Productivity Shocks and the Spatial Distribution of Economic Activity

Po-Hao Lu and Jyh-Fa Tsai*

Abstract

This research evaluates how the spatial distribution of economic activity changes after the effects of a productivity shock. We develop a two-region general equilibrium model with increasing returns and show what conditions change the original spatial distribution of a manufacturing industry. This paper advances the understanding of firm dynamics after the effects of a productivity shock. It also provides some real-world cases that are consistent with the industrial spatial distribution of our model.

Keywords: Increasing Returns, Productivity, Multiple Equilibria, Migration
JEL Classification: F12, F22, R12

---

* Corresponding author: Jyh-Fa Tsai, Distinguished Professor in the Graduate Institute of Urban Planning, National Taipei University, No. 151, University Rd., Sanxia Dist., New Taipei City 237301, Taiwan, R.O.C., Tel.: 886-2-86741111 ext. 67349, E-mail: tsaij@mail.ntpu.edu.tw. Po-Hao Lu, PhD in the Graduate Institute of Urban Planning, National Taipei University, No. 151, University Rd., Sanxia Dist., New Taipei City 237301, Taiwan, R.O.C., E-mail: s810874102@gm.ntpu.edu.tw. The authors are very grateful to three anonymous referees for their helpful comments and suggestions.

Received January 5, 2023; revised March 29, 2023; accepted March 18, 2024.

經濟研究 (Taipei Economic Inquiry), 60:2 (2024), 175-221。
臺北大學經濟學系出版

1. Introduction

Do workers and/or manufacturing firms leave cities after a big shock? In recent years, some literature studies empirical cases to answer this question (Boustan et al., 2020; Ager et al., 2020; Testa, 2021; Siodla, 2021; Indaco et al., 2021). From the perspective of population, Glaeser (2021) reviews literature and points out that after physical damage (such as explosions, fires, earthquakes, etc.), most cities will recover their population and economic vitality in the long run (Davis and Weinstein, 2002; Miguel and Roland, 2011; Hornbeck and Keniston, 2017; Xu and Wang, 2019). However, Vigdor (2008) indicates that the cities will not recover if population trends decline before the damage to infrastructure. For example, the population in Dresden, Germany raised from 390,000 to 630,000 in the period of 1900 to 1940; however, since the bombing of Dresden in 1945, the population has remained at about 500,000 people, and has not returned to its pre-World War II population of 630,000 (Vigdor, 2008). On the other hand, from the perspective of industrial agglomeration, even if infrastructure is rebuilt after a physical impact, firms may consider relocation (Siodla, 2021; Indaco et al., 2021). This causes a decrease in population size and productivity in the damaged area (Ager et al., 2020). Imaizumi et al. (2016) study the impact on industrial clusters after the Great Kantō Earthquake in 1923. They indicate that the earthquake caused particularly serious damage to the old industrial clusters and provided an opportunity for new industrial clusters in non-damaged areas to take over the market. The impact of the earthquake on the spatial distribution of industry is persistent.

Hence, a main question of this paper is: How will a productivity shock affect the original spatial distribution of industry through market force given specific conditions? Specifically, we discuss the market force for spatial distribution, which means that cities emerge based on the self-reinforcing advantages of the second nature (Cronon, 1991; Krugman, 1993).[1] In the

[1] This is different from the natural advantages of the first nature.

study of spatial distribution, Krugman (1991a) introduces an interaction of economies of scale at the plant level with transport costs into two-region general equilibrium model to analyze the industrial spatial distribution. The results show that the firms will agglomerate at either region when transport costs between the two regions are small, symmetrically distribute between the two regions when the transport costs are high, and agglomerate or symmetrically distribute when transports costs are moderate. Forslid and Ottaviano (2003) develop an analytical model of Krugman (1991a) and obtain the same spatial distribution as Krugman (1991a).[2] Moreover, empirical studies (Faber, 2014; Baum-Snow et al., 2020) support the result of the spatial industrial distribution of Krugman (1991a).

We thus develop a two-region general equilibrium model with increasing returns based on the model of Forslid and Ottaviano (2003) to explore the impact of a shock in the spatial industrial (skilled workers) distribution of the two regions. We adopt the spatial industrial distribution with transport costs of Forslid and Ottaviano (2003) as the initial distribution. In our model, a shock happens only in region 1 and does not happen in region 2. The model shows whether the distribution of skilled workers remains the same pattern after a negative impact on productivity. The model operates through a combination of three forces: a centrifugal force driven by competition among firms, and two centripetal forces fueled by high market demand and diverse variety preferences. These forces play a crucial role in determining the real wages and skilled worker migration across regions. In the event of a shock that reduces the productivity of firms in a particular region, both wages and expenditures decrease, resulting in weakening of the centripetal forces. Conversely, the centrifugal force tends to strengthen as firms are motivated to relocate to the other region with a higher market demand. The decision of skilled workers to migrate is influenced by the relative strength of the weakening centripetal forces and the strengthening centrifugal force. If the centripetal forces are stronger than the centrifugal force, skilled workers will

---

2 In Forslid and Ottaviano (2003), the skilled workers can be treated as the owners of the firms. Thus, the distribution of the firms between the two regions is the same as the distribution of the skilled workers.

tend to agglomerate at the located region. However, when the centripetal forces become weaker than the centrifugal force, skilled workers are more likely to relocate to the other region.

We then get the results as follows: The first case investigates the productivity shock with lower transport costs between the two regions. When the productivity shock in period 1 is large, skilled workers move from region 1 to region 2; when the shock is small, the skilled workers still agglomerate in region 1. The second case is for higher transports costs. Skilled workers may agglomerate in region 2 if there is a large productivity shock in period 1. However, the spatial distribution of skilled workers is symmetric in the long run after the shock. The third case is for moderate transport costs with an initial spatial agglomeration in region 1. When the shock is large enough that some skilled workers move to region 2, based on different levels of shock. There are two results. One is that skilled workers agglomerate in region 2. The other is a symmetric distribution of skilled workers. The final case is moderate transport costs with an initial symmetric distribution of skilled workers. When the shock is large, the skilled workers agglomerate in region 2 and no longer come back to region 1; when the shock is small, the distribution still is symmetric in the long run although the distribution in the short run is asymmetric.

In sum, this study advances the understanding of firm dynamics after the effects of a productivity shock. The results show that the recovery of a damaged region depends on the initial economic condition, the magnitude of the shock, and the geographic characteristic. The initial economic condition represents the relative economic power before the shock, e.g., a core region with firm agglomeration or a periphery region with only few firms. The geographic characteristic denotes the relative competitive situation due to the distance or transport costs among the damaged region and the other regions. Our study explores whether a region can recover after a productivity shock through the market mechanism consisting of the three factors above.

This paper is related to Testa (2021) who focuses on how institutions influence local recovery to population shocks and assumes no trade costs in market access.[3] However, there are two crucial differences between this paper and Testa (2021). First, we focus on how the effects of a productivity shock influence the spatial distribution of skilled workers. Second, the transport costs in our model are taken into account. In addition, differing from the stochastic shocks to commuting decisions in Ahlfeldt et al. (2015), we focus on the shock on the productivity of industries.

The remainder of this paper is as follows. Section 2 introduces the model setting. Given the location of manufacturing firms, the market equilibrium of the model is provided in Section 3. The location equilibrium after a productivity shock is provided in Section 4. Numerical simulations are used for further analysis in Section 5. Section 6 introduces some historical events consistent with the forecast of our model and discusses how the policy of provision of public goods to improve the recovery of damaged region. Finally, we provide some concluding remarks.

2. Model Setting

The country consists of two identical regions, 1 and 2, and two production sectors, the traditional sector (sector A) and the modern sector (sector M). Firms in sector A (referred to as A-firms hereafter) produce a homogenous good under perfect competition with constant returns to scale. On the other hand, firms in sector M (referred to as M-firms hereafter) produce a differentiated good under monopolistic competition and increasing returns to scale. Each variety ω of the differentiated good is produced only by a single firm in sector M. The economy is endowed with $L = 1$ unskilled workers and $H = 1$ skilled workers. The unskilled workers can move between two sectors but cannot move between region 1 and region 2. The skilled workers can be thought of as self-employed entrepreneurs who move freely between region 1 and 2. Following Krugman (1991a) and Forslid and Ottaviano (2003), each skilled worker is myopic and locates in the region

---

3 The assumption is based on two regions which are in close proximity (Testa, 2021). The price is set collectively by the two regions (Testa, 2021).

which maximizes his or her utility.[4] Finally, we assume that productivity shock $\varepsilon(t)$ only affects sector M in region 1.

2.1 Households

The representative worker maximizes her utility subject to budget constraint. The utility function and budget constraint in each period are as follows:

$$\max_{\{C_i^M(t), C_i^A(t)\}} U_i(t) = [C_i^M(t)]^{\alpha}[C_i^A(t)]^{1-\alpha},$$
$$\text{s.t.} \quad \int_0^H p_i^M(t,\omega)c_i^M(t,\omega)\mathrm{d}\omega + p_i^A(t)C_i^A(t) = Y_i(t), \quad i = 1, 2, \tag{1}$$

where $C_i^M(t) = \left\{\int_0^H [c_i^M(t,\omega)]^{(\rho-1)/\rho}\mathrm{d}\omega\right\}^{\rho/(\rho-1)}$ is the consumption of differentiated goods,[5] $c_i^M(t,\omega)$ is the consumption of variety ω, $p_i^M(t,\omega)$ is the price of variety ω, $\rho > 1$ is the constant elasticity of substitution between any two varieties, H is the sum of firms in sector M, $C_i^A(t)$ is the consumption of homogenous goods, $p_i^A(t)$ is the price of homogenous goods, $\alpha \in (0, 1)$ is constant, and $Y_i(t)$ is factor income in region i.

2.2 Technology and Profits

On the supply side, A-firms employ an unskilled worker to produce one unit of product. This implies that the marginal cost for a firm in sector A equals the unskilled worker's wages in region i, w_i^L. Assume that trading this commodity is costless and thus the prices are the same in the two regions. Due to marginal cost pricing from perfect competition, interregional price

---

4 If the migration depends on the outcomes of previous periods, the results of spatial distribution are the current results of myopic migration (Krugman, 1991b). In addition, in the models of new economic geography, the results of the forward-looking expectation migration and the myopic migration are the same (Baldwin, 2001; Ottaviano, 2001). To simplify the model, we assume that the migration behavior of skilled workers is myopic.

5 The variable ω is continuous.

equalization also implies interregional wages equalization. We can thus choose the homogeneous good as numeraire, $P_{A,i} = w_i^L = 1$.[6] In addition, both regions are endowed with the same quantity of unskilled workers, $L_1 = L_2 = L/2$.

On the other hand, in order to produce the outputs $x_i(t, \omega)$ of variety ω in period t, each M-firm incurs one unit of skilled workers and the $l_i(t)$ units of unskilled workers. The production function in each region is as follows

$$x_i(t,\omega) = \theta_i(t) l_i(t), \quad i = 1, 2, \tag{2}$$
$$\theta_1(t) = \theta e^{-\eta_1(t)}, \quad \eta_1(t=0) = \eta_1(t \geq 2) = 0, \tag{3}$$
$$\theta_2(t) = \theta, \tag{4}$$

where $\theta_i(t)$ is the productivity technology,[7] θ is a time-invariant level of productivity technology,[8] $\eta_1(t)$ is the productivity shock which decreases the productivity in region 1. To enhance clarity and streamline the model presentation, the impact of the productivity shock in region 1 disappears completely in period $t \geq 2$.

Next, the cost function includes not only the skilled workers' wages $w_i^H(t, \omega)$ but also the unskilled workers' wages. Specifically, each skilled worker's wages are fixed costs; the unskilled workers' wages are variable costs. Hence, the cost function is as follows

---

6 Wages equalization holds as long as the homogeneous good is produced in both regions. This means that there is not a region where production can satisfy the two regions' demand of agricultural goods. Thus, the non-full-specialization condition is $(1-\alpha)(Y_1 + Y_2) > L/2$.

7 The setting for the productivity technology ensures that the productivity parameter θ remains well-defined for any value of $\eta_1(t)$.

8 We set the time-invariant level of productivity technology to be 1 because the time-invariant level represents a situation in which no shock emerges. This differs from the role of homogenous goods in the model. Specifically, A-firms produce homogeneous goods and face a perfectly competitive market. The price of the homogeneous good is equal to the unskilled worker's wages in the equilibrium. Because unskilled workers are mobile between the two sectors, we set the price of homogeneous goods and the unskilled worker's wages at 1.

$$TC_i(t,\omega) = w_i^H(t,\omega) + w_i^A(t)\frac{x_i(t,\omega)}{\theta_i(t)}, \quad i = 1,2. \tag{5}$$

From the second term in the right-hand side of Equation (5), $x_i(t, \omega)/\theta_i(\mathrm{t})$, the M-firm needs to employ more unskilled workers to produce the same amount of output when the shock has an effect. Transporting one unit of manufactured goods from region i to region j incurs transport costs in accordance with the iceberg assumption, where $i = 1, 2$, $j = 1, 2$, and $i \neq j$. Specifically, $\tau > 1$ units of goods need to ship and only one unit of the goods will arrive at the target region. However, shipping the goods to local customers in the same region is costless. Finally, the profit function of M-firm in region i is

$$\Pi_i(t,\omega) = p_{ii}(t,\omega)c_{ii}^M(t,\omega) + p_{ij}(t,\omega)c_{ij}^M(t,\omega) - TC_i(t,\omega), \tag{6}$$

where $p_{ij}(t, \omega)$ is the price of variety ω produced in region i and sold in region j, $c_{ij}^M(t,\omega)$ are respectively the quantity of variety ω produced in region i and sold in region j, $x_i(t,\omega) = c_{ii}^M(t,\omega) + \tau c_{ij}^M(t,\omega)$, $i = 1, 2$, $j = 1, 2$, and $i \neq j$.

3. The Market Equilibrium

Given the location of firms in sector M, the market equilibrium is the equilibrium of interactions among consumers, firms and skilled workers. First, we calculate the utility maximization problem and the profit maximization problem in sector M respectively. On the demand side, we calculate the consumption of differentiated and homogenous goods respectively as follows

$$c_{ii}^M(t,\omega) = \frac{p_{ii}(t,\omega)^{-\sigma}}{G_i(t)^{1-\sigma}}\alpha Y_i(t), \quad c_{ji}^M(t,\omega) = \frac{p_{ji}(t,\omega)^{-\sigma}}{G_i(t)^{1-\sigma}}\alpha Y_i(t), \tag{7}$$

$$C_i^M(t) = \frac{\alpha Y_i(t)}{G_i(t)}, \quad C_i^A(t) = \frac{(1-\alpha)E_i(t)}{p_i^A(t)} = (1-\alpha)Y_i(t), \tag{8}$$

where $G_i(t)=\int_{\omega=1}^{N_i(t)}[p_i^M(t,\omega)]^{1-\rho}$ is price index, $N_i(t)$ is the mass of M-firms in region i, i = 1, 2, j = 1, 2, and $i \neq j$. The indirect utility functions in each region are, respectively,

$$V_1(t)=\left[\frac{\alpha Y_1(t)}{G_1(t)}\right]^{\alpha}[(1-\alpha)Y_1(t)]^{1-\alpha}, \tag{9}$$

$$V_2(t)=\left[\frac{\alpha Y_2(t)}{G_2(t)}\right]^{\alpha}[(1-\alpha)Y_2(t)]^{1-\alpha}. \tag{10}$$

Under the monopolistic competition of Dixit-Stiglitz type, the conditions for profit maximization of each M-firm are:

$$p_{11}(t,\omega)=\left(\frac{\rho}{\rho-1}\right)\left[\frac{1}{e^{-\eta_1(t)}}\right],\quad p_{12}(t,\omega)=\left(\frac{\rho}{\rho-1}\right)\left[\frac{\tau}{e^{-\eta_1(t)}}\right], \tag{11}$$

$$p_{22}(t,\omega)=\frac{\rho}{\rho-1},\quad p_{21}(t,\omega)=\frac{\rho}{\rho-1}\tau. \tag{12}$$

From Equation (11), the shock decreases the productivity of M-firms in region 1, and the prices increase. Next, we calculate the price index of each region as follows

$$G_1(t)=\left\{\left[\left(\frac{\rho}{\rho-1}\right)\left(\frac{1}{e^{-\eta_1(t)}}\right)\right]^{1-\rho}N_1(t)+\left[\frac{\rho}{\rho-1}\tau\right]^{1-\rho}N_2(t)\right\}^{\frac{1}{1-\rho}}, \tag{13}$$

$$G_2(t)=\left\{\left(\frac{\rho}{\rho-1}\right)^{1-\rho}N_2(t)+\left[\left(\frac{\rho}{\rho-1}\right)\left(\frac{1}{e^{-\eta_1(t)}}\right)\tau\right]^{1-\rho}N_1(t)\right\}^{\frac{1}{1-\rho}}. \tag{14}$$

Note that each M-firm employs one unit of skilled workers. We let $N_1(t) = h(t)H = h(t) \in [0, 1]$ be the share of skilled workers in region 1 and $N_2(t) = 1 - h(t)$ be the share of skilled workers in region 2. We can rewrite Equation (13) and Equation (14) as follows

$$G_1^*(t) = \left(\frac{\rho}{\rho-1}\right)\left\{\left[\frac{1}{e^{-\eta_1(t)}}\right]^{1-\rho} h(t) + \phi\left[1-h(t)\right]\right\}^{\frac{1}{1-\rho}}, \tag{15}$$

$$G_2^*(t) = \left(\frac{\rho}{\rho-1}\right)\left\{\left[1-h(t)\right] + \phi\left[\frac{1}{e^{-\eta_1(t)}}\right]^{1-\rho} h(t)\right\}^{\frac{1}{1-\rho}}, \tag{16}$$

where $\phi = \tau^{(1-\rho)} \in (0, 1)$ is the freeness of trade. From Equation (15) and Equation (16), when a region owns more skilled workers, the purchasing power is stronger in the region. The reason is that the price index is low. When the mass of M-firms in a region is large, both the varieties of imports and the impact of freeness of trade are reduced, which generate a centripetal force called the *cost-of-living effect* in Forslid and Ottaviano (2003). Note that the second term of right-hand side in Equation (16) shows that the productivity shock influences the price index in region 2 even if the shock in period 1 does not emerge in region 2. In addition, when a productivity shock emerges in region 1, both regions' price indices increase. Finally, M-firms' equilibrium profits are zero. This implies that the skilled worker's wages are equal to fixed costs. The skilled worker's wages in each region is

$$w_1^H(t,\omega) = \left[\left(\frac{\rho}{\rho-1}\right)\left(\frac{1}{e^{-\eta_1(t)}}\right) - 1\right] x_1(t,\omega), \tag{17}$$

$$w_2^H(t,\omega) = \left(\frac{1}{\rho-1}\right) x_2(t,\omega), \tag{18}$$

where $x_1(t,\omega) = c_{11}^M(t,\omega) + \tau c_{12}^M(t,\omega),\ x_2(t,\omega) = c_{22}^M(t,\omega) + \tau c_{21}^M(t,\omega),$

$$c_{11}^M(t,\omega) = \frac{\left[\frac{1}{e^{-\eta_1(t)}}\right]^{-\rho} \alpha\left[\pi_1(t)h(t) + \frac{1}{2}\right]}{\left(\frac{\rho}{\rho-1}\right)\left\{\left[\frac{1}{e^{-\eta_1(t)}}\right]^{1-\rho} h(t) + \phi\left[1-h(t)\right]\right\}},$$

$$c_{12}^{M}(t,\omega)=\frac{\tau^{-\rho}\left[\frac{1}{e^{-\eta_1(t)}}\right]^{-\rho}\alpha\left[\pi_2(t)(1-h(t))+\frac{1}{2}\right]}{\left(\frac{\rho}{\rho-1}\right)\left\{[1-h(t)]+\phi\left[\frac{1}{e^{-\eta_1(t)}}\right]^{1-\rho}h(t)\right\}},$$

$$c_{22}^{M}(t,\omega)=\frac{\alpha\left[\pi_2(t)(1-h(t))+\frac{1}{2}\right]}{\left(\frac{\rho}{\rho-1}\right)\left\{[1-h(t)]+\phi\left[\frac{1}{e^{-\eta_1(t)}}\right]^{1-\rho}h(t)\right\}},$$

$$c_{21}^{M}(t,\omega)=\frac{\tau^{-\rho}\alpha\left[\pi_1(t)h(t)+\frac{1}{2}\right]}{\left(\frac{\rho}{\rho-1}\right)\left\{\left[\frac{1}{e^{-\eta_1(t)}}\right]^{1-\rho}h(t)+\phi[1-h(t)]\right\}},$$

Given $x_1(t,\omega)$, the skilled worker's wages in region 1 are affected after the productivity shock from Equation (17). When the shock decreases the productivity of the M-firm, the skilled worker's wages in region 1 then decreases. Calculating a system of two linear equations in $w_1^{H*}(t,\omega)$ and $w_2^{H*}(t,\omega)$, yields the equilibrium wages of skilled workers

$$w_1^{H*}(t,\omega)=\frac{\{\Psi_1[1-h(t)]\Theta+2\phi h(t)\}F_1\Theta}{2\Psi_2[1-h(t)]\Theta^2-\Psi_3 h(t)\Theta+2\phi[h(t)]^2},\tag{19}$$

$$w_2^{H*}(t,\omega)=\frac{\{\Psi_4 h(t)+2\phi\Theta[1-h(t)]\}F_2\Theta}{2\Psi_2[1-h(t)]\Theta^2-\Psi_3\Theta h(t)+2\phi[h(t)]^2},\tag{20}$$

where $\Theta=e^{-\eta_1(t)}$, $F_1=F_2\{1+\rho[e^{\eta_1(t)}-1]\}[e^{\eta_1(t)}]^{-\rho}$, $F_2=\alpha/\rho$,

$\Psi_1=1-F_2+(1+F_2)\phi^2$,

$\Psi_2=[F_1F_2\phi^2+(1-F_2)\phi+F_1(1-F_2)]h(t)+\phi(1-F_2)$,

$\Psi_3=2\{(1-F_2+\phi^2)[1-h(t)]-\phi F_1 h(t)\}$,

$\Psi_4=[1+\phi^2-F_1\Theta(1-\phi^2)]h(t)$.

Note that the equilibrium wages from Equation (19) and Equation (20) show that the productivity shock influences not only the wages in region 1 but also in region 2 even if the shock emerges in region 1. Differentiating

$[\pi_1^*(t,\omega)/\pi_2^*(t,\omega)]$ with respect to $h(t)$ shows that the region with more skilled workers offers higher (lower) skilled worker's wages whenever ϕ is higher (lower) than the threshold in period 0:

$$\phi_d = \frac{\rho - \alpha}{\rho + \alpha}. \tag{21}$$

Similar to Forslid and Ottaviano (2003), ϕ_d represents a trade-off between two opposing forces of the distribution of skilled workers. One is a centrifugal force. Given freeness of trade, the more skilled workers located in a certain region, the more competing manufacturing firms there are. For given expenditures on manufacturing goods, the existence of more M-firms induces a fall in local demand per firm and depresses the local price index. This forms a centrifugal force which is called the market crowding *effect* in Forslid and Ottaviano (2003). The second is a centripetal force. Hosting more M-firms also implies additional operating profits and thus additional skilled income. A fraction of this additional income is spent on local manufactures. Hence, for a given price index, as local expenditures are high, demand per M-firm is high. This centripetal force is called the *market size effect* in Forslid and Ottaviano (2003).

4. Productivity Shocks, Location Equilibrium, and Stability

This section analyzes the migration decision of skilled workers after the productivity shock. Recall that we assume the migration behavior is myopic. Substituting Equation (15), Equation (16), Equation (19) and Equation (20) into Equation (9) and Equation (10), the indirect utility differential in each period can be written as follows

$$v(t,\omega) = V_1(t) - V_2(t) = \Xi\left[\frac{w_1^{H*}(t,\omega)}{G_1^*(t)^\alpha} - \frac{w_2^{H*}(t,\omega)}{G_2^*(t)^\alpha}\right], \tag{22}$$

where $\Xi = \alpha^\alpha(1-\alpha)^{(1-\alpha)}$. When $v(t) > 0$, it means the utility of the skilled workers in region 1 is higher than that of in region 2. The skilled workers thus move from region 2 to region 1. On the contrary, the skilled workers will move from region 1 to region 2 as $v(t) < 0$. The skilled workers in each region will not move to the other region when $v(t) = 0$, because the utility levels in the two regions are identical. Note that as the influences of a productivity shock disappear, there is a change in the indirect utility differential from Equation (22). Therefore, in our model, the long run equilibrium exists under the following three conditions: **(a)** $v(t \geq 2) > 0$, and all the skilled workers agglomerate at region 1; **(b)** $v(t \geq 2) < 0$, and all the skilled workers agglomerate at region 2; **(c)** $v(t \geq 2) = 0$, representing that the skilled workers in each region will not move to the other region. We then divide this case into three scenarios to discuss.

4.1 Extremely High Freeness of Trade

First, we discuss the case when the freeness of trade is extremely high ($\phi \rightarrow 1$), namely when there are extremely low transport costs. The skilled workers agglomerate in the core region in period 0 when the freeness of trade is high $\phi \in [\phi_B, 1)$, where ϕ_B is a break point where the symmetric distribution ends.[9] In this case, we assume that the skilled workers in period 0 agglomerate in region 1, that is, $h(t = 0) = 1$. We then define the productivity shock ε^*. Given $\phi \rightarrow 1$ and skilled workers in period 0 agglomerating in region 1, when the shock in period 1 $\eta_1(t = 1) = \varepsilon^*$ emerges in region 1, it lets Equation (22) get $v(t = 1) = 0$, where ε^* is constant. Calculation details of ε^* are in Appendix 2. The concept is as follows. In period 0, the real wages of region 1 are higher than that of region 2, namely $v(t = 0) > 0$. When the shock emerges in period 1, the real wages in each region become the same. We then get Proposition 1.

Proposition 1.

Given $\phi \rightarrow 1$ and $h(t = 0) = 1$, (a) when the productivity shock is large $\eta_1(t = 1) > \varepsilon^*$, skilled workers agglomerate in region 2; (b) when the shock is small $\eta_1(t = 1) < \varepsilon^*$, skilled workers still agglomerate in region 1.

---

9 Calculation details of break point in period 0 are in Appendix 1.

Proof. See Appendix 3.

□

Proposition 1 shows how the core-periphery distribution with $\phi \rightarrow 1$ and $h(t = 0) = 1$ changes after the productivity shock. Intuitively, in the presence of an extremely high level of trade freedom, the core region (region 1) is likely to permanently change into a peripheral region after a large shock. This change occurs due to the decline in productivity of M-firms in region 1, which weakens the centripetal force in the region. Factors such as lower wages, decreasing expenditure, and reducing market demand contribute to weaken this centripetal force. Consequently, skilled workers relocate from region 1 to region 2. Specifically, the real wages in region 2 are higher than in region 1 when the shock is large $\eta_1(t=1) > \varepsilon^*$. The skilled workers in period 1 then migrate from region 1 to region 2. Note that the core region becomes region 2 rather than region 1 when the shock emerges. In this case, although the effects of shock disappear, region 1 permanently remains a periphery region after the shock. In addition, the agglomeration equilibrium is stable. Hence, the skilled workers will not agglomerate in region 1 even if the effects of the shock disappear. On the contrary, when the shock is small $\eta_1(t=1) < \varepsilon^*$, skilled workers agglomerate in region 1 because the real wages in region 1 are still higher than in region 2.

4.2 Extremely Low Freeness of Trade

In this case, we discuss the case when the freeness of trade is extremely low ($\phi \rightarrow 0$), namely when there are extremely high transport costs. The spatial distribution of skilled workers is symmetric in period 0 when $\phi \in (0, \phi_s]$, where ϕ_s is a sustain point which the agglomeration outcome starts.[10] We assume that the distribution in period 0 is symmetric, that is $h(t = 0) = 0.5$. Next, we define two productivity shocks, ε^{**} and ε^{***}. First, we define the initial one ε^{**}. Given $\phi \rightarrow 0$ and $h(t = 0) = 0.5$, when the productivity shock in period 1, $\eta_1(t=1) = \varepsilon^{**}$, emerges in region 1, Equation (22) gets $v(t=1)\big|_{h(t=1)\rightarrow 0.5^-} = 0$, where ε^{**} is constant. Calculation details of

---

10 Calculation details of the sustain point in period 0 are also in Appendix 1.

ε^{**} are in Appendix 4. The concept is as follows. Region 1 is affected in period 1 by the shock so that the real wages in region 1 are lower than in region 2. When the first skilled worker ($h(t = 1) \rightarrow 0.5^{-}$) moves from region 1 to region 2 in period 1, the real wages in each region become the same. We define the second productivity shock ε^{***}. Given $\phi \rightarrow 1$ and $h(t = 0) = 0.5$, when the productivity shock in period 1, $\eta_1(t=1) = \varepsilon^{***}$, emerges in region 1, Equation (22) gets $v(t=1)\big|_{h(t=1)\rightarrow 0^{+}} = 0$, where ε^{***} is also constant. Calculation details of ε^{***} are in Appendix 5. The concept is as follows. When the shock is large enough, most skilled workers migrate to region 2. However, for the last skilled worker ($h(t = 1) \rightarrow 0^{+}$), the real wages in each region are still the same. Therefore, the last worker is still located in region 1 after the shock. By the above definitions, the inequality holds, $0 < \varepsilon^{**} < \varepsilon^{***} < 1$. Finally, from Equation (3), the impact of the productivity shock in region 1 disappears completely in period $t \geq 2$. We get Proposition 2 as follows.

Proposition 2.
Given $\phi \rightarrow 1$ and $h(t = 0) = 0.5$, (a) when the productivity shock in period 1 is $\eta_1(t = 1) < \varepsilon^{**}$, the pattern is still symmetric; (b) when the shock is $\eta_1(t = 1) \in (\varepsilon^{**}, \varepsilon^{***})$, the distribution is asymmetric in period 1, that is $h(t = 1) < 0.5$; (c) when the shock is $\eta_1(t = 1) > \varepsilon^{***}$, the skilled workers in period 1 agglomerate in region 2, namely $h(t = 1) = 0$; (d) The distribution returns to a symmetric outcome after the impact of the productivity shock in region 1 disappears completely.

Proof. See Appendix 6.

□

Proposition 2 shows how the symmetric distribution with $\phi \rightarrow 0$ and $h(t = 0) = 0.5$ changes after the productivity shock. Intuitively, in the presence of the extremely small trade freeness, the skilled workers finally disperse evenly between the two regions after the shock. This occurs because the centrifugal force outweighs the centripetal forces as the impact of the shock disappears. Then, the skilled workers do not have incentives to agglomerate in region 2, leading to an even distribution of skilled workers between the two regions. When the productivity shock in period 1 is large, $\eta_1(t = 1) > \varepsilon^{***}$, from Equation (22), all skilled workers in period 1 agglomerate in region 2. The reason is similar to that mentioned in Proposition 1. However, the agglomeration outcome is unstable when the freeness of trade is low. This means that the agglomeration outcome is easily influenced by small exogenous factors changing. Hence, as the productivity in region 1 recovers to the level in period 0, some skilled workers migrate to region 1 after period 1. In period $t \geq 2$, the distribution becomes symmetric. When the shock is moderate, $\eta_1(t = 1) \in (\varepsilon^{**}, \varepsilon^{***})$, the distribution is asymmetric. However, the asymmetric distribution which is the same real wages changes as the productivity in region 1 recovers. This implies that the asymmetric distribution is also unstable. Hence, in period $t \geq 2$, the spatial distribution of skilled workers also becomes symmetric. Finally, when $\eta_1(t = 1) < \varepsilon^{**}$, the spatial distribution is still symmetric.

4.3 Moderate Freeness of Trade

When the freeness of trade is moderate, $\phi \in (\phi_s, \phi_B)$, the spatial distribution of skilled workers is multiple equilibria in period 0, that is $h(t) = 0$, $h(t) = 1$ and $h(t) = 0.5$. We then use two cases to analyze the spatial distribution after a shock in this subsection. The first case is that skilled workers in period 1 agglomerate in region 1, $h(t = 0) = 1$. The second is that the distribution is symmetric, $h(t = 0) = 0.5$.

We analyze the first case given the core-periphery distribution in period 0 as follows. We define two productivity shocks, ϑ and ϑ^*. We define the initial one, ϑ. Given $\phi \in (\phi_s, \phi_B)$ and $h(t = 0) = 1$, when the productivity shock in period 1, $\eta_1(t = 1) = \vartheta$, emerges in region 1, Equation (22) gets $v(t=1)\big|_{h(t=1)=1} = 0$, where ϑ is constant. The concept is shown in Figure 1 and similar to the ε^* definition. Next, we define the second one, ϑ^*. Given $\phi \in (\phi_s, \phi_B)$ and $h(t = 0) = 1$, when the productivity shock in period 1, $\eta_1(t = 1) = \vartheta^*$, emerges in region 1, Equation (22) gets $v(t=1)\big|_{h(t=1)<0.5} = 0$ and $\partial v(t)/\partial h(t)\big|_{h(t=1)<0.5} = 0$, where ϑ^* is constant. The concept is shown in Figure 2, which illustrates that some skilled workers migrate to region 2 when the shock emerges in period 1. However, the shock is not large enough to let all skilled workers in period 1 agglomerate in region 2. Hence, the result is that the real wages in each region are the same when the distribution is asymmetric, $h(t = 1) < 0.5$. By these definitions, the inequality, $0 < \vartheta < \vartheta^{*} < 1$, holds. Finally, from Equation (3), the impact of the productivity shock in region 1 disappears completely in period $t \geq 2$. We get Proposition 3 as follows.

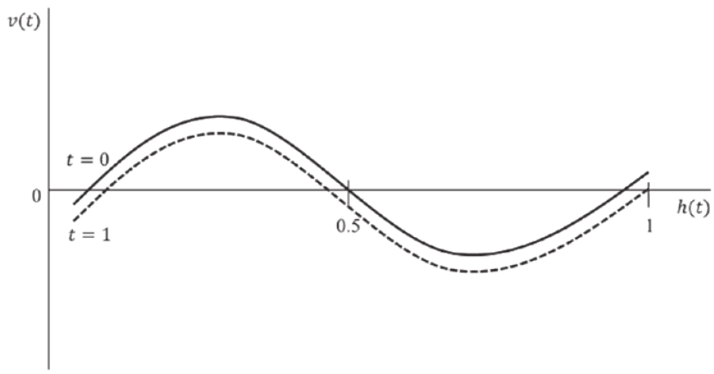


Figure 1 Productivity Shock ϑ

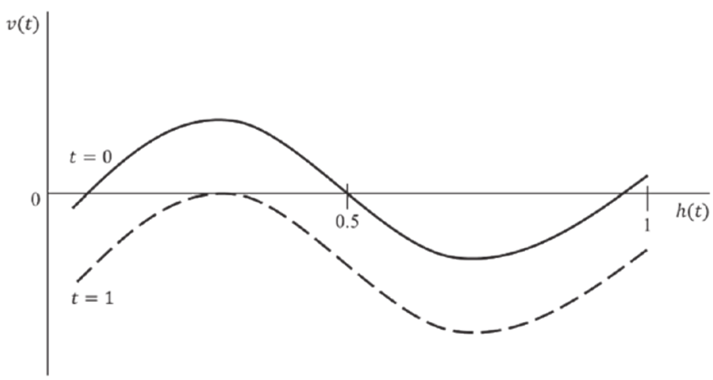


Figure 2 Productivity Shock ϑ^{*}

Proposition 3.

Given $\phi \in (\phi_s, \phi_B)$ and $h(t = 0)=1$, (a) when the productivity shock in period 1 is $\eta_1(t = 1) < \vartheta$, skilled workers still agglomerate in region 1; (b) when the *shock is* $\eta_1(t=1) \in (\vartheta, \vartheta^*)$*, the distribution in period 1 is asymmetric,* $h(t=1) < 0.5$*; (c) when the shock is* $\eta_1(t=1) > \vartheta^*$*, all skilled workers agglomerate in region 2; (d) The impact of productivity shock* $\eta_1(t=1) \in (\vartheta, \vartheta^*)$ *in period* $t \geq 2$ *disappears completely, the asymmetric distribution in the long run becomes symmetric.*

Proof. See Appendix 7.

□

Proposition 3 shows how the core-periphery distribution with $\phi \in (\phi_s, \phi_B)$ and $h(t=0)=1$ changes after the productivity shock. Intuitively, given the trade freeness $\phi \in (\phi_s, \phi_B)$, there are three paths of spatial distribution after the shocks. The results depend on whether the centripetal force is stronger or weaker than the centrifugal force. When the productivity shock in period 1 is large, $\eta_1(t=1) > \vartheta^*$, skilled workers in period 1 agglomerate in region 2. Because the core-periphery distribution in this case is stable, skilled workers still agglomerate in region 2 after the shock. When the shock is small, $\eta_1(t=1) < \vartheta$, skilled workers still agglomerate in region 1. The reason is as mentioned in Proposition 1(a). Finally, when the productivity shock is moderate, $\eta_1(t=1) \in (\vartheta, \vartheta^*)$, some skilled workers move from region 1 to region 2. However, the shock is not large enough to cause an asymmetry in distribution. The asymmetric distribution in this case is unstable. The reason is as mentioned in Proposition 2(d). Hence, the asymmetric distribution becomes the symmetric distribution which is stable in the long run.

Next, we analyze the second case given the symmetric distribution in period 0 as follows. In this case, there are also two different levels of productivity shock, ϑ^{**} and ϑ^*. We define the former one, ϑ^{**}, as follows. Given $\phi \in (\phi_s, \phi_B)$ and $h(t=0)=0.5$, when the productivity shock, $\eta_1(t=1) = \vartheta^{**}$, emerges in region 1, Equation (22) gets $v(t=1)|_{h(t=1)\to 0.5^-} = 0$ and $\partial v(t)/\partial h(t)|_{h(t=1)\to 0.5^-} < 0$, where ϑ^{**} is constant. The concept is shown in Figure 3 and similar to the ε^{**} definition. The ϑ^* definition is also as mentioned above. By these definitions, the inequality, $0 < \vartheta^{**} < \vartheta^* < 1$, holds. Finally, from Equation (3), the impact of the productivity shock in region 1 disappears completely in period $t \geq 2$. We get Proposition 4 as follows.

Proposition 4.

Given $\phi \in (\phi_s, \phi_B)$ *and* $h(t = 0) = 0.5$, *(a) when the productivity shock is* $\eta_1(t = 1) < \vartheta^{**}$, *the distribution is still symmetric; (b) when the shock is* $\eta_1(t = 1) \in (\vartheta^{**}, \vartheta^{*})$, *the distribution in period 1 is asymmetric,* $h(t = 1) < 0.5$; *(c) when the shock is* $\eta_1(t = 1) > \vartheta^{*}$, *all skilled workers agglomerate in region 2; (d) as the impact of productivity shock* $\eta_1(t = 1) \in (\vartheta^{**}, \vartheta^{*})$ *disappears completely in period* $t \geq 2$, *the asymmetric distribution of skilled workers in the long run still returns to symmetry.*

Proof. See Appendix 8.

□

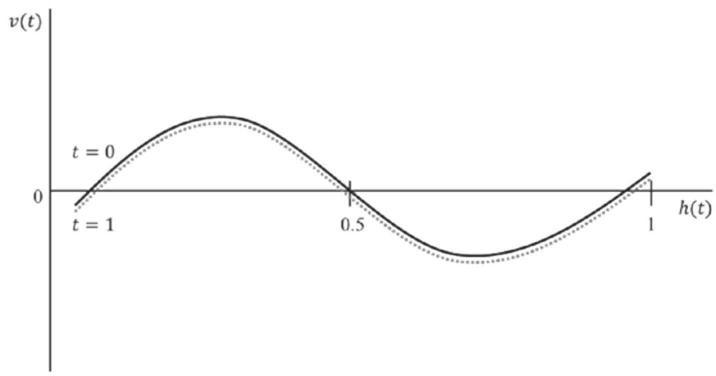


Figure 3 Productivity Shock ϑ^{**}

Proposition 4 shows how the symmetric distribution with $\phi \in (\phi_s, \phi_B)$ changes after the productivity shock. Intuitively, given the trade freeness $\phi \in (\phi_s, \phi_B)$, Proposition 4 also provides three paths of spatial distribution after the shocks. Similarly, the results depend on whether the centripetal force is stronger or weaker than the centrifugal force. Given $\phi \in (\phi_s, \phi_B)$ and $h(t = 0) = 0.5$, when the shock is large, $\eta_1(t = 1) > \vartheta^{*}$, all skilled workers agglomerate in region 2. The reason is that the agglomeration equilibrium is stable even if the distribution in period 0 is symmetric. When the shock is moderate, $\eta_1(t = 1) \in (\vartheta^{**}, \vartheta^{*})$, the asymmetric distribution returns to symmetry in the long run. The reason is as mentioned in Proposition 2(d) and Proposition 3(d). Finally, when the shock is small, $\eta_1(t = 1) < \vartheta^{**}$, the distribution still is symmetric.

5. Numerical Simulations

In this section, following the method of DSGE (dynamic stochastic general equilibrium) studies (Dib, 2003; Evgenidis et al., 2021), the simulations in the baseline are computed for a 1% productivity shock. Moreover, we then moderately vary the level of productivity shock according to each case. First, we show the bifurcation diagram that is the distribution of skilled workers as the transport costs change, given the productivity shock in period 1. Next, given different transport costs in each case, we show the time paths of spatial distribution after the productivity shock. Before illustrating the time paths, we choose the following values of parameters as a basic case: $\alpha = 0.3, \rho = 4$. The first two parameters follow Krugman (1991a). Moreover, Crozet (2004) estimates the range of the elasticity of substitution ρ to be [1.3,5.6].

5.1 Bifurcation Diagrams

Figure 4 shows the distribution of skilled workers in period 1 when there is no productivity shock. The values of the parameters in Figure 4 are set as $\alpha = 0.3$, $\rho = 4$, and $\eta_1(t = 1) = 0$. When transport costs are low ($\tau \leq 1.1242$), namely when there is high freeness of trade, the market size effect is stronger than the market crowding effect so that the nominal wages in the core-periphery pattern are higher than the symmetric pattern. In addition, the price index in the core-periphery pattern is lower than in the symmetric pattern. Hence, the distribution of skilled workers is a core-periphery pattern. Note that here we haven't been given the distribution of skilled workers. Therefore, the agglomeration outcome may emerge in region 1 or 2. When transport costs are high ($\tau \geq 1.1249$), namely when there is low freeness of trade, the market crowding effect is stronger than the market size effect so that skilled workers are attracted by the high wages in the other relatively small region, and move to the other region. However, the price index in the core-periphery pattern is still lower than in the symmetric pattern. The distribution of skilled workers is symmetric. Finally, when $\tau \in (1.1242, 1.1249)$, the distribution is multiple equilibria.

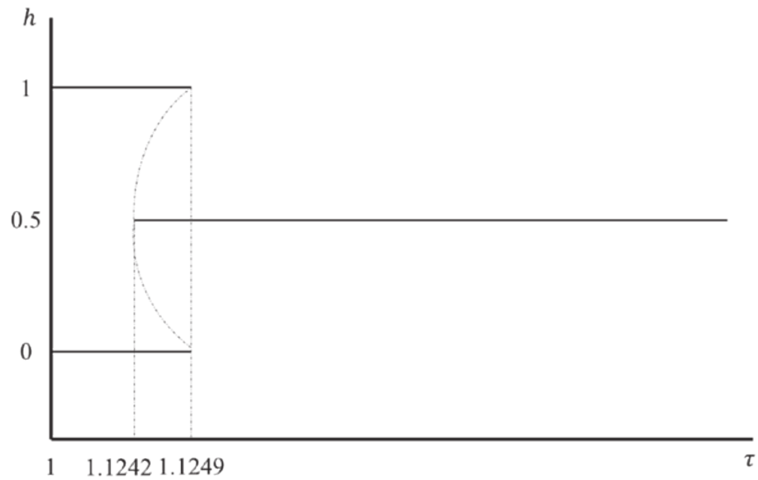


Figure 4 Bifurcation Diagram with No Productivity Shock in Region 1

Figure 5 shows the distribution of skilled workers in period 1 when the productivity shock emerges. The values of the parameters in Figure 5 are set as $\alpha = 0.3$, $\rho = 4$, $\eta_1(t = 1) = 0.01$. The differences between Figure 4 and Figure 5 are as follows: (1) There are no multiple equilibria; (2) the distribution of skilled workers is just approximately symmetric as transport costs increase. The former difference indicates two things. One is that the price index in region 2 is more affordable for skilled workers, so skilled workers tend to agglomerate in region 2. The other is that the nominal wages in region 1 are lower than region 2 when the productivity shock has an effect. This tends to make skilled workers agglomerate in region 2. Moreover, these results imply $h(t=1)\big|_{\pi^*_1=\pi^*_2} < 0.5$ and $h(t=1)\big|_{G^*_1=G^*_2} < 0.5$ so that there is only an core-periphery pattern in period 1 when the shock emerges. In summary, the skilled workers migrate to region 2 to avoid the negative impact of productivity shock in region 1.

5.2 Productivity Shock and the Time Path of Spatial Distribution

First, Proposition 1 is as shown as in Figure 6, Figure 7 and Figure 8. Moreover, Figure 6 and Figure 7 show the spatial distribution when the

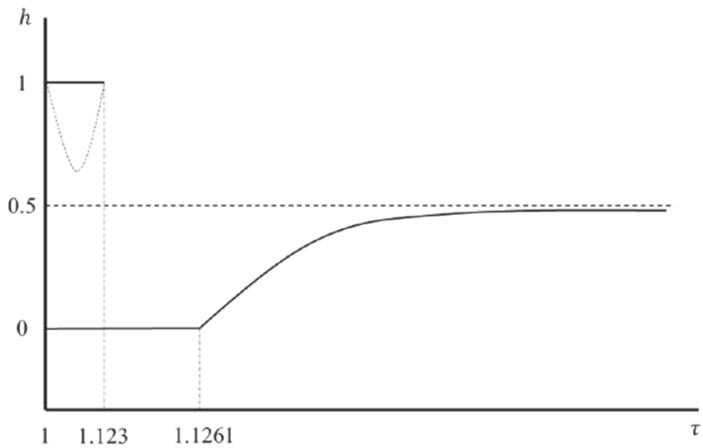
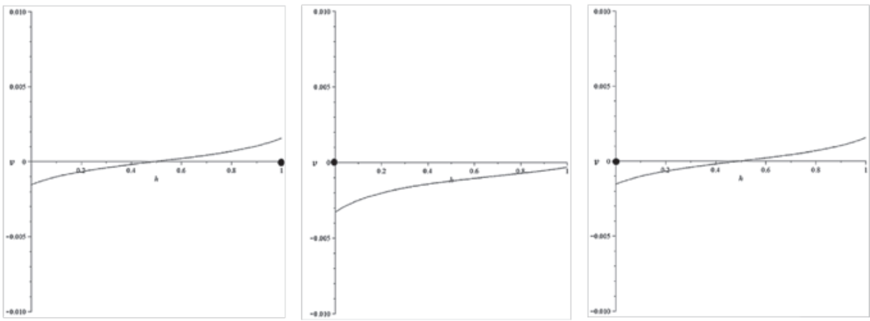


Figure 5 Bifurcation Diagram with a Productivity Shock in Region 1

productivity shock is large and transport costs are low, namely when there is high freeness of trade. The former shows the difference of indirect utility between two regions in each period; the latter is the time path of distribution based on Figure 6. The values of the parameters in Figure 6 and Figure 7 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1$, $\eta_1(t = 1) = 0.05$. We assume $h(t = 0) = 1$. Figure 6 shows that the real wages in region 2 are higher than in region 1 when the shock is large. Hence, all skilled workers agglomerate in region 2. Even if the impact of shock disappears, the skilled workers won't migrate back to region 1. The reason is as mentioned in Proposition 1(a). On the other hand, Figure 8 shows the path of distribution when the shock is small. The values of the parameters in Figure 8 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1$, $\eta_1(t = 1) = 0.01$. Because the shock is small, Figure 8 shows that the skilled workers still agglomerate in region 1. In other words, region 1 is still a core region.

Proposition 2 is as shown as in Figure 9, Figure 10, and Figure 11. We assume that distribution is symmetric in period 0. Figure 9 shows the time path with a large productivity shock and high transport costs, namely when there is low freeness of trade. The values of the parameters in Figure 9 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.13$, and $\eta_1(t = 1) = 0.05$. Figure 9 shows that the skilled workers in period 1 agglomerate in region 2 because of the large shock. However, as the productivity in region 1 recovers to the original level



(a) $t = 0$ (b) $t = 1$ (c) $t \geq 2$

Figure 6 The Difference of Indirect Utility in Each Period

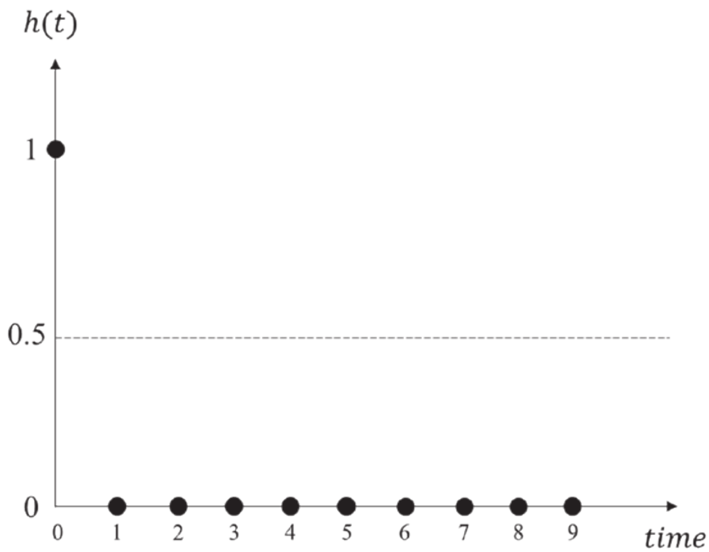


Figure 7 The Path Time of Core-periphery Distribution with a Large Shock and Low Transport Costs

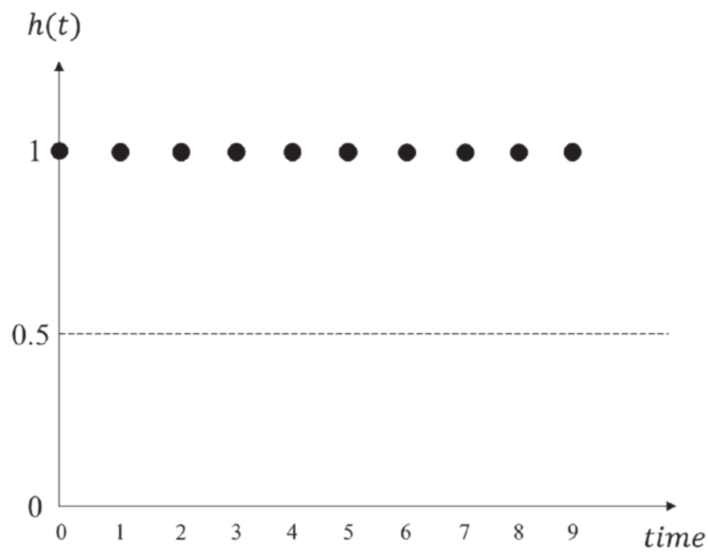


Figure 8 The Path Time of Core-periphery Distribution with a Small Shock and Low Transport Costs

in period 0, the distribution in period 7 returns to symmetry. Figure 10 shows the time path with a moderate productivity shock. The values of the parameters in Figure 10 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.13$, and $\eta_1(t = 1) = 0.01$. The distribution in period 1 is asymmetric because of the small shock. As mentioned above, the distribution finally returns to symmetry. Finally, Figure 11 shows the time path with a small productivity shock. The values of the parameters in Figure 11 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.13$, and $\eta_1(t = 1) = 0.0001$. The distribution is still symmetric even if the shock emerges. The reason is as mentioned in Proposition 2(a).

Proposition 3 is as shown as in Figure 12, Figure 13 and Figure 14. We also assume $h(t = 0) = 1$. Figure 12 shows the time path with a large productivity shock and moderate transport costs. The values of the parameters in Figure 12 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1248$, and $\eta_1(t = 1) = 0.01$. As mentioned in Proposition 3 (c), skilled workers agglomerate in region 2 after the large shock. Next, Figure 13 shows the time path with a small productivity shock and moderate transport costs. The values of the parameters in Figure 13 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1248$, and $\eta_1(t = 1) = 0.001$. As mentioned

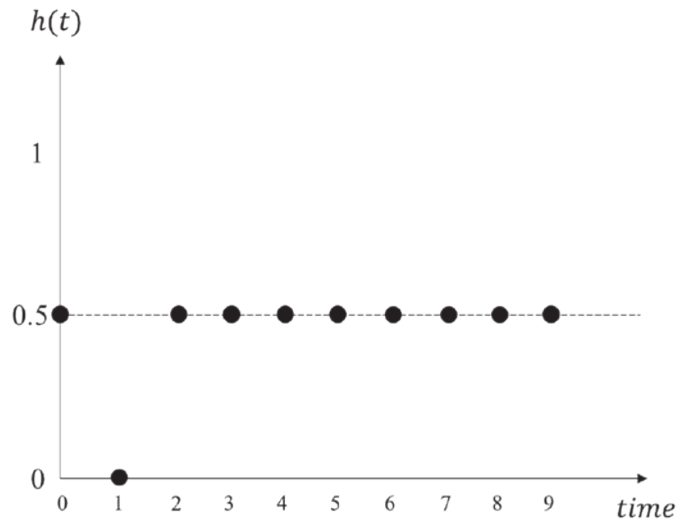


Figure 9 The Path Time of Symmetric Distribution with a Large Shock and High Transport Costs

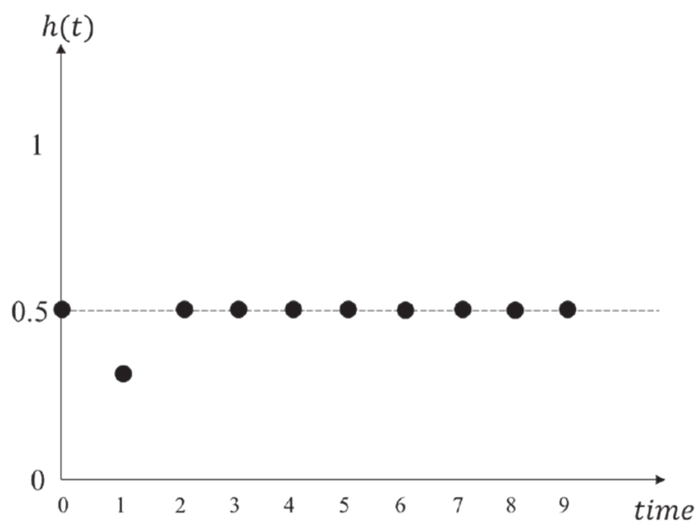


Figure 10 The Path Time of Symmetric Distribution with a Moderate Shock and High Transport Costs

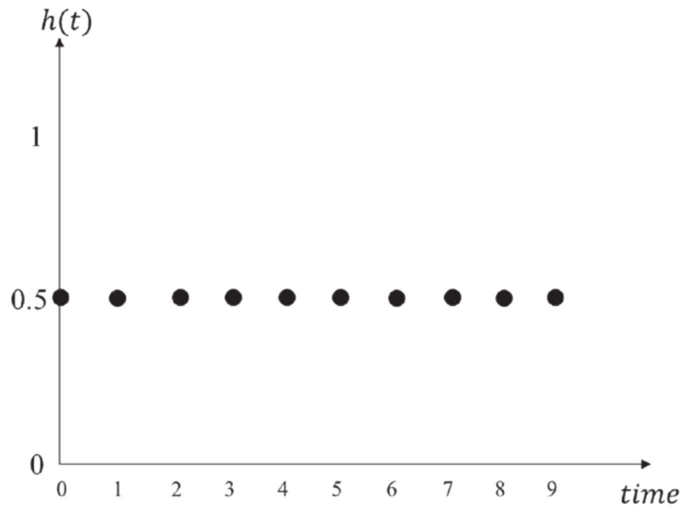


Figure 11 The Path Time of Symmetric Distribution with a Small Shock and High Transport Costs

in Proposition 3(a), the skilled workers still agglomerate in region 1 after the small shock. Finally, Figure 14 shows the time path with a moderate productivity shock and moderate transport costs. The values of the parameters in Figure 14 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1248$, and $\eta_1(t = 1) = 0.0015$. Because the shock is not large enough to let all skilled workers agglomerate in region 2 when the shock emerges, the distribution is asymmetric in period 1. The asymmetric distribution becomes symmetric after period 4. The reason is as mentioned in Proposition 3(d).

Proposition 4 is as shown as in Figure 15, Figure 16 and Figure 17. In addition, the distribution in Figure 15, Figure 16 and Figure 17 is assumed $h(t = 0) = 0.5$. Figure 15 shows the time path with a large productivity shock and moderate transport costs. The values of the parameters in Figure 15 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1248$, and $\eta_1(t = 1) = 0.01$. The skilled workers agglomerate in region 2 after the shock. The reason is as mentioned in Proposition 4(c). Next, Figure 16 shows the time path with a moderate productivity shock and transport costs. The values of the parameters in Figure 16 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1248$, and $\eta_1(t = 1) = 0.001$. The spatial distribution in period 1 is asymmetric when the shock emerges. However, the

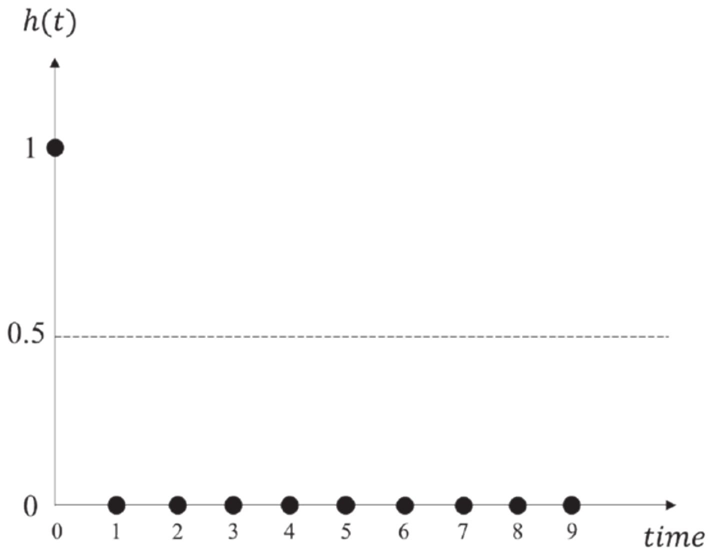


Figure 12 The Path Time of Core-periphery Distribution with a Large Shock and Moderate Transport Costs

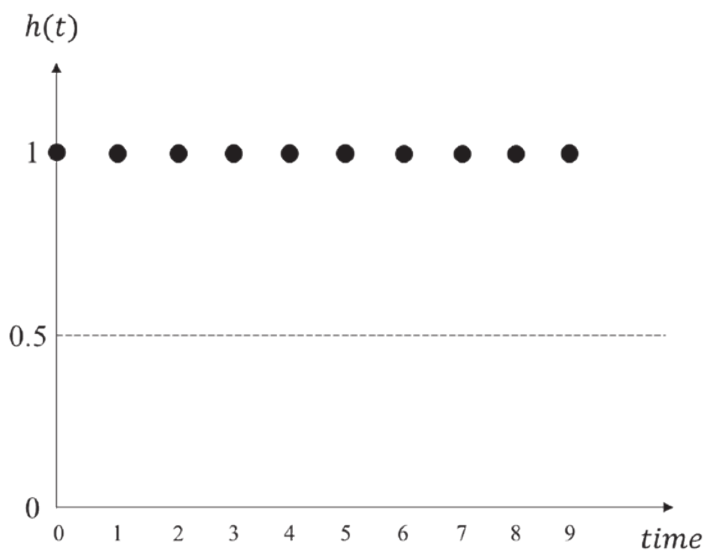


Figure 13 The Path Time of Core-periphery Distribution with a Small Shock and Moderate Transport Costs

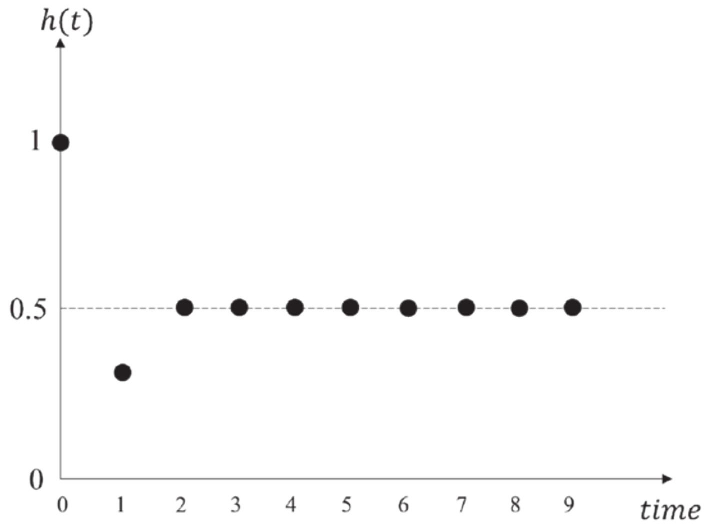


Figure 14 The Path Time of Core-periphery Distribution with a Moderate Shock and Moderate Transport Costs

asymmetric distribution returns to symmetry in the long run. The reason is as mentioned in Proposition 4(d). Finally, Figure 17 shows the time path with a small productivity shock and moderate transport costs. The values of the parameters in Figure 11 are set as $\alpha = 0.3$, $\rho = 4$, $\tau = 1.1248$, and $\eta_1(t = 1) = 0.0001$. The distribution is still symmetric even if the shock emerges. The reason is as mentioned in Proposition 4(a).

6. Discussion

In this section, we provide some events which are consistent with the cases of our model.

6.1 The Cases of the Low Transport Costs

6.1.1 The 1906 San Francisco Earthquake and Fire

In April 1906, a large earthquake struck San Francisco. Water lines burst and gas lines ruptured, causing small fires to erupt into a massive blaze

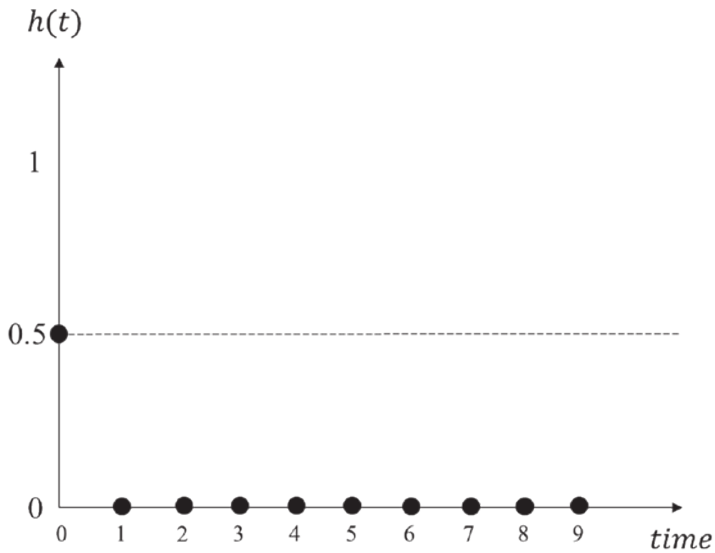


Figure 15　The Path Time of Symmetric Distribution with a Large Shock and Moderate Transport Costs

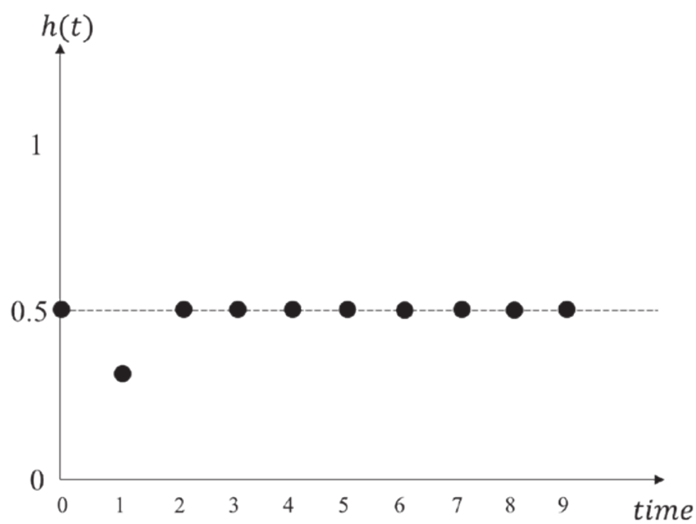


Figure 16　The Path Time of Symmetric Distribution with a Moderate Shock and Moderate Transport Costs

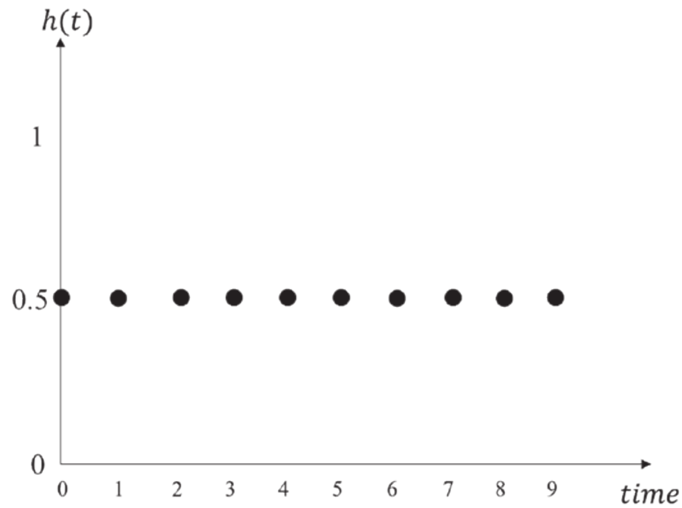


Figure 17 The Path Time of Symmetric Distribution with a Small Shock and Moderate Transport Costs

that quickly overtook many neighborhoods. Tobriner (2006) indicates that the fire's destruction is estimated to have comprised 80%-95% of the total damage from the disaster. The disruption led to a sharp drop in the supply of industrial premises in San Francisco, forcing businesses to close or relocate to the suburbs or even to other cities. Although the fire had a huge and temporary impact on the city, Siodla (2021) points out that the disaster did not change the tendency of these manufacturing firms to agglomerate, and the distance between them was still close.

6.1.2 The Great Kantō Earthquake in Japan

In 1923, the Great Kantō Earthquake struck the southern region of the Kantō district in Japan, resulting in a devastating impact. The earthquake caused a staggering loss of over 100,000 lives and left more than 460,000 buildings completely destroyed or burnt. Particularly hard-hit were the southeastern areas of Tokyo special wards, namely Fukagawa, Honjo, Kyōbashi, and Kanda, where the ratio of completely destroyed or burnt buildings exceeded 70%. Note that these areas were densely populated prior to the earthquake. The earthquake presented an opportunity for the emergence of newly developing industrial clusters in undamaged areas of Tokyo special wards such as Akasaka, Koishikawa, and Ushigome, which were located near the affected regions (Imaizumi et al., 2016). These areas were able to seize the market previously held by the damaged regions. Additionally, both the local population and the government in the undamaged areas actively sought to capitalize on this opportunity by attracting industries. These combined efforts had a lasting impact on the spatial distribution of industries following the earthquake.

In summary, both the 1906 San Francisco earthquake and the Great Kantō Earthquake led to the relocation of manufacturing firms to suburban or nearby areas, resulting in the formation of new industrial clusters. Our model suggests that we can view the urban area and the suburbs (or areas near the original clusters) as two distinct regions, with the distance between them representing low transport costs. According to the model, when transport costs are low and there is a significant productivity shock, industries tend to agglomerate in new regions. This observation aligns with our model.

6.2 The Cases of the Moderate Transport Costs

6.2.1 The 1999 Earthquake in Taiwan

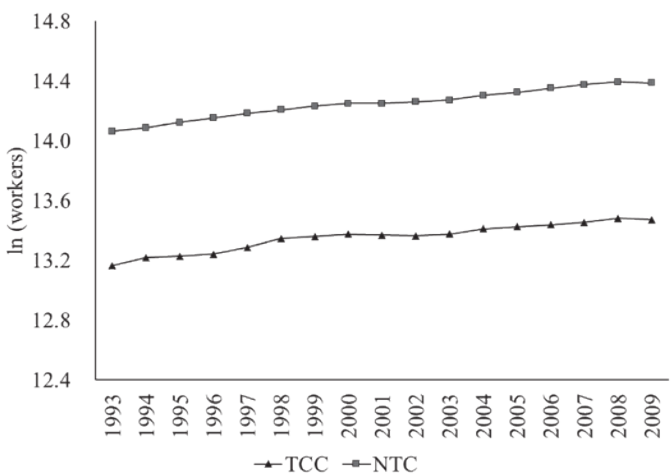
Taiwan is situated in the Circum-Pacific Seismic Belt. From 1901 to the present, there have been 102 catastrophic earthquakes. A 7.3-magnitude earthquake, known as the 1999 Jiji earthquake, hit central Taiwan in 1999. As the most damaging earthquake to date, it caused many casualties and great damage to buildings. The quake resulted in a total of NT$13 billion in direct losses to plants and equipment, and a total of NT$69.1 billion in indirect losses due to a subsequent blackout and power rationing (Chen and Ho, 1999). While 86% of manufacturers resumed operations within a month, there were still a small number of manufacturers that took longer to resume operations. In terms of employment change, the number of industrial workers in Taichung County (damaged region) reduced by a total of 1,172. Chen and Ho (1999) considered that this was because the manufacturers' premises were severely damaged or because manufacturers took too long to resume operations, and so workers moved to non-damaged areas to find jobs.

Following Indaco et al. (2021) and Imaizumi et al. (2016), we use the number of industrial workers in damaged and non-damaged regions to analyze the impact of the 1999 Jiji earthquake. We choose two counties in Taiwan. One is Taichung County (TCC), and the other is Taipei County (now called New Taipei City, NTC). Their relative position is as shown as Figure 18. In addition, TCC is the experimental group (damaged region) and NTC is the control group (non-damaged region). Figure 19 shows that the trend in both regions is similar. In order to assess the impact of the 1999 Jiji earthquake, we focus on time series in the number of workers, where the series are deviations between the empirical data and Hodrick-Prescott filtered trend. Figure 20 shows that the experimental group in 1999 experienced a recession one year earlier than the control group. Moreover, we also observe the time series in manufacturers' operating profits. Figure 21 shows that the experimental group in 1999 also suffered a recession one year earlier than the control group, although most firms in the experimental group resumed operations. The experimental group in Figure 19 and Figure 20 bounced back and respectively leveled off at 0 and 0.05 from 2004 to 2007.

From our model, we consider the moderate transport costs in two regions. The reason is that transportation between TCC and NTC is convenient, although TCC is not directly adjacent to NTC. Based on the results in Chen and Ho (1999), most manufacturers resumed operations within a month as mentioned above. In addition, we assume that they have symmetric distribution because the industrial clusters were located in two counties respectively before the shock had an effect. Hence, given moderate transport costs and a moderate productivity shock, the industrial distribution in the long run is still symmetric, although the industry in the damaged region is affected in the short run. The case is also consistent with Proposition 4 of our model. Besides the 1999 earthquake in Taiwan, there is another case that aligns with our model as follows.

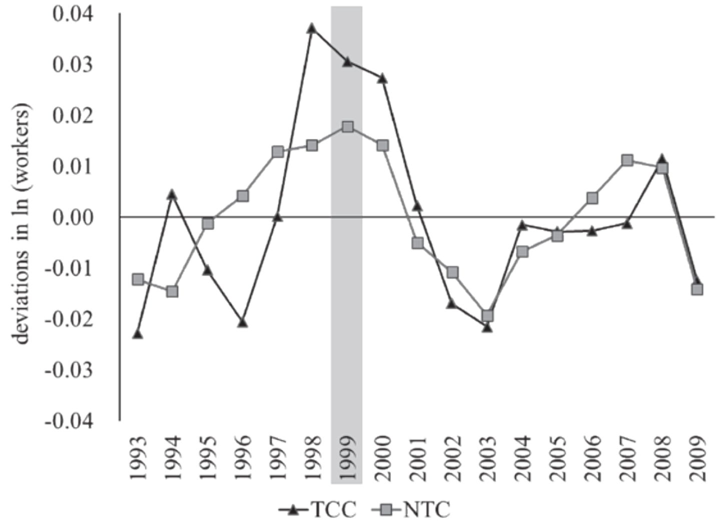
Sources: National Land Surveying and Mapping Center, Ministry of the Interior; Central Geological Survey, Taiwan.

Figure 18 The Relative Position between Experimental and Control Groups before 2010



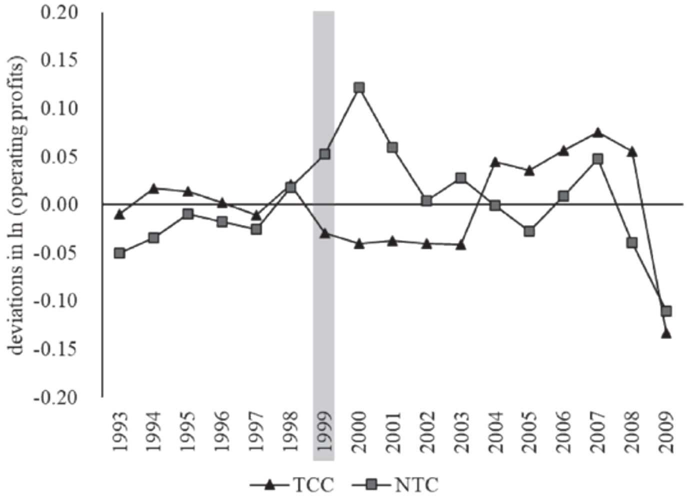
Sources: Directorate General of Budget, Accounting and Statistics (DGBAS), Executive Yuan, Taiwan.

Figure 19 Trend of Industrial Workers in Experimental and Control Groups



Notes: A standard deviation in the experimental group is 0.02; in the control group it is 0.01.

Figure 20 Worker Numbers Deviations in Experimental and Control Groups



Sources: DGBAS, Executive Yuan, Taiwan.

Notes: A standard deviation in both the experimental group and the control group is 0.05.

Figure 21 Operating Profits Deviations in Experimental and Control Groups

6.2.2 The 1995 Hanshin Earthquake in Japan

In 1995, the Hanshin Earthquake struck southern Hyogo Prefecture in Japan, making it the most severe earthquake since the 1923 Kantō Earthquake. The Kobe city was 20 kilometers away from the epicenter. Kobe had a population of approximately 1.5 million in 1990. The population growth rate of Kobe city during the period of 1985 to 1990 was comparable to that of other unaffected designated cities, including Nagoya, and Hiroshima, etc. However, after the earthquake, the Kobe city immediately experienced a population decline of about 4%. After 2000, Kobe fully recovered and reached its pre-earthquake population levels (Xu and Wang, 2019). The change in population in Kobe is consistent with the Proposition 4 in our model, considering moderate transport costs.

6.3 Extension for Policy Analysis

This subsection is to discuss how the policy of provision of public goods (infrastructure) in the damaged region improves the recovery. Our model can be extended to incorporate public goods into the utility function of residents. For instance, the model of Andersson and Forslid (2003) can be employed for this analysis. Specifically, $U(t)=[C^{M}(t)]^{\alpha}[C^{A}(t)]^{1-\alpha}Z^{d}$, where Z is public goods, and d is the preference parameter for the public goods. To produce the public goods, a fraction r of income is needed. The indirect utility function for the skilled workers in the region will be $(1-r)w_i^{H*}(t,\omega)Z^{d}/[G^{*}(t)]^{\alpha}$. This means the public goods will increase the utility at the cost of a decrease in the consumption for private goods. A proper r ratio of income for producing the public goods may increase the indirect utility level. However, a high r may decrease the indirect utility level due to the decrease in the consumption of private goods too much.

Note that the recovery of people for a damaged region means the people will move back to the region from other regions. That is, the indirect utility level for mobile workers in the damaged region has to be higher than the other regions. However, the damaged region may not win the game to compete with the other regions. The government may finance the damaged region to provide the public goods in the real world. This is equivalent to the damaged region receiving a subsidy from the other regions. This subsidy will lower the indirect utility level in other regions and increase the indirect utility level in the damaged region. This will thus shrink the difference of indirect utility levels between the damaged region and the other regions. The mobile workers will move back to the damaged region as the indirect utility level in the damaged region is higher than the other regions. The recovery of population will happen and the spatial distribution may come back the original pattern or a new stable distribution. The policy is to shorten the period for recovery. However, the spatial distribution after a shock will follow the results in the previous section depending on the magnitude of the shock and the transport costs among the regions.

Our idea in this subsection is similar to Testa's (2021) study of how institutions influence local recovery from a population shock. We compare our idea with his as follows. First, we consider that the government provides public goods to improve recovery after a productivity shock. On the other hand, Testa (2021) introduces an economic geography model with institutions in which he assumes that the quality of institutions is the same in two regions. Second, we assume that a shock decreases the production function of manufacturing firms, while Testa assumes that a shock decreases the population of the damaged region. Third, there are trade costs between regions in our model; however, Testa's model assumes no trade costs. Fourth, our model and Testa's model similarly include centripetal forces. The centripetal forces in our model are based on the variety preferences of consumers and the increasing returns of manufacturing firms. However, Testa (2021) assumes that the production function is with constant returns. In addition, the production function includes agglomeration externalities which cause a centripetal force. Finally, in our model, whether the final spatial distribution is the initial pattern or a new stable distribution depends on the magnitude of the productivity shock and the transport costs among the region. On the other hand, Testa shows that in the context of a large population shock, weak institutions reinforce the effects of the initial shock and make recovery difficult.

7. Conclusion

This paper develops a two-region general equilibrium model with increasing returns to analyze how industrial distribution changes the pattern after a productivity shock. The competition between two regions to attract mobile workers rather than only the improvement of the damaged region is considered to analyze the recovery of the damaged region to form the spatial distribution. Specifically, the results show that the recovery of a damaged region depends on the initial economic condition, the magnitude of the shock, and the geographic characteristic. When the productivity shock is large but the transport costs are not high, the industrial distribution is not the initial distribution after the shock. When both the productivity shock and the transport costs are moderate, the damaged region cannot recover to the initial distribution. Finally, some real-world cases are provided to support the results of our model.

Appendix 1 Sustain Point and Break Point

Here we calculate the sustain and break points in period 0 as follows:

Sustain Point

The agglomeration outcome emerges as $h(t) = 0$ with $v(0, \phi) < 1$ or $h(t) = 1$ with $v(1, \phi) > 1$. From Equation (25), we have:

$$v(0,\phi) = -v(1,\phi) = \frac{[(F_2+1)\phi^2 + 1 - F_2]}{2} - \phi^{1+\frac{\alpha}{1-\rho}}. \tag{A1}$$

When the trade costs are low enough, namely ϕ being higher than the sustain point ϕ_s, the agglomeration outcome is a stable equilibrium. The sustain point is implicitly defined to set Equation (26) equal to 1 as:

$$(F_2+1)\phi_s^2 + 1 - F_2 = 2\phi_s^{1+\frac{\alpha}{1-\rho}}. \tag{A2}$$

Break Point

The symmetric outcome is a stable equilibrium whenever $v_h(0.5, \phi) < 0$, where the trade costs are high enough. Specifically, the freeness of trade ϕ is lower than the break point ϕ_B, which is defined as:

$$\phi_B = \frac{\rho-\alpha}{\rho+\alpha} \cdot \frac{1-\dfrac{\alpha}{\rho-1}}{1+\dfrac{\alpha}{\rho-1}}. \tag{A3}$$

To avoid a situation where the market size and cost-of-living effects dominate the market crowding effect, we assume that the no-black-hole condition $\mu < \sigma - 1$ holds. Moreover, at the breakpoint, where the real wages are equal, the small region is attractive for skilled workers so that $\phi_B < \phi_t$, which is similar to Forslid and Ottaviano (2003).

Hence, when $\phi \in [\phi_B, 1)$, the distribution is the full agglomeration outcome. When $\phi \in (0, \phi_s]$, the distribution is the full symmetric outcome. When $\phi \in (\phi_s, \phi_B)$, the distribution is the multiple equilibria, that is $h(t) = 0$, $h(t) = 1$ and $h(t) = 0.5$.

Appendix 2 The Productivity Shock ε*

Here we calculate the productivity shock ε^*. Given $\phi \to 1$ and $h(t = 1) = 1$, when the productivity shock in period 1, ε^*, emerges in region 1, Equation (22) gets $\lim_{\phi\to 1} v(t) = \lim_{\phi\to 1}[V_1(t) - V_2(t)] = 0$, that is

$$\lim_{\phi\to 1}\left\{\frac{w_1^{H*}(t,\omega)}{[G_1^*(t)]^\alpha}\right\} = \lim_{\phi\to 1}\left\{\frac{w_2^{H*}(t,\omega)}{[G_2^*(t)]^\alpha}\right\}. \tag{A4}$$

Next, substituting $\phi \to 1$ and $h(t = 1) = 1$ into Equation (15), Equation (16), Equation (19) and Equation (20), we calculate respectively $\lim_{\phi\to 1} w_1^{H*}(t,\omega)$, $\lim_{\phi\to 1} w_2^{H*}(t,\omega)$, $\lim_{\phi\to 1} G_1^*(t)$, and $\lim_{\phi\to 1} G_2^*(t)$ as follows

$$\lim_{\phi\to 1} w_1^{H*}(t,\omega) = \frac{2\alpha e^{-\varepsilon^*}[1+\rho(e^{\varepsilon^*}-1)](e^{\varepsilon^*})^{-\rho}}{\rho\{2-2F_2 e^{-\varepsilon^*}[1+\rho(e^{\varepsilon^*}-1)](e^{\varepsilon^*})^{-\rho}\}}, \tag{A5}$$

$$\lim_{\phi\to 1} w_2^{H*}(t,\omega) = \frac{2\alpha e^{-\varepsilon^*}}{\rho\{2-2F_2 e^{-\varepsilon^*}[1+\rho(e^{\varepsilon^*}-1)](e^{\varepsilon^*})^{-\rho}\}}, \tag{A6}$$

$$\lim_{\phi\to 1} G_1^*(t) = \frac{\rho e^{\varepsilon^*}}{\rho - 1}, \tag{A7}$$

$$\lim_{\phi\to 1} G_2^*(t) = \frac{\rho e^{\varepsilon^*}}{\rho - 1}. \tag{A8}$$

Substituting (A5)-(A8) into (A4), we can get that ε^* is the solution as in the following equation

$$[1+\rho(e^{\varepsilon^*}-1)](e^{\varepsilon^*})^{-\rho} - 1 = 0. \tag{A9}$$

Appendix 3 Proof for Proposition 1

(a) By ε^* definition, when $\eta_1(t=1) > \varepsilon^*$, Equation (22) gets $v(t \geq 1) < 0$. In addition, agglomeration equilibrium is stable when $\phi \in [\phi_B, 1)$. Therefore, skilled workers agglomerate in region 2 after period 1 and will not come back to region 1;

(b) By ε^* definition, when $\eta_1(t=1) < \varepsilon^*$, Equation (22) still gets $v(t \geq 1) > 0$. Because agglomeration equilibrium is stable in this case, skilled workers still agglomerate in region 1.

□

Appendix 4 The Productivity Shock ε**

Here we calculate the productivity shock ε^{**}. Given $\phi \to 0$, when the productivity shock in period 1, ε^{**}, emerges in region 1, the first skilled worker (namely $h(t=1) \to 0.5^-$) moves from region 1 to region 2, Equation (22) gets $\lim_{(\phi,h)\to(0,0.5^-)} v(t) = \lim_{(\phi,h)\to(0,0.5^-)} [V_1(t) - V_2(t)] = 0$, that is

$$\lim_{(\phi,h)\to(0,0.5^-)} \left\{ \frac{w_1^{H*}(t,\omega)}{[G_1^*(t)]^\alpha} \right\} = \lim_{(\phi,h)\to(0,0.5^-)} \left\{ \frac{w_2^{H*}(t,\omega)}{[G_2^*(t)]^\alpha} \right\}. \tag{A10}$$

Next, substituting $\phi \to 0$ and $h(t=1) \to 0.5^-$ into Equation (15), Equation (16), Equation (19) and Equation (20), we calculate respectively $\lim_{(\phi,h)\to(0,0.5^-)} w_1^{H*}(t,\omega)$, $\lim_{(\phi,h)\to(0,0.5^-)} w_2^{H*}(t,\omega)$, $\lim_{(\phi,h)\to(0,0.5^-)} G_1^*(t)$, and $\lim_{(\phi,h)\to(0,0.5^-)} G_2^*(t)$ as follows

$$\lim_{(\phi,h)\to(0,0.5^-)} w_1^{H*}(t,\omega) = \frac{\frac{\alpha e^{-2\varepsilon^{**}}}{2}(1-F_2)[1+\rho(e^{\varepsilon^{**}}-1)](e^{\varepsilon^{**}})^{-\rho}}{\frac{\rho}{2}[e^{-2\varepsilon^{**}}(1-F_2)F_1 + (1-F_2)e^{-\varepsilon^{**}}]}, \tag{A11}$$

$$\lim_{(\phi,h)\to(0,0.5^-)} w_2^{H*}(t,\omega) = \frac{\frac{\alpha e^{-\varepsilon^{**}}}{2}(1-F_1 e^{-\varepsilon^{**}})}{\frac{\rho}{2}[e^{-2\varepsilon^{**}}(1-F_2)F_1 + (1-F_2)e^{-\varepsilon^{**}}]}, \tag{A12}$$

$$\lim_{(\phi,h)\to(0,0.5^-)} G_1^*(t) = \left(\frac{\rho}{\rho-1}\right)(e^{\varepsilon^{**}})\left(\frac{1}{2}\right)^{\frac{1}{1-\rho}}, \tag{A13}$$

$$\lim_{(\phi,h)\to(0,0.5^-)} G_2^*(t) = \left(\frac{\rho}{\rho-1}\right)\left(\frac{1}{2}\right)^{\frac{1}{1-\rho}}. \tag{A14}$$

Substituting (A11)-(A14) into (A10), we get that ε^{**} is the solution as in the following equation

$$(1-F_2)e^{-2\varepsilon^{**}}F_1 - F_2(1+F_1e^{-\varepsilon^{**}}) = 0. \tag{A15}$$

Appendix 5 The Productivity Shock ε***

Here we calculate the productivity shock ε^{***}. Given $\phi \to 0$, when the productivity shock in period 1, ε^{**}, emerges in region 1, the last skilled worker (namely $h(t = 1) = h^* \to 0^+$) moves from region 1 to region 2, Equation (22) gets $\lim_{(\phi,h)\to(0,h^*)} v(t) = \lim_{(\phi,h)\to(0,h^*)} [V_1(t) - V_2(t)] = 0$. The equation can be rewritten as $\lim_{(\phi,h)\to(0,h^*)} \{w_1^{H*}(t,\omega)/[G_1^*(t)]^\alpha\} = \lim_{(\phi,h)\to(0,h^*)} \{w_2^{H*}(t,\omega)/[G_2^*(t)]^\alpha\}$. Finally, substituting $\phi \to 0$ and $h(t = 1) = h^* \to 0^+$ into Equation (15), Equation (16), Equation (19) and Equation (20), we get that ε^{***} is the solution as in the following equation

$$\frac{F_1(1-h^*)}{[h^*(e^{\varepsilon^{**}})^{1-\rho}]^{\frac{\alpha}{1-\rho}}} = \frac{h^*\{1-F_1\}}{(1-h^*)^{\frac{\alpha}{1-\rho}}}. \tag{A16}$$

Appendix 6 Proof for Proposition 2

(a) By ε^{**} definition, when $\eta_1(t = 1) < \varepsilon^{**}$, Equation (22) gets $v(t = 1) = 0$. Hence, there is no skilled worker to migrate;

(b) By ε^{**} and ε^{***} definitions, when $\eta_1(t = 1) \in (\varepsilon^{**}, \varepsilon^{***})$, Equation (22) gets $v(t=1)\big|_{h(t=1)<0.5} = 0$. This shows that the distribution in period 1 is asymmetric

$h(t = 1) < 0.5$ when the shock is not large enough, $\eta_1(t = 1) < \varepsilon^{***}$. Hence, there are some skilled workers who migrate to region 2 in period 1;

(c) By ε^{***} definition, when $\eta_1(t = 1) > \varepsilon^{***}$, Equation (22) gets $v(t=1)|_{h(t=1)=0} = 0$. This shows that all skilled workers agglomerate in region 2, $h(t = 1) = 0$, when the shock which emerges in region 1 is large enough $\eta_1(t = 1) > \varepsilon^{***}$ in period 1;

(d) Symmetric distribution is a stable equilibrium when $\phi \in (0, \phi_s]$. This implies that the core-periphery and asymmetric distributions are unstable. As the productivity in period $t \geq 2$ returns to the level in period 0, $\theta(t \geq 2) = \theta(t = 0)$, Equation (22) gets $v(t \geq 2)|_{h(t\geq 2)=0.5} = 0$. This shows that the core-periphery and asymmetric distributions in this case return to symmetry after period 2.

□

Appendix 7 Proof for Proposition 3

(a) By ϑ definition, when $\eta_1(t = 1) < \vartheta$, Equation (22) gets $v(t = 1) > 0$. Hence, skilled workers agglomerate in region 1;

(b) By ϑ and ϑ^* definitions, when $\eta_1(t = 1) \in (\vartheta, \vartheta^*)$, Equation (22) gets $v(t=1)|_{h(t=1)=1} < 0$ and $v(t=1)|_{h(t=1)<0.5} = 0$, where $\partial v(t) / \partial h(t)|_{h(t=1)<0.5} < 0$. This shows that the shock in period 1 is not large enough to let all skilled workers agglomerate in region 2. Hence, the distribution in period 1 is asymmetric, $h(t = 1) < 0.5$;

(c) By ϑ^* definition, when $\eta_1(t = 1) > \vartheta^*$, Equation (22) gets $v(t = 1) < 0$. In addition, given $\phi \in (\phi_s, \phi_B)$, the agglomeration equilibrium is stable. The skilled workers agglomerate in region 2 after the shock;

(d) Given $\phi \in (\phi_s, \phi_B)$, both core-periphery and symmetric distributions are stable. In other words, the asymmetric distribution is unstable. Equation (22) then gets $v(t \geq 2)|_{h(t\geq 2)=0.5} = 0$ and $\partial v(t \geq 2) / \partial h(t \geq 2)|_{h(t\geq 2)=0.5} < 0$. Hence, as the productivity in region 1 recovers to the original level, $\theta(t \geq 2) = \theta(t = 0)$, the distribution in the long run (period $t \geq 2$) returns to symmetry.

□

Appendix 8 Proof for Proposition 4

(a) By ϑ^{**} definition, when $\eta_1(t=1) < \vartheta^{**}$, Equation (22) still gets $v(t=1) = 0$, where $\partial v(t)/\partial h(t)|_{h(t=1)=0.5} < 0$. Hence, the symmetric distribution is stable although the shock in period 1 affects region 1;

(b) By ϑ^{**} and ϑ^{*} definitions, when $\eta_1(t=1) \in (\vartheta^{**}, \vartheta^{*})$, Equation (22) gets $v(t=1)|_{h(t=1)<0.5} = 0$ and $\partial v(t)/\partial h(t)|_{h(t=1)<0.5} < 0$. Because the shock is not large enough that the distribution in period 1 is asymmetric, $h(t=1) < 0.5$;

(c) By ϑ^{*} definition, when $\eta_1(t=1) > \vartheta^{*}$, Equation (22) gets $v(t=1) < 0$. In addition, because the agglomeration equilibrium is stable when $\phi \in (\phi_s, \phi_B)$, skilled workers still agglomerate in region 2 after the shock.

(d) As the impact of productivity shock, $\eta_1(t=1) \in (\vartheta^{**}, \vartheta^{*})$, completely disappears in period $t \geq 2$, the productivity in region 1 returns to the level in period 0, $\theta(t \geq 2) = \theta(t=0)$. In addition, Equation (22) gets $v(t \geq 2)|_{h(t\geq 2)=0.5} = 0$ and $\partial v(t \geq 2)/\partial h(t \geq 2)|_{h(t\geq 2)=0.5} < 0$. The asymmetric distribution is unstable. In other words, the asymmetric distribution is unstable and returns to symmetry in the long run.

□

References

陳彥仲、何東坡 Chen, Yen-Jong and Tong-Po Ho (1999)，「921震災後產業重建之永續發展評估及政策分析(I)」“Evaluating the Sustainability and Policy Analysis on Industrial Recovery after 921 Taiwan Earthquake Disaster (I)”，行政院國家科學及技術委員會National Science and Technology Council, Executive Yuan, Taiwan (R.O.C.)。(in Chinese with English abstract)

Ager, P., K. Eriksson, C. W. Hansen, and L. Lønstrup (2020), “How the 1906 San Francisco Earthquake Shaped Economic Activity in the American West,” *Explorations in Economic History*, 77, Article 101342.

Ahlfeldt, G. M., S. J. Redding, D. M. Sturm, and N. Wolf (2015), “The Economics of Density: Evidence from the Berlin Wall,” *Econometrica*, 83:6, 2127-2189.

Andersson, F. and R. Forslid (2003), “Tax Competition and Economic Geography,” *Journal of Public Economic Theory*, 5:2, 279-303.

Baldwin, R. E. (2001), “Core-periphery Model with Forward-looking Expectations,” *Regional Science and Urban Economics*, 31:1, 21-49.

Baum-Snow, N., J. V. Henderson, M. A. Turner, Q. Zhang, and L. Brandt (2020), “Does Investment in National Highways Help or Hurt Hinterland City Growth?” *Journal of Urban Economics*, 115, Article 103124.

Boustan, L. P., M. E. Kahn, P. W. Rhode, and M. L. Yanguas (2020), “The Effect of Natural Disasters on Economic Activity in US Counties: A Century of Data,” *Journal of Urban Economics*, 118, Article 103257.

Cronon, W. (1991), *Nature’s Metropolis: Chicago and the Great West*, New York: W. W. Norton & Company.

Crozet, M. (2004), “Do Migrants Follow Market Potentials? An Estimation of a New Economic Geography Model,” *Journal of Economic Geography*, 4:4, 439-458.

Davis, D. R. and D. E. Weinstein (2002), “Bones, Bombs, and Break Points: The Geography of Economic Activity,” *American Economic Review*, 92:5, 1269-1289.

Dib, A. (2003), "An Estimated Canadian DSGE Model with Nominal and Real Rigidities," *Canadian Journal of Economics*, 36:4, 949-972.

Evgenidis, A., M. Hamano, and W. N. Vermeulen (2021), "Economic Consequences of Follow-up Disasters: Lessons from the 2011 Great East Japan Earthquake," *Energy Economics*, 104, Article 105559.

Faber, B. (2014), "Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System," *Review of Economic Studies*, 81:3, 1046-1070.

Forslid, R. and G. I. P. Ottaviano (2003), "An Analytically Solvable Core-periphery Model," *Journal of Economic Geography*, 3:3, 229-240.

Glaeser, E. L. (2021), "Urban Resilience," *Urban Studies*, 59:1, 3-35.

Hornbeck, R. and D. Keniston (2017), "Creative Destruction: Barriers to Urban Growth and the Great Boston Fire of 1872," *American Economic Review*, 107:6, 1365-1398.

Imaizumi, A., K. Ito, and T. Okazaki (2016), "Impact of Natural Disasters on Industrial Agglomeration: The Case of the Great Kantō Earthquake in 1923," *Explorations in Economic History*, 60, 52-68.

Indaco, A., F. Ortega, and A. S. Taṣpınar (2021), "Hurricanes, Flood Risk and the Economic Adaptation of Businesses," *Journal of Economic Geography*, 21:4, 557-591.

Krugman, P. (1991a), "Increasing Returns and Economic Geography," *Journal of Political Economy*, 99:3, 483-499.

Krugman, P. (1991b), "History versus Expectations," *The Quarterly Journal of Economics*, 106:2, 651-667.

Krugman, P. (1993), "First Nature, Second Nature, and Metropolitan Location," *Journal of Regional Science*, 33:2, 129-144.

Miguel, E. and G. Roland (2011), "The Long-run Impact of Bombing Vietnam," *Journal of Development Economics*, 96:1, 1-15.

Ottaviano, G. I. P. (2001), "Monopolistic Competition, Trade, and Endogenous Spatial Fluctuations," *Regional Science and Urban Economics*, 31:1, 51-77.

Siodla, J. (2021), "Firms, Fires, and Firebreaks: The Impact of the 1906 San Francisco Disaster on Business Agglomeration," *Regional Science and Urban Economics*, 88, Article 103659.

Testa, P. A. (2021), "Shocks and the Spatial Distribution of Economic Activity: The Role of Institutions," *Journal of Economic Behavior & Organization*, 183, 791-810.

Tobriner, S. (2006), *Bracing for Disaster: Earthquake-Resistant Architecture and Engineering in San Francisco, 1838-1933*, Berkeley, CA: Heyday Books.

Vigdor, J. (2008), "The Economic aftermath of Hurricane Katrina," *Journal of Economic Perspectives*, 22:4, 135-154.

Xu, H. and S. Wang (2019), "Urban Redevelopment and Residential Location Choice: Evidence from a Major Earthquake in Japan," *Journal of Regional Science*, 59:5, 850-882.

生產力衝擊與經濟活動的空間分佈

盧伯豪、蔡智發*

摘　要

本文乃探討在一個生產力衝擊的效果後，經濟活動的空間分佈如何改變。我們提出一個規模報酬遞增的兩區域一般均衡模型，並且分析在什麼條件會改變原有製造業的空間分佈。本研究對一個生產力的衝擊效果後的廠商動態提供更深入的瞭解。最後，我們也提供一些與本模型產業空間分佈一致的實際案例。

關鍵詞：報酬遞增、生產力、多重均衡、遷徙
JEL分類代號：F12, F22, R12

* 兩位作者分別為聯繫作者：蔡智發，國立臺北大學都市計劃研究所特聘教授，237303 新北市三峽區大學路 151 號，電話：02-86741111 轉 67349，E-mail：tsaij@mail.ntpu.edu.tw；盧伯豪，國立臺北大學都市計劃研究所博士，237303 新北市三峽區大學路 151 號，E-mail：s810874102@gm.ntpu.edu.tw。

投稿日期：112 年 1 月 5 日；修訂日期：112 年 3 月 29 日；
接受日期：113 年 3 月 18 日。