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# Median Location and Economic Geography

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This study explores the role of median location in a footloose entrepreneur (FE) version and Helpman's (1998) version of NEG models. Two kinds of location distribution for three regions are considered: One is an equilateral triangle (with no median location). The other is the distribution in which three points are equidistant between two adjacent points on a line (the middle region is the median region). The results show that there are some differences between these two settings. In the setting with no median location, firms will agglomerate at any of the three regions with low transport costs in the FE model and high transport costs in the Helpman model and will equally distribute among the three regions with high transport costs in the FE model and low transport costs in the Helpman model. In the setting with a median location, the symmetric industrial dispersion among the three regions emerges when transport costs are larger than those in the triangle with no median location in the FE model, because the advantage of median location is lost only when transport costs are larger. However, this symmetric dispersion never emerges in the Helpman model unless transport costs approach zero. In the Helpman model, a unique asymmetric distribution at the median location increases from one-third as transport costs increases. This shows that the advantage of median location exists even in the Helpman model, which provides housing services as a major centrifugal force.

Keywords: median location, core-periphery model, New Economic Geography, agglomeration, three regions
JEL classification: R12, R30

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## 1 Introduction

The agglomeration of economic activities has received much attention in both economics and geography. Based on the monopolistic competition model developed by Dixit and Stiglitz (1977), Krugman (1991) shows that the emergence of a core and periphery or symmetric regions depends on transport costs, economies of scale, and the share of manufacturing in national income. His study and the following ones are called New Economic Geography (NEG). To achieve analytical solutions instead of simulation results, some studies on the distribution of firms in two or more regions have been done. Forslid and Ottaviano (2003) develop an analytically solvable core-periphery model by introducing heterogeneity between workers and by coupling a higher level of skill with higher interregional mobility. The costs incurred by skilled labor will contribute to only fixed costs instead of marginal costs for firms. The number of firms in each region is thus determined by giving the amount of skilled labor and the fixed input requirement for a firm. The skilled labor can be thought of as self-employed entrepreneurs, and the model is called the footloose entrepreneur (FE) model.[1] In these studies based on Krugman's mechanism, the distribution of firms depends on the level of transport costs. Agglomeration or a no-firm outcome (a core-periphery pattern) emerges when transport costs are small and a symmetric (dispersion) distribution emerges when transport costs are large. However, Helpman's (1998) introduces the availability of housing (land) as the main dispersion force of economic activities and obtains opposite outcomes for firms' distribution with transport costs.

Location theory is traditionally a sub-field of urban and regional economics. von Thünen (1826) plays an important role in this field as well as some other fields He not only created marginalism and marginal economics, but also elaborated one of the first models of general equilibrium (Samuelson, 1983). Von Thünen also anticipates the Marshall-Weber theory of industrial agglomeration, the Christaller-Losch theory of central place system,

[1] Some analytically solvable CP models have been developed. For instance, Baldwin (1999) presents a model where factor accumulation, rather than factor migration, causes agglomeration. Ottaviano, Tabuchi, and Thisse (2002) employ a quadratic utility function and linear demand instead of constant elasticity of substitution and show some spatial stable equilibria. Pflüger (2004) uses a quasi-linear function rather than a Cobb-Douglas function of the upper layer of the utility function. The income effect in the manufacturing sector is thus removed to simplify the process of the model.

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and the recent development of new economic geography (Fujita, 2012). Alfred Weber (1909) in his location model, set up a paradigm for location based on the minimization of transport costs. This theory can be treated as basic theory and is applied to a very broad set of topics in urban economics. For instance, facility location analysis deals with locating new facilities with regard to existing facilities in order to optimize one or several economic criteria (Hansen et al., 1987). Some studies following Weber (1909) are raised. The P-median problem is one of the basic models in discrete location theory (Mladenović et al., 2007). A multisource Weber problem model is used to simultaneously locate facilities to minimize the total transport costs for satisfying the demand of many users (Brimberg et al., 2000). The basic principle of various versions of median location is used to explain the optimal location in the facility location problem as well as the production optimal location of firms with many inputs (O'Sullivan, 2012)[2] Drezner et al. (2002) provide a comprehensive survey for the studies of the Weber problem.

In the studies of NEG, symmetric location configuration is normally used for multiple regions. For example, three regions form an equilateral triangle or twelve regions form a clock cycle configuration (Krugman, 1993; Fujita, Krugman, and Venables, 1999)[3] In these configurations, locational difference does not exist and the difference of locations cannot be discussed in NEG for the distribution of firms. From the regional configuration in Taiwan, we can find that the major cities are located on the west side of the island. The major cities including Taipei, Taichung, and Kaoshiung form a line configuration with a median location (Taichung) and two non-median locations. As we know, Taipei is the largest city in Taiwan due to many reasons such as being the political and economic center and large infrastructure investments. However, the continuing migration into Taichung in recent years has resulted in more population than Kaoshiung at the end of July in 2017. An interesting question might be raised: Does the median location play an active role in the regional economic development?

This paper is thus intended to analyze the role of median location in the models of NEG — specifically, whether the firms will be attracted to the

[2]The spatial competition model of Hotelling (1929) and the total transport cost minimization (Weber, 1909) are combined in Lai and Tabuchi (2012).

[3]Urban hierarchy and central places are incorporated in new economic geography models (Tabuchi and Thisse, 2006; Tabuchi and Thisse, 2011). However, symmetric configurations with multiple regions are employed.

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median location rather than the non-median location in a multiple-region configuration with monopolistic competitive firms. For comparison, two configurations of three regions are employed. One is an equilateral triangle formed with three regions on the end points and the other is one line segment formed with three regions distributed with equal distance between adjacent regions. The line configuration can be used to analyze the role of median location for firms' locational choice. The middle region of the line segment is the median location in the configuration. By using the analysis of the FE version of the core-periphery model, we can show the conditions under which the median location is beneficial for agglomeration. In addition, the version of Helpman's (1998) model is incorporated in these two spatial configurations to compare the outcomes with those from the FE model. Transport costs play an important role in both versions of NEG models. In the triangle configuration, the transport costs between any two regions are identical. However, in the line configuration with a median location, the transport cost between the median location and each non-median location is much smaller than that between the two non-median locations. The different transport costs from the configuration setting will incur new interactions among the three regions. Specifically, the transport costs will influence the demand for manufacturing goods in each region, which will then affect the wage level of workers. In the long-run, the migration of labor and the manufacturing firms among the three regions will change.

There are some studies in the literature related to our paper. Ago, Isono, and Tabuchi (2006) show that the advantages of the central region of the three regions on a line disappear in the model of Ottaviano, Tabuchi, and Thisse (2002) when markets are opened up. This is because the price competition is so keen in the central region that the manufacturing sector moves to the peripheral regions. However, the model they employed is different from ours. In addition, our study focuses on the properties and the conditions of agglomeration of the median location. Castro, Correia-da-Silva, and Mossay (2012) compare the properties of a core-periphery model with three regions with those of the standard 2-region model. The conditions for the stability of dispersion and concentration are established. However, the median location is absent in their model. The remainder of the paper is organized as follows. Section 2 develops the model associated with the two three-region configurations. In Section 3, the conditions of short-run equilibrium and long-run equilibrium and the agglomeration for the median location are examined. Section 4 makes some numerical simulations

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with different expenditure shares for manufactured goods. Section 5 conducts the analysis under the Helpman's (1998) mechanism and comparisons with the outcomes from FE models. Section 6 provides the main finding of the paper and potential avenues for future research.

## 2 The Model

This study explores the role of median location in a core-periphery model based on the footloose entrepreneur version (see Forslid and Ottaviano (2003)). It is assumed the economy consists of three regions. There are two layouts for the relative locations of these three regions. Scenario I (with no median location): the three regions form an equilateral triangle with the same distance, $d$, between any two regions (see Figure 1) Scenario II (with median location): the three regions lie on a line with equal distance, $d$, between two adjacent regions (see Figure 2). Thus, Scenario I is the traditional core-periphery model with three regions as a trademark for comparison. Scenario II incorporates region 2 as the median location in the layout. There are two production factors skilled labor and non-skilled labor and their amounts are denoted by $H$ and $L$. That is, $H_1 + H_2 + H_3 = H$ and $L_1 + L_2 + L_3 = L$, where $H_i$ and $L_i$ represent these two endowments in region $i = 1, 2, 3$. Each worker can provide only one unit of labor. The skilled worker is mobile among the three regions while non-skilled workers are not. Each region has two sectors, an agricultural sector (sector $A$) and a manufacturing sector (sector $X$). The agriculture sector is perfectively competitive and produces a single, homogenous good, whereas the manufacturing sector provides a large variety of differentiated goods.[4] The former exhibits constant returns to scale while the latter exhibits increasing returns to scale.

### 2.1 Demand side

It is assumed that all individuals, including skilled labor and non-skilled labor, have the same Cobb-Douglas utility function as follows:

$$U_i = X_i^u A_i^{1-u}, \quad i = 1, 2, 3, \tag{1}$$

[4]The service sector in an economy can be interpreted as a part of the manufacturing sector in this model. Specifically, the manufacturing sector in this model produces goods and services. The basis for classification of sectors in this model is the increasing returns to scale or constant returns to scale.

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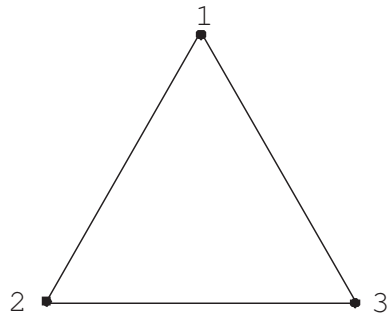



Figure 1: Three regions with no median location




Figure 2: Three regions with noe median location

where $X_i$ denotes a composite index of the consumption of manufacturing goods in region $i$; $A_i$is the consumption of the agricultural good in region $i$; $\mu$ is the expenditure share for manufacturing goods, and $1-\mu$ is that for the agricultural good.

According to Dixit and Stiglitz (1977), the composite index for manufacturing goods is defined by a constant elasticity of substitution (CES) function:

$$X_i = \left( \int_0^N d_i(s) \frac{\sigma - 1}{\sigma} ds \right)^{\frac{\sigma}{\sigma - 1}}, \quad i = 1, 2, 3. \tag{2}$$

where $d_i(s)$ is the consumption for variety, $s$, of manufacturing goods in region $i$, and the parameter $\sigma$ denotes the elasticity of substitution between any two varieties ($\sigma > 1$). $N$ is the number of varieties of manufacturing goods.

This problem can be solved by minimizing the expenditure for the sum of all the manufacturing varieties to attain the composite index for manu-

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facturing goods, $X_i$:

$$\min_{d_i} \quad \int_0^N p_i(s)d_i(s)ds, \tag{3}$$

$$\text{s.t.} \quad \left(\int_0^N d_i(s)\frac{\sigma-1}{\sigma}ds\right)^{\frac{\sigma}{\sigma-1}} = X_i, \quad i = 1, 2, 3. \tag{4}$$

The relationship of the consumption of the two varieties is:

$$d_i(s) = d_i(k)\left(\frac{p_i(k)}{p_i(s)}\right)^{\sigma}, \quad i = 1, 2, 3. \tag{5}$$

Substituting (5) into (4) yields the consumption for variety k of manufacturing goods:

$$d_i(k) = \frac{p_i(k)^{-\sigma}}{\left(\int_0^N p_i(s)^{1-\sigma}ds\right)^{\frac{\sigma}{\sigma-1}}}X_i, \quad i = 1, 2, 3. \tag{6}$$

Substituting (6) into (3) yields the expenditure function:

$$\left(\int_0^N p_i(s)^{1-\sigma}ds\right)^{\frac{1}{1-\sigma}} X_i, \quad i = 1, 2, 3. \tag{7}$$

The price for the composite index of manufacturing goods is thus:

$$P_i = \left(\int_0^N p_i(s)^{1-\sigma}ds\right)^{\frac{1}{1-\sigma}}. \tag{8}$$

The transport cost for shipping the manufacturing goods employs the 'iceberg' form introduced by Samuelson (1954).[5] Specifically, if $\tau > 1$ units of any variety of manufacturing good are shipped from a region to another with a distance $d$, only one unit of the good is received at the destination. In Scenario I, the distance $d$ between any two regions is the same and thus the

[5]The setting for transport cost with iceberg form can avoid a transport sector in the model (Fujita, Krugman, and Venables, 1999). However, this setting will not change the results of firms' agglomeration.

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prices for the composite goods index of manufacturing goods in the three regions are:

$$P_1 = \left( \int_0^{n_1} p_1(s)^{1-\sigma} ds + \int_0^{n_2} [\tau p_2(s)]^{1-\sigma} ds + \int_0^{n_3} [\tau p_3(s)]^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}}, \tag{9}$$

$$P_2 = \left( \int_0^{n_1} [\tau p_1(s)]^{1-\sigma} ds + \int_0^{n_2} p_2(s)^{1-\sigma} ds + \int_0^{n_3} [\tau p_3(s)]^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}}, \tag{10}$$

$$P_3 = \left( \int_0^{n_1} [\tau p_1(s)]^{1-\sigma} ds + \int_0^{n_2} [\tau p_2(s)]^{1-\sigma} ds + \int_0^{n_3} p_3(s)^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}}, \tag{11}$$

where $n_i$ denotes the number of the variety of goods in region $i$. In Scenario II, the parameter of transport costs between region 1 and region 2 and between region 2 and region 3 are $\tau > 1$, while that between region 1 and region 3 is $\tau^2$ due to the double distance for shipment. The prices for the composite goods index of manufacturing goods in the three regions are:

$$P_1 = \left( \int_0^{n_1} p_1(s)^{1-\sigma} ds + \int_0^{n_2} [\tau p_2(s)]^{1-\sigma} ds + \int_0^{n_3} [\tau p_3(s)]^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}}, \tag{12}$$

$$P_2 = \left( \int_0^{n_1} [\tau p_1(s)]^{1-\sigma} ds + \int_0^{n_2} p_2(s)^{1-\sigma} ds + \int_0^{n_3} [\tau p_3(s)]^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}}, \tag{13}$$

$$P_3 = \left( \int_0^{n_1} \left[\tau^2 p_1(s)\right]^{1-\sigma} ds + \int_0^{n_2} [\tau p_2(s)]^{1-\sigma} ds + \int_0^{n_3} p_3(s)^{1-\sigma} ds \right)^{\frac{1}{1-\sigma}}. \tag{14}$$

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The consumer's problem is to divide total income in region $i$, $Yi$, between agriculture and manufactured goods in aggregate. Maximizing the utility function in (1) under the income constraint yields the demand for agriculture and manufactures in aggregate as follows:

$$A_i = (1-\mu)\frac{Y_i}{P_i^A}, \quad i = 1, 2, 3. \tag{15}$$

$$X_i = \mu\frac{Y_i}{P_i}, \quad i = 1, 2, 3. \tag{16}$$

Substituting (16) and (8) into (6) yields the demand in region $i$ facing the consumers in region $j$:

$$d_{ij}(k) = \left(\frac{P_{ij}(k)^{-\sigma}}{P_j^{1-\sigma}}\right)\mu Y_j. \tag{17}$$

## 2.2 Supply side

It is assumed that the agricultural sector employs only non-skilled labor and the production of one unit of product needs one unit of labor. The production cost of the agricultural good is thus the wage of one non-skilled worker, $w_i^L$. The agricultural good is freely traded, so its price is the same everywhere ($P_1^A = P_2^A = P_3^A$). Then due to marginal cost pricing, interregional price equalization also implies interregional wage equalization ($w_1^L = w_2^L = w_3^L$).[6] Choosing the agricultural good as the numeraire implies $P_i^A = w_i^L = 1$, $i = 1, 2, 3$. On the other hand, the manufacturing sector is monopolistically competitive and produces differentiated products in three regions ($X_i$, $i = 1, 2, 3$) by employing both skilled and non-skilled workers Assume that the production of manufacturing variety $x_i(s)$ needs $\alpha$ units of skilled labor with wage $w_i$ and $\beta x_i(s)$ units of non-skilled labor. Thus, total costs for variety $s$ in region $i$ are:

$$TC_i(s) = w_i\alpha + w_i^L\beta x_i(s), \quad i = 1, 2, 3. \tag{18}$$

Given the constant input $\alpha$, the equilibrium number of firms in region $i$ is:

$$n_i = \frac{H_i}{\alpha}, \quad i = 1, 2, 3. \tag{19}$$

[6] Wage equalization holds as long as the agricultural good is produced in three regions. The condition is $\mu < \sigma/(3\sigma - 2)$, which is derived for the case when any two regions cannot supply economy-wide demand.

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where $H_i$ is the amount of skilled labor in region $i$.

The supply of Scenario I is analyzed as follows The profit function of a manufacturing firm producing variety s in region $i$ is:

$$\pi_i = p_{ii}(s)d_{ii}(s) + \sum_{j=1}^{3} p_{ij}(s)d_{ij}(s) - w_i\alpha - \beta\left[d_{ii}(s)\sum_{j=1}^{3}\tau d_{ij}(s)\right],$$
$$i = 1, 2, 3, \quad j = 1, 2, 3, \quad i \neq j, \tag{20}$$

where $p_{ii}(s)$ is the price of variety $s$ produced and sold in region $i$,
$d_{ii}(s)$ is the quantity of variety $s$ produced and sold in region $i$,
$p_{ij}(s)$ is the price of variety $s$ produced in region $i$ and sold in region $j$,
$d_{ij}(s)$ is quantity of variety $s$ produced in region $i$ and sold in region $j$.
$w_i$ is the wage of skilled labor in region $i$.

Solving the profit maximization problem yields:

$$p_{ii}(s) = \beta\left(\frac{\sigma}{\sigma - 1}\right), \quad i = 1, 2, 3. \tag{21}$$

$$p_{ij}(s) = \tau\beta\left(\frac{\sigma}{\sigma - 1}\right), \quad i = 1, 2, 3, \quad j = 1, 2, 3, \quad i \neq j. \tag{22}$$

Substituting (21) and (22) into (8) yields

$$P_i = \left(\frac{\beta\sigma}{\sigma - 1}\right)\left(n_i + \sum_{j=1}^{3}\phi n_j\right)^{\frac{1}{1-\sigma}}, \quad \phi \equiv \tau^{\frac{1}{1-\sigma}},$$
$$i = 1, 2, 3, \quad j = 1, 2, 3, \quad i \neq j, \tag{23}$$

where $\phi$ is the ratio of total demand by region $i$ for each export variety from region $j$ to their local variety, $\phi \in (0, 1]$. Transport cost is decreasing in $\phi$. Specifically, if trade is costless, $\phi = 1$; if trade is impossible, it approaches zero.

Substituting (21) and (22) into (20) yields the equilibrium profit of the firm. The wage $w_i$ can then be obtained by setting the equilibrium profit equal to zero due to the free entry and exit in the industry:

$$w_i = \frac{\beta x_i}{\alpha(\sigma - 1)}, \quad i = 1, 2, 3, \tag{24}$$

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where $x_i = d_{ii}(s) + \sum_{j=1}^{3} \tau d_{ij}(s)$, $i = 1, 2, 3$, $j = 1, 2, 3$, $i \neq j$.

When market clearing is reached, substituting (21), (22), and (23) from the supply side into (17) from the demand side yields:

$$\tau d_{ij}(k) = \left(\frac{\sigma - 1}{\beta\sigma}\right)\left(\frac{\phi\mu Y_j}{\phi n_i + n_j}\right), \quad i = 1, 2, 3, \quad j = 1, 2, 3, \quad i \neq j. \tag{25}$$

$$d_{ii}(k) = \left(\frac{\sigma - 1}{\beta\sigma}\right)\left(\frac{\mu Y_i}{n_i + \phi n_j}\right), \quad i = 1, 2, 3, \quad j = 1, 2, 3, \quad i \neq j. \tag{26}$$

Substituting (19), (25), and (26) into (24) yields the skilled worker's wage function in each region:

$$w_i = \left(\frac{\mu}{\sigma}\right)\left[\frac{Y_i}{H_i + \sum_{j=1}^{3} \phi H_j} + \sum_{j=1}^{3} \frac{\phi\mu Y_j}{H_j + \sum_{i=1}^{3} \phi H_i}\right], \quad i = 1, 2, 3, \quad j = 1, 2, 3, \quad i \neq j. \tag{27}$$

The supply of Scenario II is analyzed as follows. The profit function in region 2 is the same as (20), while those in region 1 and region 3 need to be modified for transport costs as:

$$\pi_1 = \sum_{j=1}^{3} p_{1j}(s) d_{1j}(s) - w_1 - \beta\left[d_{11}(s) + \tau d_{12}(s) + \tau^2 d_{13}(s)\right], \tag{28}$$

$$\pi_3 = \sum_{j=1}^{3} p_{3j}(s) d_{3j}(s) - w_3 - \beta\left[\tau^2 d_{11}(s) + \tau d_{12}(s) + d_{13}(s)\right]. \tag{29}$$

The analysis in Scenario I can be employed in Scenario II and the skilled

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worker's wage function in each region is obtained:

$$w_1 = \left(\frac{\mu}{\sigma}\right)\left[\frac{Y_1}{H_1+\phi H_2+\phi^2 H_3}+\frac{\phi Y_2}{\phi H_1+H_2+\phi H_3} +\frac{\phi^2 Y_3}{\phi^2 H_1+\phi H_2+H_3}\right], \tag{30}$$

$$w_2 = \left(\frac{\mu}{\sigma}\right)\left[\frac{Y_1}{H_1+\phi H_2+\phi^2 H_3}+\frac{\phi Y_2}{\phi H_1+H_2+\phi H_3} +\frac{\phi^2 Y_3}{\phi^2 H_1+\phi H_2+H_3}\right], \tag{31}$$

$$w_3 = \left(\frac{\mu}{\sigma}\right)\left[\frac{Y_1}{H_1+\phi H_2+\phi^2 H_3}+\frac{\phi Y_2}{\phi H_1+H_2+\phi H_3} +\frac{\phi^2 Y_3}{\phi^2 H_1+\phi H_2+H_3}\right]. \tag{32}$$

In this model, non-skilled labor cannot migrate among regions. Assume that this type of labor is equally distributed among these three regions, $L_i = L/3$. The income of this type of worker in each region is thus $L/3$ due to $w_i^L = 1$. The income in region $i$ is thus:

$$Y_i = \frac{L}{3} + w_i H_i, \quad i = 1, 2, 3. \tag{33}$$

## 3 Short-Run Equilibrium and Long-Run Equilibrium

This section analyzes the short-run equilibrium and long-run equilibrium for the model. The former represents the equilibrium given the distribution of skilled labor in each region while the latter describes the equilibrium under the condition of the mobility of skilled labor among regions.

### 3.1 Short-run equilibrium

Under the short-run condition given$H_1$, $H_2$, and $H_3$, substituting the income in each region in (33) into (27) yields:

$$\left(\frac{\sigma}{\mu}-\frac{H_1}{H_1+\phi H_2+\phi H_3}\right)w_1 - \frac{\phi H_2}{\phi H_1+H_2+\phi H_3}w_2$$

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$$-\frac{\phi H_3}{\phi H_1+\phi H_2+H_3}w_3=\frac{1}{3}\left(\frac{1}{H_1+\phi H_2+\phi H_3}+\frac{\phi}{\phi H_1+H_2+\phi H_3}+\frac{\phi}{\phi H_1+\phi H_2+H_3}\right), \tag{34}$$

$$-\frac{\phi H_1}{H_1+\phi H_2+\phi H_3}w_1+\left(\frac{\sigma}{\mu}-\frac{H_2}{\phi H_1+H_2+\phi H_3}\right)w_2-\frac{\phi H_3}{\phi H_1+\phi H_2+H_3}w_3=\frac{1}{3}\left(\frac{\phi}{H_1+\phi H_2+\phi H_3}+\frac{1}{\phi H_1+H_2+\phi H_3}+\frac{\phi}{\phi H_1+\phi H_2+H_3}\right), \tag{35}$$

$$-\frac{\phi H_1}{H_1+\phi H_2+\phi H_3}w_1-\frac{\phi H_2}{\phi H_1+H_2+\phi H_3}w_2+\left(\frac{\sigma}{\mu}-\frac{H_3}{\phi H_1+\phi H_2+H_3}\right)w_3=\frac{1}{3}\left(\frac{\phi}{H_1+\phi H_2+\phi H_3}+\frac{\phi}{\phi H_1+H_2+\phi H_3}+\frac{1}{\phi H_1+\phi H_2+H_3}\right). \tag{36}$$

Simultaneously solving (34)–(36) for $w_1$, $w_2$, and $w_3$ yields the equilibrium skilled worker's wage in each region for Scenario I:

$$w_i=\frac{\Delta_i}{\Delta},\quad i=1,2,3, \tag{37}$$

where

$$\Delta=\begin{vmatrix}\left(\frac{\sigma}{\mu}-\frac{H_1}{\lambda_1}\right) & -\frac{\phi H_2}{\lambda_2} & -\frac{\phi H_3}{\lambda_3}\\ -\frac{\phi H_1}{\lambda_1} & \left(\frac{\sigma}{\mu}-\frac{H_2}{\lambda_2}\right) & -\frac{\phi H_3}{\lambda_3}\\ -\frac{\phi H_1}{\lambda_1} & -\frac{\phi H_2}{\lambda_2} & \left(\frac{\sigma}{\mu}-\frac{H_3}{\lambda_3}\right)\end{vmatrix},$$

$$\Delta_1=\begin{vmatrix}\frac{1}{3}\left(\frac{1}{\lambda_1}+\frac{\phi}{\lambda_2}+\frac{\phi}{\lambda_3}\right) & -\frac{\phi H_2}{\lambda_2} & -\frac{\phi H_3}{\lambda_3}\\ \frac{1}{3}\left(\frac{\phi}{\lambda_1}+\frac{1}{\lambda_2}+\frac{\phi}{\lambda_3}\right) & \left(\frac{\sigma}{\mu}-\frac{H_2}{\lambda_2}\right) & -\frac{\phi H_3}{\lambda_3}\\ \frac{1}{3}\left(\frac{\phi}{\lambda_1}+\frac{\phi}{\lambda_2}+\frac{1}{\lambda_3}\right) & -\frac{\phi H_2}{\lambda_2} & \left(\frac{\sigma}{\mu}-\frac{H_3}{\lambda_3}\right)\end{vmatrix},$$

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$$\Delta_2 = \begin{vmatrix} \left(\frac{\sigma}{\mu} - \frac{H_1}{\lambda_1}\right) & \frac{1}{3}\left(\frac{1}{\lambda_1} + \frac{\phi}{\lambda_2} + \frac{\phi}{\lambda_3}\right) & -\frac{\phi H_3}{\lambda_3} \\ -\frac{\phi H_1}{\lambda_1} & \frac{1}{3}\left(\frac{\phi}{\lambda_1} + \frac{1}{\lambda_2} + \frac{\phi}{\lambda_3}\right) & -\frac{\phi H_3}{\lambda_3} \\ -\frac{\phi H_1}{\lambda_1} & \frac{1}{3}\left(\frac{\phi}{\lambda_1} + \frac{\phi}{\lambda_2} + \frac{1}{\lambda_3}\right) & \left(\frac{\sigma}{\mu} - \frac{H_3}{\lambda_3}\right) \end{vmatrix},$$

$$\Delta_3 = \begin{vmatrix} \left(\frac{\sigma}{\mu} - \frac{H_1}{\lambda_1}\right) & -\frac{\phi H_2}{\lambda_2} & \frac{1}{3}\left(\frac{1}{\lambda_1} + \frac{\phi}{\lambda_2} + \frac{\phi}{\lambda_3}\right) \\ -\frac{\phi H_1}{\lambda_1} & \left(\frac{\sigma}{\mu} - \frac{H_2}{\lambda_2}\right) & \frac{1}{3}\left(\frac{\phi}{\lambda_1} + \frac{1}{\lambda_2} + \frac{\phi}{\lambda_3}\right) \\ -\frac{\phi H_1}{\lambda_1} & -\frac{\phi H_2}{\lambda_2} & \frac{1}{3}\left(\frac{\phi}{\lambda_1} + \frac{\phi}{\lambda_2} + \frac{1}{\lambda_3}\right) \end{vmatrix},$$

$$\lambda_1 = H_1 + \phi H_2 + \phi H_3,$$
$$\lambda_2 = \phi H_1 + H_2 + \phi H_3,$$
$$\lambda_3 = \phi H_1 + \phi H_2 + H_3.$$

By the same analytical process above for Scenario II, substituting (33) into (30)–(32) yields:

$$\left(\frac{\sigma}{\mu} - \frac{H_1}{H_1 + \phi H_2 + \phi^2 H_3}\right) w_1 - \frac{\phi H_2}{\phi H_1 + H_2 + \phi H_3} w_2 - \frac{\phi^2 H_3}{\phi^2 H_1 + \phi H_2 + H_3} w_3 = \frac{1}{3}\left(\frac{1}{H_1 + \phi H_2 + \phi^2 H_3} + \frac{\phi}{\phi H_1 + H_2 + \phi H_3} + \frac{\phi}{\phi^2 H_1 + \phi H_2 + H_3}\right), \tag{38}$$

$$-\frac{\phi H_1}{H_1 + \phi H_2 + \phi^2 H_3} w_1 + \left(\frac{\sigma}{\mu} - \frac{H_2}{\phi H_1 + H_2 + \phi H_3}\right) w_2 - \frac{\phi H_3}{\phi^2 H_1 + \phi H_2 + H_3} w_3 = \frac{1}{3}\left(\frac{\phi}{H_1 + \phi H_2 + \phi^2 H_3} + \frac{1}{\phi H_1 + H_2 + \phi H_3} + \frac{\phi}{\phi^2 H_1 + \phi H_2 + H_3}\right), \tag{39}$$

$$-\frac{\phi^2 H_1}{H_1 + \phi H_2 + \phi^2 H_3} w_1 - \frac{\phi H_2}{\phi H_1 + H_2 + \phi H_3} w_2 + \left(\frac{\sigma}{\mu} - \frac{H_3}{\phi^2 H_1 + \phi H_2 + H_3}\right) w_3 = \frac{1}{3}\left(\frac{\phi^2}{H_1 + \phi H_2 + \phi^2 H_3} + \frac{\phi}{\phi H_1 + H_2 + \phi H_3} + \frac{1}{\phi^2 H_1 + \phi H_2 + H_3}\right). \tag{40}$$

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Simultaneously solving (38)–(40) for $w_1$ and $w_2$, and $w_3$ yields the equilibrium skilled worker's wage in each region for Scenario II:

$$w_i = \frac{D_i}{D}, \quad i = 1, 2, 3, \tag{41}$$

where

$$D = \begin{vmatrix} \left(\frac{\sigma}{\mu} - \frac{H_1}{\eta_1}\right) & -\frac{\phi H_2}{\eta_2} & -\frac{\phi^2 H_3}{\eta_3} \\ -\frac{\phi H_1}{\eta_1} & \left(\frac{\sigma}{\mu} - \frac{H_2}{\eta_2}\right) & -\frac{\phi H_3}{\eta_3} \\ -\frac{\phi^2 H_1}{\eta_1} & -\frac{\phi H_2}{\eta_2} & \left(\frac{\sigma}{\mu} - \frac{H_3}{\eta_3}\right) \end{vmatrix},$$

$$D_1 = \begin{vmatrix} \frac{1}{3}\left(\frac{1}{\eta_1} + \frac{\phi}{\eta_2} + \frac{\phi^2}{\eta_3}\right) & -\frac{\phi H_2}{\eta_2} & -\frac{\phi^2 H_3}{\eta_3} \\ \frac{1}{3}\left(\frac{\phi}{\eta_1} + \frac{1}{\eta_2} + \frac{\phi}{\eta_3}\right) & \left(\frac{\sigma}{\mu} - \frac{H_2}{\eta_2}\right) & -\frac{\phi H_3}{\eta_3} \\ \frac{1}{3}\left(\frac{\phi^2}{\eta_1} + \frac{\phi}{\eta_2} + \frac{1}{\eta_3}\right) & -\frac{\phi H_2}{\eta_2} & \left(\frac{\sigma}{\mu} - \frac{H_3}{\eta_3}\right) \end{vmatrix},$$

$$D_2 = \begin{vmatrix} \left(\frac{\sigma}{\mu} - \frac{H_1}{\eta_1}\right) & \frac{1}{3}\left(\frac{1}{\eta_1} + \frac{\phi}{\eta_2} + \frac{\phi^2}{\eta_3}\right) & -\frac{\phi^2 H_3}{\eta_3} \\ -\frac{\phi H_1}{\eta_1} & \frac{1}{3}\left(\frac{\phi}{\eta_1} + \frac{1}{\eta_2} + \frac{\phi}{\eta_3}\right) & -\frac{\phi H_3}{\eta_3} \\ -\frac{\phi^2 H_1}{\eta_1} & \frac{1}{3}\left(\frac{\phi^2}{\eta_1} + \frac{\phi}{\eta_2} + \frac{1}{\eta_3}\right) & \left(\frac{\sigma}{\mu} - \frac{H_3}{\eta_3}\right) \end{vmatrix},$$

$$D_3 = \begin{vmatrix} \left(\frac{\sigma}{\mu} - \frac{H_1}{\eta_1}\right) & -\frac{\phi H_2}{\eta_2} & \frac{1}{3}\left(\frac{1}{\eta_1} + \frac{\phi}{\eta_2} + \frac{\phi^2}{\eta_3}\right) \\ -\frac{\phi H_1}{\eta_1} & \left(\frac{\sigma}{\mu} - \frac{H_2}{\eta_2}\right) & \frac{1}{3}\left(\frac{\phi}{\eta_1} + \frac{1}{\eta_2} + \frac{\phi}{\eta_3}\right) \\ -\frac{\phi^2 H_1}{\eta_1} & -\frac{\phi H_2}{\eta_2} & \frac{1}{3}\left(\frac{\phi^2}{\eta_1} + \frac{\phi}{\eta_2} + \frac{1}{\eta_3}\right) \end{vmatrix},$$

$$\eta_1 = H_1 + \phi H_2 + \phi^2 H_3,$$
$$\eta_2 = \phi H_1 + H_2 + \phi H_3,$$
$$\eta_3 = \phi^2 H_1 + \phi H_2 + H_3.$$

### 3.2 Long-run equilibrium

Long-run equilibrium considers the perfect mobility of skilled labor among regions. The migration of the skilled labor depends on the indirect utility function or the real wage. The movement can be expressed as:

$$\dot{h}_i \equiv \frac{dh_i}{dt} = \begin{cases} W_i(h_i, \phi) \\ \min\{0, W_i(h_i, \phi)\} \\ \max\{0, W_i(h_i, \phi)\} \end{cases} \quad \begin{cases} \text{if } 0 < h_i < 1 \\ \text{if } h_i = 1 \\ \text{if } h_i = 0 \end{cases}, \tag{42}$$

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where $t$ is the time, $h_i = H_i / \Sigma H_i$, and (42) specifies that the share of skilled workers in region $i$ will adjust with time and depends on the difference between the indirect function in region $i$ and the average one, which is expressed as follows:

$$W_i\left(h_i, \phi\right) \equiv \delta\left(\frac{W_i}{P_i^{\mu}} - \sum_{j=1}^{3} h_j \frac{W_j}{P_j^{\mu}}\right), \quad i = 1, 2, 3, \tag{43}$$

where

$$\delta = \mu^{\mu}(1-\mu)^{1-\mu}.$$

Under this migration mechanism, the long-run equilibrium for Scenario I and for Scenario II can be obtained. Some important findings are described in the following propositions.

**Proposition 1.** In the configuration with no median location, agglomeration at one region is a stable equilibrium when transport costs are small.

*proof.* In scenario I, the distance between any two of the three regions is the same; there is thus no geographical advantage for any one region. For simplicity, the analysis of location agglomeration for region 1 is explored for this scenario. Substituting $H_1 = H$, and $H_2 = H_3 = 0$ into (23) yields the prices for the composite goods index of manufacturing goods in the three regions as follows:

$$P_1 = \frac{\beta\sigma}{\sigma - 1}\left(\frac{H}{\alpha}\right)^{\frac{1}{1-\sigma}}, \quad P_2 = P_3 = \frac{\beta\sigma}{\sigma - 1}\left(\frac{\phi H}{\alpha}\right)^{\frac{1}{1-\sigma}}.$$

Substituting the above price index into (37) yields the skilled worker's wage in each region. These wage levels in region 1 and region 2 are modified by the cost-of-living index, and the real wage ratio is obtained:

$$\frac{\omega_1}{\omega_2} = \frac{w_1 \cdot P_1^{-\mu}}{w_2 \cdot P_2^{-\mu}} = \frac{3\sigma\phi}{\left(\phi^2 + \phi + 1\right)(\sigma - \mu) + 3\phi^2\mu} \cdot \phi^{\frac{\mu}{1-\sigma}}. \tag{44}$$

Let $\phi$ be defined by $\phi_s^1$ (called the sustain point by Fujita, Krugman, and Venables (1999)) when this real wage ratio in (44) is equal to one. When $\phi > \phi_s^1$, (44) will be greater than one, $\omega_1/\omega_2 > 1$. This condition means that the agglomeration at region 1 is stable. Due to $\phi \in (0, 1]$ and a greater value of $\phi$ representing smaller transport cost, this means a smaller transport cost will ensure that the agglomeration at one region is a stable equilibrium. □

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**Proposition 2.** In the configuration with no median location, even dispersion among the three regions is stable when transport costs are high.

*proof.* If the firms are evenly distributed among the three regions, the condition, $h_1 = h_2 = h_3 = 1/3$ will hold. For any two of the three regions (region 1 and region 2, for instance) in scenario I, the even dispersion is a stable equilibrium when the following two conditions hold.

$$\frac{w_j}{P_1^{\mu}} - \frac{w_2}{P_2^{\mu}} = 0, \tag{45}$$

$$\frac{\partial \left(w_1 \cdot P_1^{-\mu} - w_2 \cdot P_2^{-\mu}\right)}{\partial h_1} < 0. \tag{46}$$

Condition (45) is for equilibrium and condition (46) is for stability. Substituting condition $h_1 = h_2 = h_3 = 1/3$ into (45) yields $w_1 = w_2$ and $P_1^{\mu} = P_2^{\mu}$ and thus (45) is satisfied. The same substitution for condition (46) yields the following condition:

$$\phi < \frac{1 + \frac{\mu^2 - 4\sigma\mu - \mu}{\sigma^2 - \sigma}}{1 + \frac{\mu^2 + 4\sigma\mu - 2\mu}{\sigma^2 - \sigma}} = \phi_b^I. \tag{47}$$

The condition in (47) expresses the stable condition with a higher transport cost. That is, the even dispersion of firms among the three regions is stable for higher transport costs. The parameter $\phi_b^I$ in (47) is called the break point in Fujita, Krugman, and Venables (1999). When transport costs are lower than this point ($\phi > \phi_b^I$), the even distribution will be broken. Thus, if $\phi_b^I < 0$, the symmetric outcome is never stable independently of parameter values (Forslid and Ottaviano, 2003). To avoid this situation, the 'no black hole' condition ($\mu < \sigma - 1$) is assumed.[7] □

**Proposition 3.** In the configuration with a median location, agglomeration at the median location as well as a non-median location is a stable equilibrium when transport costs are small. However, agglomeration at a median location is more likely than at a non-median location

*proof.* (1) In scenario II, if agglomeration at the median location exists, condition, $h_2 = 1$ and $h_1 = h_3 = 0$ will hold. The prices for the composite

[7] This condition is derived by setting $\phi_b^I > 0$.

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goods index of manufacturing goods in a non-median location (region 1, for example) and the median location (region 2) will be as follows:

$$P_1 = \frac{\beta\sigma}{\sigma-1}\left(\frac{H\phi}{\alpha}\right)^{\frac{1}{1-\sigma}}, \quad P_2 = P_3 = \frac{\beta\sigma}{\sigma-1}\left(\frac{H}{\alpha}\right)^{\frac{1}{1-\sigma}}.$$

Substituting the above price index into (37) yields the skilled worker's wage in each region. These wage levels in region 1 and region 2 are modified by the cost-of-living index, and the real wage ratio is obtained:

$$\frac{w_2 \cdot P_2^{-\mu}}{w_1 \cdot P_1^{-\mu}} = \frac{3\sigma\phi^{1+\frac{\mu}{1-\sigma}}}{\sigma-\mu+2\sigma\phi^2+\mu\sigma^2}. \tag{48}$$

Let $\phi$ be defined by $\phi_{sm}^{II}$ (termed the sustain point by Fujita, Krugman, and Venables (1999)) when this real wage ratio in (48) is equal to one. When $\phi > \phi_{sm}^{II}$, the real wage ratio in (48) is greater than 1. Thus the agglomeration at region 2 is a stable equilibrium when transport costs are small.

(2) In scenario II, if agglomeration at a non-median location exists, conditions $H_1 = H$ and $H_2 = H_3 = 0$ hold. The prices for the composite goods index of manufacturing goods in a non-median location (region 1, for example) and the median location (region 2) will be as follows:

$$P_1 = \frac{\beta\sigma}{\sigma-1}H^{\frac{1}{1-\sigma}}, \quad P_2 = P_3 = \frac{\beta\sigma}{\sigma-1}(\phi H)^{\frac{1}{1-\sigma}}.$$

Substituting the above price index into (37) yields the skilled worker's wages in each region. These wages in region 1 and region 2 are modified by the cost-of-living index and the real wage ratio is obtained:

$$\frac{w_1 \cdot P_1^{-\mu}}{w_2 \cdot P_2^{-\mu}} = \frac{3\sigma\phi^{1+\frac{\mu}{1-\sigma}}}{2\sigma-2\mu+\sigma\phi^2+2\mu\sigma^2}. \tag{49}$$

Let $\phi$ be defined by $\phi_{sn}^{II}$ when this real wage ratio in (49) is equal to one. When $\phi > \phi_{sn}^{II}$, the real wage ratio in (49) is greater than 1. Thus the agglomeration at region 1 is a stable equilibrium when transport costs are small. □

However, comparing these two sustain points for the agglomeration at the median location and that at a non-median location, it can be found that $\phi_{sm}^{II}$ for the median location is smaller than $\phi_{sn}^{II}$ for a non-median location.

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Table 1: Sustain point for the agglomeration at median location

| $\phi_{sm}^{II}$ | $\mu = 0.2$ | $\mu = 0.4$ | $\mu = 0.6$ | $\mu = 0.8$ |
|---|---|---|---|---|
| $\sigma = 2$ | 0.2703 | 0.1176 | 0.0265 | 0.0003 |
| $\sigma = 3$ | 0.3633 | 0.2550 | 0.1685 | 0.1006 |
| $\sigma = 4$ | 0.4018 | 0.3185 | 0.2475 | 0.1869 |
| $\sigma = 5$ | 0.4232 | 0.3556 | 0.2959 | 0.2431 |

Table 2: Sustain point for the agglomeration at non-median location

| $\phi_{sn}^{II}$ | $\mu = 0.2$ | $\mu = 0.4$ | $\mu = 0.6$ | $\mu = 0.8$ |
|---|---|---|---|---|
| $\sigma = 2$ | N.A. | 0.4723 | 0.1599 | 0.0102 |
| $\sigma = 3$ | N.A. | 0.9120 | 0.6078 | 0.3863 |
| $\sigma = 4$ | N.A. | N.A. | 0.8712 | 0.6565 |
| $\sigma = 5$ | N.A. | N.A. | N.A. | 0.8477 |

Note: N.A. denotes that the value for $\phi_{sn}^{II}$ does not exist; that is, the agglomeration at a non-median location does not exist.

Note that $\phi \in (0, 1]$, and transport cost is decreasing in $\phi$. This implies that agglomeration is more likely at the median location than at a non-median location due to the range of transport costs to ensure that agglomeration at a median location is wider than that at non-median location. The values for these two sustain points are shown in Table 1 and Table 2 for various $\sigma$ and $\mu$. For higher $\sigma$ and smaller $\mu$, the agglomeration at a non-median location is impossible. On the other hand, the sustain point for the agglomeration at the median location exists for all the values of the parameters.

**Proposition 4.** In the configuration with median location, even dispersion among the three regions is stable when transport costs are very high.

*proof.* If the firms are evenly distributed among the three regions, the condition, $h_1 = h_2 = h_3 = 1/3$ will hold. For two of the three regions (region 1 and region 2, for instance) in scenario II, the even dispersion is a stable equilibrium when the following three conditions hold.

$$\frac{w_1}{P_1^{\mu}} - \frac{w_2}{P_2^{\mu}} = 0, \tag{50}$$

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$$\frac{\partial\left(w_1 \cdot P_1^{-\mu} - w_2 \cdot P_2^{-\mu}\right)}{\partial h_1} < 0, \tag{51}$$

$$\frac{\partial\left(w_2 \cdot P_2^{-\mu} - w_1 \cdot P_1^{-\mu}\right)}{\partial h_2} < 0. \tag{52}$$

Substituting $h_1 = h_2 = h_3 = 1/3$ into (50) yields

$$\frac{w_2 \cdot P_2^{-\mu}}{w_1 \cdot P_1^{-\mu}} = \frac{RA + RB}{RA + RC} \times \left(\frac{1 + 2\phi}{1 + \phi + \phi^2}\right)^{\frac{\mu}{\sigma - 1}} = 1, \tag{53}$$

where

$$\begin{aligned} RA &= \mu^2\phi^4 - 2\mu^2\phi^2 - 4\mu\phi\sigma + \sigma^2 + 8\phi^3\sigma^2 - 2\mu\sigma + 4\phi\sigma^2 \\ &\quad + \mu^2 + 5\phi^4\sigma^2, \\ RB &= 6\mu\phi^4\sigma - 4\mu\phi^2\sigma + 4\mu\phi^3\sigma + 9\phi^2\sigma^2, \\ RC &= 3\mu\phi^4\sigma - \mu\phi^2\sigma + \mu\phi^3\sigma + 6\phi^2\sigma^2 + 3\mu\phi^5\sigma + 3\phi^5\sigma^2. \end{aligned}$$

When transport costs are extremely large, $\phi \to 0$, then (50) is satisfied. Substituting $\phi \to 0$ into (51) and (52) yields[8]

$$-\frac{3\mu L(\sigma - \mu - 1)}{(\sigma - 1)(\sigma - \mu)H}\left[\frac{\beta\sigma\left(\frac{H}{3\alpha}\right)^{\frac{1}{1-\sigma}}}{\sigma - 1}\right]^{-\mu} \quad < 0 \text{ if } \; > \mu + 1.$$

Thus, when transport costs are extremely high, firms are equally distributed among the three regions. □

## 4 Numerical Analysis

To provide the firms' distribution among regions under various transport costs, numerical simulations are conducted for two cases Different expenditure shares for manufactured goods are selected. Specifically, $\mu = 0.4$ and $\mu = 0.6$ are used for the following analysis.

Case 1. Parameter values: $\mu = 0.4, \sigma = 4, \beta = 0.1, \alpha = 1$

[8]The break point in Scenario II is difficult to solve analytically. However, it can be shown that a small positive $\phi$ (approaching zero) will ensure the stability condition for the symmetric distribution under the condition, $\mu < \sigma - 1$ (no black hole condition).

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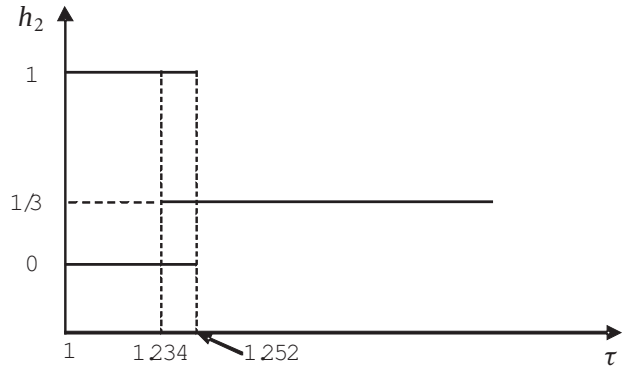



Figure 3: Firms' distribution for Scenario I (with no median location) with $\mu = 0.4$

In Scenario I (with no median location), firms' distribution among regions under various transport costs is shown in Figure 3. When transport cost is small ($\tau < 1.234$), firms agglomerating at any region is a stable equilibrium. When transport cost is high ($\tau > 1.252$), firms are equally distributed among the three regions. When transport cost is moderate ($1.234 < \tau < 1.252$), both equal distribution and agglomeration at one region are stable equilibria. In Scenario II (with the median location), firms' distribution at the median location and a non-median location is shown in Figure 4 and Figure 5, respectively. When transport cost is small ($\tau < 1.474$), firms' agglomeration at the median location is a stable equilibrium, while agglomeration at a non-median location does not exist, because the advantage of the median location dominates the non-median location. When transport cost is high ($\tau > 1.784$), firms are equally distributed among the three regions. When transport cost is moderate ($1.474 < \tau < 1.784$), both equal distribution and agglomeration at one region are stable equilibria. Comparing these two scenarios, the range of transport cost for agglomeration in Scenario II is larger than that in Scenario I. This means the agglomeration at the median location in Scenario II is more likely than agglomeration at the non-median location in Scenario I. Moreover, the transport cost for equal distribution in Scenario II is larger than that in Scenario I. That is, the equal distribution in Scenario II is not more likely than that in Scenario I. This is because the advantage of median location is evident for small transport cost, and disappears when transport

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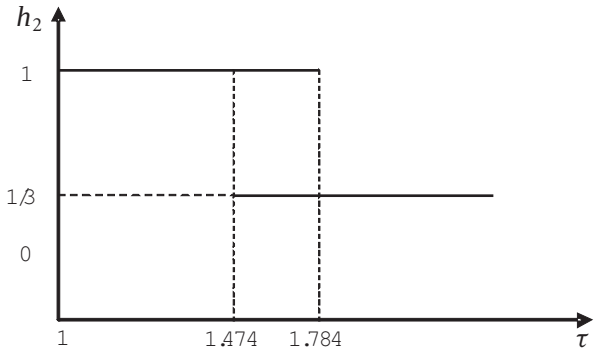



Figure 4: Firms' distribution at the median location for Scenario II (with median location) with $\mu = 0.4$

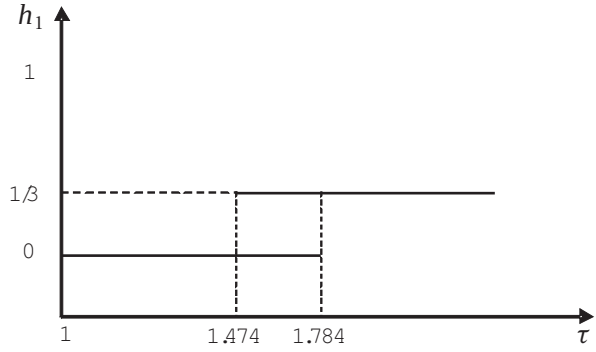



Figure 5: Firms' distribution at non-median location for Scenario II (with median location) with $\mu = 0.4$

cost is large enough.

Case 2. Parameter values: $\mu = 0.6, \sigma = 4, \beta = 0.1, \alpha = 1$

In Scenario I (with no median location), firm' distribution among regions under various transport costs is shown in Figure 6. The distribution pattern is similar with Figure 3 ($\mu = 0.4$). The difference is that transport cost range for agglomeration ($\tau < 1.360$) enlarges and the transport cost to ensure the equal distribution ($\tau > 1.397$) increases. In Scenario II (with me-

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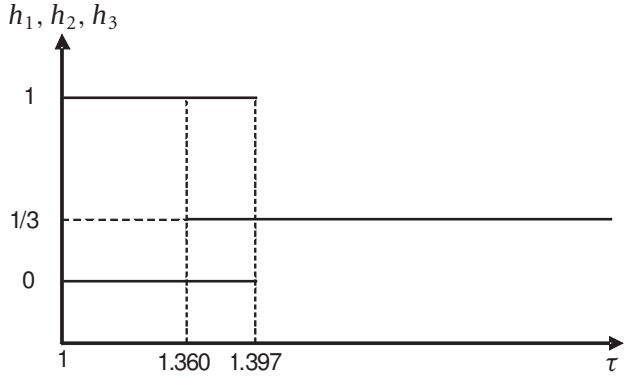



Figure 6: Firms' distribution for scenario I (with no median location) with $\mu = 0.6$

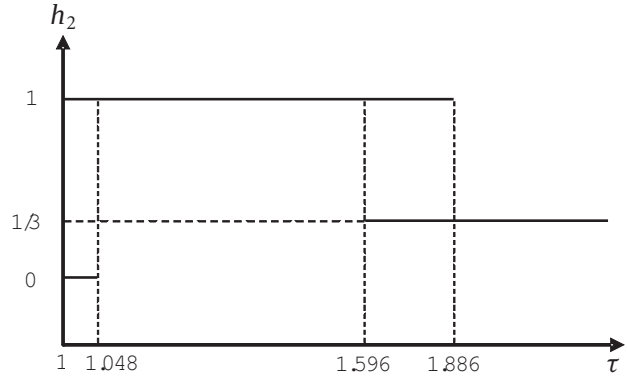



Figure 7: Firms' distribution at median location for scenario II (with median location) with $\mu = 0.6$

dian location), firms' distribution with a median location and non-median location are shown in Figure 7 and Figure 8, respectively. Compared with Figure 4 and Figure 5 ($\mu = 0.4$), the distribution pattern is different. When transport cost is very small ($\tau < 1.048$), the agglomeration at a non-median location is a stable equilibrium. This agglomeration does not exist in the case with $\mu = 0.4$. In addition, the agglomeration at the median location exists in a larger range ($\tau < 1.596$). However, the equal distribution emerges for a larger transport cost ($\tau > 1.886$).

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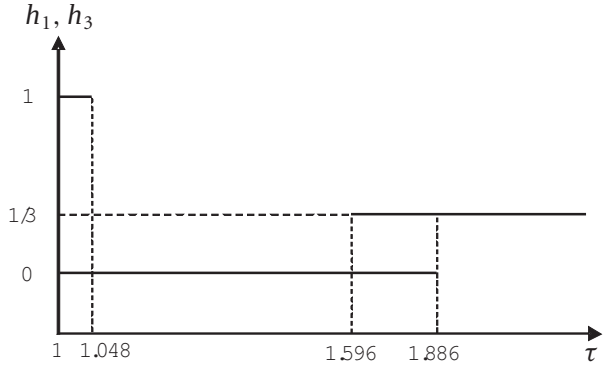



Figure 8: Firms' distribution at non-median location for scenario II (with median location) with $\mu = 0.6$

## 5 Analysis with Helpman's Mechanism

The analysis for the role of median location of three regions in previous sections is under the setting of Forslid and Ottaviano (2003), which essentially is in the economic mechanism of Krugman (1991). This section is to explore the issue by the approach of Helpman's (1998). The reason is because the agglomeration mechanism is very different between Krugman (1991) and Helpman's (1998). The comparative statics of trade costs are exactly opposite. It is worth probing the implications of the model in previous sections under Helpman's agglomeration mechanism.

### 5.1 Helpman's basic model

The economy consists of three regions which form two layouts as the setting in section 2 (see Figure 1 and Figure 2). Each region has a fixed stock of housing and people can choose in which region to reside. There are M identical individuals, each having a Cobb-Douglas utility function which can be expressed by (1) after replacing agricultural goods $A_i$ with housing services $S_i$ Then eqs. (2)–(14) are also applied in this model.

Assume that it takes $\mathbf{a} + \mathbf{x}$ units of labor to produce $\mathbf{x}$ units of a single brand of manufacturing good, where $\mathbf{a}$ represents fixed costs and marginal cost is normalized to one unit of labor. Then with a wage rate $w_i$, the mill

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price of each locally produced brand in region $i$ equals

$$p_i = \frac{\sigma}{\sigma - 1} w_i.$$

The free entry of zero profit condition yields a constant output level for each brand, $x = a(\sigma - 1)$. Thus, the number of brands (number of firms) is thus $n_i = M_i/(a\sigma)$, where $M_i$ denotes the number of individuals in region $i$ Each individual spends a fraction $1 - \mu$ of personal income on housing from the Cobb –Douglas utility function. The aggregate housing spending equals $(1 - \mu)Y$, where $Y = \Sigma_i Y_i$. The income consists of wage and housing revenue $(1 - \mu)Y$. Assume that housing stocks are equally owned by all individuals. Thus, income from housing revenue in region $i$ equals the fraction $M_i/M$ of total income revenue. The income of region $i$ equals

$$Y_i = w_i M_i + \frac{1 - \mu}{\mu} \frac{M_i}{M} \left( \sum w_i M_i \right) \quad \text{for } i = 1, 2, 3. \tag{54}$$

The utility in region $i$ equals

$$u_i = \left( \frac{S_i}{M_i} \right)^{1-\mu} \left( \frac{\mu Y_i}{M_i P_i} \right)^{\mu}, \tag{55}$$

where $S_i$ denotes the housing stock in region $i$. Thus, consumption of housing per resident equals $S_i/M_i$.

## Scenario I

For the manufactured good, the condition of supply equals the aggregate demand for each brand produced in region $i$ $(i = 1, 2, 3)$, respectively:

$$a(\sigma - 1) = \mu Y_1 p_1^{-\sigma} P_1^{\sigma-1} + \mu Y_2 (p_1\tau)^{-\sigma} P_2^{\sigma-1}\tau + \mu Y_3 (p_1\tau)^{-\sigma} P_3^{\sigma-1}\tau,$$
$$a(\sigma - 1) = \mu Y_1 (p_2\tau)^{-\sigma} P_1^{\sigma-1}\tau + \mu Y_2 P_2^{-\sigma} P_2^{\sigma-1} + \mu Y_3 (p_2\tau)^{-\sigma} P_3^{\sigma-1}\tau,$$
$$a(\sigma - 1) = \mu Y_1 (p_3\tau)^{-\sigma} P_1^{\sigma-1}\tau + \mu Y_2 (p_3\tau)^{-\sigma} P_2^{\sigma-1}\tau + \mu Y_3 P_3^{-\sigma} P_3^{\sigma-1}.$$

The relative utilities can be expressed as

$$V_I = \frac{u_2}{u_1} = \Gamma^{1-\mu} \Lambda^{\mu} \Psi^{\frac{\mu}{\sigma-1}}, \tag{56}$$

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where

$$\Gamma = \frac{S_2}{S_1}\frac{f_1}{f_2}, \tag{57}$$

$$\Lambda = \frac{\mu q_{21} + (1-\mu)\,(f_1 + f_2 q_{21} + f_3 q_{31})}{\mu + (1-\mu)\,(f_1 + f_2 q_{21} + f_3 q_{31})}, \tag{58}$$

$$\Psi = \frac{f_1 \tau^{1-\sigma} + f_2 q_{21}^{1-\sigma} + f_3\,(\tau q_{31})^{1-\sigma}}{f_1 + f_2\,(\tau q_{21})^{1-\sigma} + f_3\,(\tau q_{31})^{1-\sigma}}, \tag{59}$$

$$f_i = M_i/M \ \text{ for } \ i = 1, 2, 3, \ \ q_{21} = w_2/w_1 = p_2/p_1, \quad q_{31} w_3/w_1 = p_3/p_1.$$

Scenario II

For the manufactured good, the condition of supply equals the aggregate demand for each brand produced in region $i$ ($i = 1, 2, 3$), respectively:

$$\begin{aligned}
a(\sigma-1) &= \mu Y_1 p_1^{-\sigma} P_1^{\sigma-1} + \mu Y_2\,(p_1\tau)^{-\sigma}\, P_2^{\sigma-1}\tau \\
&\quad + \mu Y_3\,(p_1\tau)^{-\sigma}\, P_3^{\sigma-1}\tau^2, \\
a(\sigma-1) &= \mu Y_1\,(p_2\tau)^{-\sigma}\, P_1^{\sigma-1}\tau + \mu Y_2 P_2^{-\sigma} P_2^{\sigma-1} \\
&\quad + \mu Y_3\,(p_2\tau)^{-\sigma}\, P_3^{\sigma-1}\tau, \\
a(\sigma-1) &= \mu Y_1\,(p_3\tau)^{-\sigma}\, P_1^{\sigma-1}\tau^2 + \mu Y_2\,(p_3\tau)^{-\sigma}\, P_2^{\sigma-1}\tau \\
&\quad + \mu Y_3 P_3^{-\sigma} P_3^{\sigma-1}.
\end{aligned}$$

The relative utilities can be expressed as

$$V_{II} = \frac{u_2}{u_1} = \Gamma^{1-\mu}\Lambda^{\mu}\Omega^{\frac{\mu}{\sigma-1}}, \tag{60}$$

where

$$\Omega = \frac{f_1 \tau^{1-\sigma} + f_2 q_{21}^{1-\sigma} + f_3\,(\tau q_{31})^{1-\sigma}}{f_1 + f_2\,(\tau q_{21})^{1-\sigma} + f_3\,(\tau^2 q_{31})^{1-\sigma}}, \tag{61}$$

$\Gamma$, $\Lambda$ are defined in (57) and (58).

**Proposition 5.** In both configurations with no median location and with median location, even dispersion among the three regions is stable when transport costs are extremely small under Helpman's mechanism with equal housing stock in each region.

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*proof.* If the firms are evenly distributed among the three regions, it implies $f_1 = f_2 = f_3 = 1/3$. For any two of the three regions (region 1 and region 2, for instance) in scenario I, the even dispersion is a stable equilibrium when the following two conditions hold: $V_I = 1$, and $\partial V_I / \partial f_2 < 0$.

When the housing stock in each region is the same, it means $S_1 = S_2$. The even distribution condition $f_1 = f_2$, implies $w_1 = w_2$. Inserting these conditions into (57)–(59) yields $\Gamma = \Lambda = \Psi = 1$, thus $V_I = 1$ holds. Due to the distribution of each of the three regions varying with each other we set $f_1 = f_3 = (1 - f_2)/2$ to analyze the impact of change in $f_2$. For the condition of transport costs being extremely small, $\tau \to 1$, we obtain $\Psi = 1$. Thus

$$\begin{aligned}
\frac{\partial V_I}{\partial f_2} &= (1-\mu)\Gamma^{-\mu}\frac{\partial \Gamma}{\partial f_2}\Lambda^{\mu} + \mu\Lambda^{\mu-1}\frac{\partial \Lambda}{\partial f_2}\Gamma^{1-\mu}, \qquad (62)\\
\frac{\partial \Gamma}{\partial f_2} &= -\frac{1}{f_2^2},\\
\frac{\partial \Lambda}{\partial f_2} &= \frac{\mu(1-\mu)\left(q_{21} - \frac{1}{2} - \frac{q_{31}}{2}\right)(1-q_{21})}{\left[\mu + (1-\mu)\left(f_1 + f_2 q_{21} + f_3 q_{31}\right)\right]^2} = 0.
\end{aligned}$$

Inserting $f_1 = f_2 = f_3 = 1/3$ (implying $q_{21} = q_{31} = 1$) into equation (62), $\partial V_I / \partial f_2 < 0$ holds. □

In scenario II, the condition of transport costs being extremely small, $\tau \to 1$, yields $\Omega = 1$. Thus, the proof in scenario I can be applied to scenario II, and $V_{II} = 1$, and $\partial V_{II} / \partial f_2 < 0$ hold.

## 5.2 Numerical simulation

For the cases with larger transport costs, the analytical approach is intractable and thus the firms' distribution is analyzed by numerical simulations. The results can be classified into two types. The first type is under the condition of $(1-\mu)\sigma > 1$. The other type is under the condition of $(1-\mu)\sigma < 1$. The difference represents the role of elasticity of substitution $\sigma$ and the preference (expenditure share) of housing service, $1-\mu$. The higher elasticity of substitution represents the decreasing role of variety of manufactured products. This implies that the advantages of a region with more population decrease. In addition, a higher value of preference for housing strengthens the dispersion force of distribution due to less population enjoying lower

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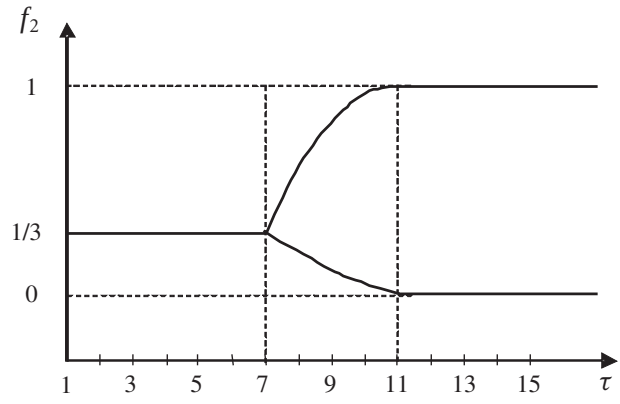



Figure 9: Firms' distribution for scenario I with Helpman model

housing costs. Therefore, the first type yields symmetric (dispersion) distribution, $f_1 = f_2 = f_3 = 1/3$, regardless of the value of transport costs in both scenario I and scenario II.[9] Note that the general advantages of median location are dominated by the two effects (higher elasticity of substitution and higher housing preference).

The other type has lower elasticity of substitution and lower housing preference. The values for the parameters are $\sigma = 2$, $\mu = 0.6$ in the following simulations. In scenario I, the firms' distribution for region 2 (or any region) is shown in Figure 9. The result shows that $f_2 = 1/3$ as $\tau < 7$, and $f_2 \to 1$ as $\tau > 11$. When transport costs are in a moderate range, two asymmetric distributions (one larger than 1/3 and the other smaller than 1/3) exist. In scenario II, the firms' distribution for region 2 (median region) is shown in Figure 10. The result shows that $f_2 \to 1/3$ as $\tau \to 1$, then $f_2$ increases as $\tau$ increases to 10, $f_2 \to 1$ as $\tau > 10$, and two kinds of distribution ($f_2 \to 1$ and $f_2 \to 0$) exist as $\tau > 13.6$. Note that when $10 < \tau < 13.6$, there is a unique agglomeration, which does not exist in scenario I. The firms' distribution for a non-median location (region 1 or region 3) in scenario II is shown in Figure 11. The result shows that $f_1 \to 1/3$ as $\tau \to 1$, then $f_1$ decreases as $\tau$ increases to 10, $f_1 \to 0$ as $\tau > 10$, and two kinds of distribution ($f_1 \to 1$ and $f_1 \to 0$) exist as

[9] An example with $\sigma = 2$, $\mu = 0.6$ yields this symmetric distribution. This situation for three regions with median location or non-median location yields the same symmetric distribution, which is consistent with that for two regions in Helpman's (1998).

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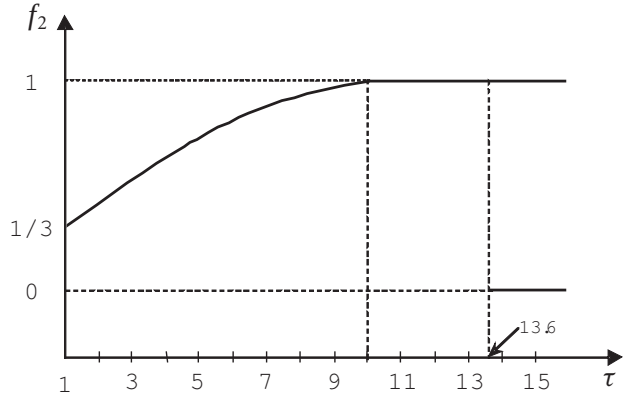



Figure 10: Firms' distribution at median location for scenario II with Helpman model

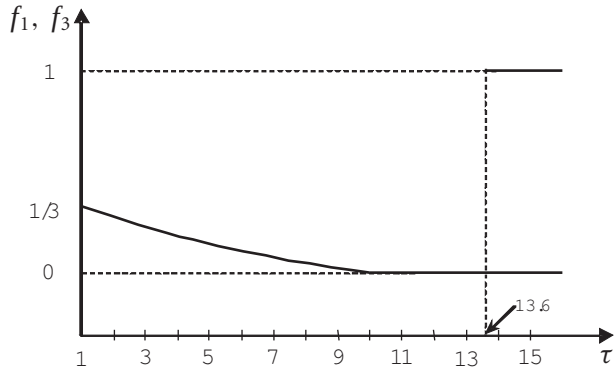



Figure 11: Firms' distribution at non-median location for scenario II with Helpman model

$\tau > 13.6$.

## 5.3 Comparison for the results of FE and Helpman models

The FE model is based on the mechanism of Krugman, while the Helpman mechanism introduces a housing sector as the main dispersion force in the NEG model. For the case without median location (scenario I), there are some findings in these two models. First, the symmetric (dispersion) distribution emerges at low transport costs in the Helpman model but at

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high transport costs in the FE model. Second, the two stable equilibria, agglomeration and no-firm distribution (core and periphery), emerge at high transport costs in the Helpman model and at low transport costs in the FE model. Third, the two asymmetric distributions (one larger than the symmetric distribution and the other less than the symmetric distribution) emerge at moderate transport costs in the Helpman model but do not exist in the FE model. Fourth, three stable equilibria including symmetric, agglomerated, and no-firm distribution exist for moderate transport costs in the FE model but do not exist in the Helpman model.

For the case in scenario II (with median location), there are some findings in these two models. First, a unique full agglomeration emerges at a median location in the range of low transport costs in the FE model, while it is in the range of moderate transport costs in the Helpman model. Second, a unique asymmetric distribution increases from one third in transport costs in the Helpman model. This distribution does not exist in the FE model. Third, the two stable equilibria of agglomeration and no-firm distribution emerge at high transport costs in the Helpman model, but at low transport costs in the FE model. This difference is the same as that in scenario I.

For empirical studies by NEG models,[10] the FE model (Krugman's mechanism) and Helpman's mechanism provide very different agglomeration and dispersion forces with respect to transport costs. The Helpman model introduces housing services as a dispersion force for economic activities due to its non-tradable feature among regions. Both mechanisms represent the different circumstances of urban and spatial economies. Ades and Glaeser (1995) provide persuasive results using a substantially different method. The data include a cross-section of 85 countries. Three variables capturing transport costs within each country include area, expenditures on transport and communication and road density. All three variables point to a positive relation between trade costs and agglomeration. This contradicts the prediction of Krugman's model but is consistent with the Helpman model (Head and Mayer, 2004). In the Helpman model, the value of $(1 - \mu)\sigma$ represents the strength of dispersion, which leads to different distribution outcomes.

[10]The related empirical studies include various issues such as interregional wage difference, home market effect, long-term impact of temporary shocks, and spatial distribution of economic activities in North America, the European Union, and Asia. For a detailed review, please see Head and Mayer (2004), Holmes and Steven (2004), Combes and Overman (2004), and Fujita et al. (2004).

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When $(1-\mu)\sigma > 1$, there exists only a unique dispersion equilibrium. When $(1-\mu)\sigma < 1$, the distribution tends to agglomerate as transport costs increase. Redding and Sturm (2008), to explore German division and reunification, employ Helpman's model and select $\sigma = 4$, $(1-\mu) = 1/3$, and thus a unique dispersion stable equilibrium is adopted for the analysis. Baum-Snow et al. (2017) investigate the effects of the Chinese national highway system constructed between the late 1990s and 2010 on local economic outcomes. They conclude that transportation improvement (such as national highways) leads the population and economic activities away from small cities and towns (hinterland preferences) to big cities (regional primates). Specifically, with better regional highways, the latter specialize more in manufacturing and services while the former lose manufacturing but gains in agriculture. The evidence shows that the decrease in transport costs encourages the agglomeration of distribution, which is consistent with the Krugman prediction (or FE model) rather than the Helpman prediction.

## 6 Concluding Remarks

This study combines two main issues in urban and regional economics, the location theory and new economic geography. The role of median location in the models of FE version and Helpman's (1998) is explored. In an equilateral triangle with no median location, industrial agglomeration or no-firm distribution (a core-periphery pattern) emerge when transport costs are small in the FE model but large in the Helpman model. Symmetric industrial dispersion among the three regions emerges when transport costs are large in the FE model but small in the Helpman model. Three distributions including agglomeration, no-firm and symmetric dispersion exist when transport costs are moderate for a particular range in the FE model but do not exist in the Helpman model. However, two asymmetric distributions emerge at moderate transport costs in the Helpman model but do not exist in the FE model.

On a line with equal distance between two adjacent regions, the median location is the center region. The symmetric industrial dispersion among the three regions emerges when transport costs are larger than those in the triangle with no median location in the FE model, because the advantage of median location is lost only when transport costs are larger. However, this symmetric dispersion never emerges in the Helpman model unless transport costs approach zero. In the FE model with small transport costs, the

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agglomeration at the median location is more likely to achieve stable equilibrium than agglomeration at a non-median location. The agglomeration stable equilibrium for a non-median location exists for only a small range of transport costs, when $\mu$ is large or $\sigma$ is small. That is, the median location in the FE model also provides advantages over non-median locations as in the model of Weber's location theory. Moreover, agglomeration at a median location is more likely than at a non-median location for the case with lower transport cost between regions. In the Helpman model, a unique asymmetric distribution at the median location increases from one-third as transport costs increase. This shows that the advantage of median location exists even in the Helpman model, which provides housing services as a major centrifugal force.

There are at least three possible avenues for future research. First, one city with more population might attract more housing producers to supply more housing services. Thus, endogenizing the housing services in Helpman's (1998) with a median location setting might be worth exploring. Second, we may introduce intermediate goods into the production function of the final good, as it may be interesting to analyze the role of median location in the vertical production linkage. Third, some interesting empirical issues (such as interregional wage difference, home market effect and long-term impact of the temporary shock of an earthquake or tsunami) can be re-examined under Helpman's mechanism and the configuration with median location.

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# 中間區位與經濟地理

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本研究探討中間區位在 NEG 模型的隨處資本家 (FE) 版本與 Helpman's (1998) 版本中的角色。考慮包含三區域的兩種空間型態: 一爲等邊三角形 (無中間區位); 另一爲一線上的三點且相鄰兩點等距 (中點的區位爲中間區位)。研究結果顯示這兩種型態會有一些差異。在無中間區位的型態中, 在 FE 模型的低運輸成本以及 Helpman 模型的高運輸成本時, 廠商會聚集於任一區域; 而在 FE 模型的高運輸成本以及 Helpman 模型的低運輸成本時, 廠商會平均分布 (分散) 在三區域。在具中間區位的型態中, 廠商分散 (對稱分布) 的情況在 FE 模型運輸成本較高 (比較無中間區位) 時才會出現, 因爲此時中間區位的優勢才會消失。但是此種對稱分布在 Helpman 模型中不會出現, 除非運輸成本趨近於 0。在 Helpman 模型中, 當運輸成本上升時, 一個非對稱分布出現且中間區位的廠商比例由 1/3 遞增, 表示在以住宅爲主要離心力的 Helpman 模型中, 中間區位的優勢仍然存在。

**關鍵詞**: 中間區位, 核心邊陲模型, 經濟地理, 聚集, 三區域
**JEL 分類代號**: R12, R30

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