* This is because the transport costs to the region where the large number of manufacturing firms are located increase and then the price index in the region increases. Furthermore, using (20), we obtain

$$\frac{\partial p_{12}}{\partial n_1^M} \geq 0 \Leftrightarrow g(x) \geq 0$$

where $g(x) \equiv -x^3(\mu - v) + x^2 \frac{3}{2} \sqrt{\frac{5}{2} \omega\mu} + x [h - (\mu - v)(\beta/\gamma - 1) - \mu K/2m] + \frac{2b + cK/m}{2c} \sqrt{\frac{5}{2} \omega\mu}$ and $x \equiv \sqrt{n_1^M}$. Notice that $g(x)$ is a cubic function of x . Now, we focus on some specific

cases. If $\mu \leq v$, we readily obtain $\partial p_{12}/\partial n_1^M > 0$ because of $g'''(0) > 0$, $g''(0) > 0$, $g'(0) > 0$, and $g(0) > 0$. Whereas, if $\mu > v$ and $h - (\mu - v)(\beta/\gamma - 1) - \mu K/2m > 0$, because $g'''(0) < 0$, $g''(0) > 0$, $g'(0) < 0$, and $g(0) > 0$, we readily obtain $\partial p_{12}/\partial n_1^M > 0$ when n_1^M is small enough and $\partial p_{12}/\partial n_1^M < 0$ when n_1^M is large enough. If $\mu > v$ and $h - (\mu - v)(\beta/\gamma - 1) - \mu K/2m < -\frac{45}{24} \frac{\omega\mu}{(\mu-v)}$, we also obtain $\partial p_{12}/\partial n_1^M > 0$ when n_1^M is small enough and $\partial p_{12}/\partial n_1^M < 0$ when n_1^M is large enough because $g'''(0) < 0$, $g''(0) > 0$, $g'(x) < 0$ and $g(0) > 0$. That is, the present model has the similar effect of the number of manufacturing firms on the price of local products to that in the model of Ottaviano, Tabuch and Thisse (2002), if the number of local manufacturing firms are small or the scale parameter for backhaul transportation is not smaller than that for fronthaul transportation. Otherwise, the price of manufactured goods may decrease as the number of manufacturing firms increases.

3.4. Capital returns and the number of transport firms

Substituting (4), (5), (6), (15), (18), and (20) into (7) and using the zero profit condition yields the capital returns in region 1:

$$r_1^*(s) = \left[\frac{2a + t_{21}^*(s)c(1-s)K/m}{2(2b + cK/m)} \right]^2 W/m + \left[\frac{2a - t_{12}^*(s)(2b + c(1-s)K/m)}{2(2b + cK/m)} \right]^2 W/m \quad (27)$$

where $W \equiv (b + cK/m)L/2$. Furthermore, $t_{21}^*(s)$ is given by $\sqrt{5\omega\mu(1-s)K/2m + h - \mu(1-s)K/2m - vsK/2m}$ if $(1-s)K/m > 2\omega/\mu$ and $h - \mu(1-s)K/2m - vsK/2m$ if $(1-s)K/m \leq 2\omega/\mu$. Similarly, $t_{12}^*(s)$ is given by $\sqrt{5\omega\mu sK/2m + h - \mu sK/2m - v(1-s)K/2m}$ if $sK/m > 2\omega/\mu$, and $h - \mu sK/2m - v(1-s)K/2m$ if $sK/m \leq 2\omega/\mu$.

Substituting (5), (6), (15) and (20) into (10) and using zero profit condition yields the equilibrium number of transport firms:

$$n^{T^*}(s) = \frac{sK}{m} [t_{12}^*(s) - c_{12}^*(s)]W \cdot \frac{2a - t_{12}^*(s) [2b + c(1-s)K/m]}{2(2b + cK/m)} + \frac{(1-s)K}{m} [t_{21}^*(s) - c_{21}^*(s)]W \cdot \frac{2a - t_{21}^*(s) [2b + csK/m]}{2(2b + cK/m)}, \quad (28)$$

where $c_{12}^*(s) \equiv h - \mu sK/2m - v(1-s)K/2m + \omega k_1^*$ and $c_{21}^*(s) \equiv h - \mu(1-s)K/2m - vsK/2m + \omega k_2^*$. It is straight forward to see that $t_{12}^*(s) = c_{12}^*(s)$ or $t_{21}^*(s) = c_{21}^*(s)$ if the transport market is perfectly competitive. That is, *if the transport market on either fronthaul or backhaul is under imperfect competition, transport firms exist. Otherwise, transport firms do not exist in the economy because transport firms use an increasing-returns technology under perfect competition in both transport markets. In the case of perfect competition in both fronthaul and backhaul, if transport firms are exists, numerous transporters such as the truck industry expressed in De Vany and Saving (1977), choose a constant-returns technology.* To analyze more complicated cases on industrial location, we focus on transport firms which use an increasing-returns technology.

4. Industrial location

In this section, we find when the core-periphery pattern is sustainable and when the symmetric distribution of firms breaks. Because there are many types of change of trans-

port charges under imperfect competition in the transport market, we focus on the case when $4\omega/\mu < K/m$. That is, a competitive transport market emerges in the periphery, whereas an imperfect competitive transport market emerges in the core. Furthermore, the transport market is under imperfect competition in the symmetric pattern.

4.1. The sustainability of a core-periphery pattern

We derive conditions when a core-periphery pattern is sustainable. We start with the core-periphery pattern where all manufacturing firms locate in region 1, positing the situation in which $s = 1$. We obtain the gap of capital returns when all capital is agglomerated in region 1:

$$[r_1^*(s=1) - r_2^*(s=1)] A = -(t_{12cp}^* - t_{21cp}^*)[4a - (t_{21cp}^* + t_{12cp}^*)2b] - (t_{21cp}^{*2} + t_{12cp}^{*2})cK/m \quad (29)$$

where $A \equiv 4(2b + cK/m)/[(b + cK/m)L/2m]$, $t_{12cp}^* \equiv \sqrt{5\omega\mu K/2m} + h - \mu K/2m$ and $t_{21cp}^* \equiv h - \nu K/2m$. So, we obtain $r_1^M(s=1) - r_2^M(s=1) < 0$ if transport charges are the same in both transport markets. A difference of transport costs may lead to a core-periphery structure: from (29), we obtain $r_1^M(s=1) - r_2^M(s=1) < 0$ if $t_{12cp}^* - t_{21cp}^* \geq 0$. In other words, *if transport charges from the core are larger than from the periphery, the core-periphery structure is not sustainable*. That is, if $\mu \leq \nu$, we always obtain $t_{12cp}^* - t_{21cp}^* \geq 0$ and then $r_1^M(s=1) < r_2^M(s=1)$. Hence, *if the scale parameter for fronthaul is smaller than that for backhaul, the core-periphery pattern does not exist*. To avoid the ambiguity in the case when $\mu > \nu$, rewriting (29), we obtain

$$[r_1^M(s=1) - r_2^M(s=1)] A = t_{21cp}^* [4a - t_{21cp}^*(2b + cK/m)] - 4at_{12cp}^* + (2b - cK/m)t_{12cp}^{*2},$$

which is a quadratic function of t_{12cp}^* . The determinant of this quadratic function of t_{12cp}^* is

$$D_1/4 = 4a^2 - 4a(2b - cK/m)t_{21cp}^* + (2b - cK/m)(2b + cK/m)t_{21cp}^{*2}.$$

Furthermore, the determinant of $D_1/4$ is

$$D_2 = -32a^2(2b - cK/m)cK/m.$$

Because $D_2 < 0$ if $2b - cK/m > 0$, we obtain $D_1 > 0$ if $2b - cK/m > 0$. Whereas, because $D_2 > 0$ if $2b - cK/m < 0$, we obtain $D_1 > 0$ if $t_{21cp}^* < \frac{2a(2b-cK/m)-2a\sqrt{-2(2b-cK/m)cK/m}}{(2b-cK/m)(2b+cK/m)}$ and $2b - cK/m < 0$. Furthermore, if $2b - cK/m = 0$, we have $\frac{2a(2b-cK/m)-2a\sqrt{-2(2b-cK/m)cK/m}}{(2b-cK/m)(2b+cK/m)} > \frac{2a}{2b+cK/m}$, so we obtain $D_1 > 0$. Thus, using (29) and setting $r_1^M(s=1) = r_2^M(s=1)$ yields

$t_{12cp}^* = \frac{2a \pm \sqrt{D_1/4}}{2b - cK/m}$. If $2b - cK/m > 0$, we find that $r_1^M(s=1) > r_2^M(s=1)$ equivalents to $0 < t_{12cp}^* < \frac{2a - \sqrt{D_1/4}}{2b - cK/m}$ and $r_1(s=1) \leq r_2(s=1)$ is equivalent to $\frac{2a - \sqrt{D_1/4}}{2b - cK/m} \leq t_{12cp}^* < \frac{2a}{2b + cK/m}$. Whereas, if $2b - cK/m < 0$, we find that $r_1^M(s=1) > r_2^M(s=1)$ is equivalent to $0 < t_{12cp}^* < \frac{2a - \sqrt{D_1/4}}{2b - cK/m}$ and $r_1(s=1) \leq r_2(s=1)$ is equivalent to $\frac{2a - \sqrt{D_1/4}}{2b - cK/m} \leq t_{12cp}^* <$

$\frac{2a}{2b+cK/m}$. Furthermore, if $2b - cK/m = 0$, we obtain $r_1^M(s = 1) \gtrless r_2^M(s = 1)A \Leftrightarrow t_{21cp}^* [4a - t_{21cp}^*(2b + cK/m)] / 4a \gtrless t_{12cp}^*$.

Thus, supposing $2b \neq cK/m$, we find that the core-periphery pattern is sustainable if

$$0 < t_{12cp}^* < \frac{2a - \sqrt{4a^2 - 2(2b - cK/m)t_{21cp}^* [4a - t_{21cp}^*(2b + cK/m)]}}{2b - cK/m}, \quad (30)$$

whereas the core-periphery pattern is not sustainable if and only if

$$\frac{2a - \sqrt{4a^2 - 2(2b - cK/m)t_{21cp}^* [4a - t_{21cp}^*(2b + cK/m)]}}{2b - cK/m} \leq t_{12cp}^* < \frac{2a}{2b + cK/m}. \quad (31)$$

If t_{21cp}^* is close to zero, the left-hand side of (31) is also close to zero. Thus, the core-periphery pattern is not sustainable in any case. Since $D_1/4$ is decreasing in t_{21cp}^* if $2b - cK/m > 0$ whereas $D_1/4$ is increasing in t_{21cp}^* if $2b - cK/m < 0$, *the range of t_{12cp}^* for sustaining the core-periphery pattern expands as t_{21cp}^* increases.*⁴ Furthermore, if $2b = cK/m$, we find that the core-periphery pattern is sustainable if

$$0 < t_{12cp}^* < t_{21cp}^* [a - t_{21cp}^* b] / a, \quad (32)$$

whereas the core-periphery pattern is not sustainable if

$$t_{21cp}^* [a - t_{21cp}^* b] / a \leq t_{12cp}^*.$$

We obtain the same tendency if $2b \neq cK/m$.

Since t_{12cp}^* includes μ and ω and t_{21cp}^* includes v , combining (30) and the condition for which imperfect competition in the transportation market emerges, we find that core-periphery pattern is sustained if the following condition is satisfied:

$$0 < \omega < \min \left\{ \frac{[T - (h - \mu K/2m)]^2}{5\mu K/2m}, \mu K/4m \right\}$$

where T is the left-hand side of (31) or the right-hand side of (32). That is, *the core-periphery pattern is sustained if additional search costs are small enough.*

4.2. The breaking of the symmetric pattern

We now examine the breaking of the symmetric pattern which is an equilibrium at $s = 0.5$. To obtain the effect of an increase s on $r_1^M(s = 0.5) - r_2^M(s = 0.5)$, the capital return, (27), is differentiated around $s = 0.5$:

$$\frac{\partial \Delta r}{\partial s} \cdot \frac{4(2b + cK/m)}{W/m} = -t_{sy}^2 cK/m - 2 \frac{\partial t_{12}}{\partial s} (a - t_{sy} b) \quad (33)$$

⁴Endogenizing transport costs by introducing a search process, we find that the core-periphery pattern is an equilibrium when transport costs in transport market of the core is small enough, whereas the core-periphery pattern is not stable if transport costs in the transport market of the periphery are small enough or if transport costs in the transport market of the core are large enough.

where $t_{sy} \equiv \frac{1}{2}\sqrt{5\omega\mu K/m} + h - \mu K/4m - vK/4m = t_{12} = t_{21}$ and $\partial t_{12}/\partial s = \frac{1}{2}\sqrt{5\omega\mu K/m} - (\mu - v)K/2m$.

The first term of (33) represents tough competition among firms, which is a dispersion force, as in Ottaviano, Tabuchi and Thisse (2002). That means, because manufacturing firms relocate from region 2 to region 1, the competition in region 1 becomes tougher and that in region 2 becomes milder. Thus, the symmetric pattern does not break. The first term of (33) is always negative. If we suppose $\partial t_{12}/\partial s = 0$ such as in typical footloose capital model, the symmetric pattern is always an equilibrium.

The last term of (33) represents the effects of a change in transport costs on the capital returns. The part of the last term on the right-hand side of (33) in parentheses is always positive. This is because, since we choose parameters which satisfy $p_{12} - t_{12} > 0$, $p_{12} - t_{12} > 0$ equals $a - t(b + cn_2^M/2) > 0$, so $a - tb$ is always positive. Therefore, the last term is negative if $\partial t_{12}/\partial s > 0$, whereas the last term is positive if $\partial t_{12}/\partial s < 0$. That is, when transport costs from region 1 to region 2 rise (fall) and transport costs from region 2 to region 1 fall (rise) by the relocation of manufacturing firms to region 1, manufacturing firms in region 1 may (not) have an incentive to relocate to region 2. Thus, dispersion or agglomeration emerges, depending on the sign of $\partial t_{12}/\partial s$.

Using (16), we obtain $\partial t_{12}/\partial s \gtrless 0 \Leftrightarrow \omega \lesseqgtr [(\mu - v)^2 K/m]/5\mu$ if $\mu > v$, whereas $\partial t_{12}/\partial s > 0$ if $\mu \leq v$. That is, the sign of $a - t_{sy}b$ is positive if $\omega > [(\mu - v)^2 K/m]/5\mu$ and $\mu > v$, whereas it is non-positive if $\omega \leq [(\mu - v)^2 K/m]/5\mu$ and $\mu > v$ or if $\mu \leq v$. In other words, *agglomeration force by economy of transport density occurs if search costs are large and the scale parameter for backhaul is larger than that for fronthaul, whereas dispersion force by diseconomies of transport density occurs if search costs are small and the scale parameter for fronthaul is larger than that for backhaul or if the scale parameter for backhaul is larger than that for fronthaul.*

When the agglomeration force does not emerge, the symmetric pattern is always an equilibrium. However, agglomeration forces may break the symmetric pattern. Summing up agglomeration forces and dispersion forces, we examine the sign of $\partial \Delta r/\partial s_M$ around $s = 0.5$ when $\partial t_{12}/\partial s < 0$. Using $\partial t_{12}/\partial s = t_{sy} - h - \mu K/4m + 3vK/4m$, the right-hand side of (33) can be rewritten as

$$2Ha - 2(a + bH)t_{sy} + (2b - cK/m)t_{sy}^2 \equiv F(t_{sy}),$$

where $H \equiv h + \mu K/4m - 3vK/4m$. We are interested in the case when $\partial t_{12}/\partial s < 0$, so we focus on $t_{sy} < H$. It is straightforward to obtain $F(t_{sy} = 0) > 0$, $F'(t_{sy} = 0) < 0$ and $F(t_{sy} = H) < 0$. Furthermore, the determinant of $F(t_{sy})$ is positive. Since $F(t_{sy})$ is quadratic function of t_{sy} , the value of t_{sy}^* such that $F(t_{sy}) = 0$ is

$$t_{sy}^* = \frac{a + bH - \sqrt{(a - bH)^2 + 2HacK/m}}{2b - cK/m}.$$

Thus, we find that $\partial \Delta r/\partial s$ around $s = 0.5$ is positive when $0 < t_{sy} < t_{sy}^*$, whereas it is negative when $t_{sy}^* < t_{sy} < H$. Substituting $t_{sy} = \frac{1}{2}\sqrt{5\omega\mu K/m} + h - \mu K/4m - vK/4m$ into $t_{sy}^* \gtrless t_{sy}$ yields

$$t_{sy}^* \gtrless t_{sy} \Leftrightarrow 4(t_{sy}^* - h + \mu K/2m + vK/4m)^2 / 5(\mu K/m) \gtrless \omega.$$

Thus, adding the condition for imperfect competition to emerge, we obtain that $\partial\Delta r/\partial s_M$ around $s = 0.5$ is positive when

$$0 < \omega < 4 [t_{sy}^* - h + (\mu + v)K/4m]^2 / 5 (\mu K/m)$$

whereas $\partial [r_1^M(s = 1) - r_2^M(s = 1)] / \partial s_M$ is negative when

$$4 [t_{sy}^* - h + (\mu + v)K/4m]^2 / 5 (\mu K/m) < \omega < \mu K/4m.$$

Using H , it is readily verified that $4 [t_{sy}^* - h + (\mu + v)K/4m]^2 / 5 (\mu K/m) < \mu K/4m$. Summarizing the derived results, we obtain the following proposition:

Proposition 2 *Endogenizing transport costs by introducing a search process, we find that the symmetric pattern is stable if $4 [t_{sy}^* - h + (\mu + v)K/4m]^2 / 5 (\mu K/m) \leq \omega \leq \mu K/4m$, whereas the symmetric pattern breaks if $0 < \omega < 4 [t_{sy}^* - h + (\mu + v)K/4m]^2 / 5 (\mu K/m)$.*

5. Conclusion

We have presented a general spatial equilibrium model based with endogenized transport costs determined by a search process. The main results of our paper can be summarized as follows. The transport charges are decided under imperfect competition if the number of manufacturing firms is large enough or the additional search costs are small enough. The source of mark-up in transport charges stems from the possibility that transport firms do not accept all requests from manufacturing firms. Otherwise, transport charges are decided by marginal-cost pricing. Focusing on the case when transport firm may not accept all requests, if the scale parameter on the cost for backhaul is not smaller than that for fronthaul, transport charges decrease as the number of manufacturing firms increases. Otherwise, transport charges increase (decrease) when the number of manufacturing firms are small (large) as the number of manufacturing firms increases. Economy of transport density works if search costs are large and the scale parameter for backhaul is larger than that for fronthaul, whereas dispersion forces from diseconomies of transport density occur if search costs are small and the scale parameter for fronthaul is larger than that for backhaul or when the scale parameter for backhaul is larger than that for fronthaul.

Choosing the range of additional search costs so that imperfect competition emerges in a symmetric distribution of manufacturing firms, the transport charges from the periphery are determined by marginal-cost pricing, however, the transport charges from the core have a mark-up.

Then, if transport charges from the core are larger than those from the periphery, the core-periphery structure is not sustainable. Likewise, if the scale parameter for fronthaul is smaller than that for backhaul, the core-periphery pattern does not exist. The core-periphery pattern is sustainable and symmetric patterns break, if additional search costs are small enough. The range of transport charges for sending products from the core to the periphery that sustains the core-periphery pattern expands as transport charges from the periphery increase.

Owing to the many components of transport costs, our model does not capture all relevant aspects. However, many other concepts in transport economics could be incorporated into NEG models in future research.

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