1. Introduction

Designs of transport system have critical impacts on spatial structure of an economy. The major topic in the studies of spatial economics has been to investigate the effects of transport cost change on spatial structure of the economy; whether transport cost reductions induce agglomeration or dispersion of economic activities (Fujita, Krugman, Venables (1999)). The results depend on the formulations of agglomeration and dispersion forces. For example, Krugman (1991) shows that agglomeration occurs at low transport costs, while Helpman (1998) shows opposite result. Since two studies use the same formulation of agglomeration force, different results stem from different formulations of dispersion forces. Krugman introduces immobile consumers as a dispersion force while Helpman focuses on land constraint for housing. This paper shows that different designs of transport network may cause either agglomeration or dispersion, without changing the formulations of agglomeration and dispersion forces.

Most existing studies assume two region economy, in which spatial aspects are not sufficiently explored. The sources of transport cost reductions are roughly classified into technological changes and improvements of infrastructures\(^1\). Models of two regions are not capable to distinguish

\(^1\) Combes, Lafourcade (2003) compute transport cost reduction in France decomposing into several factors such as technological changes (including deregulations) and infrastructure improvement. They show that contributions of the former factor are dominant in quantity terms, and infrastructure improvements have significant effects on spatial variations.
the effects of these two factors: technological changes are uniform across space, while improvements of infrastructures are non-uniform. This paper focuses on the role of network designs in shaping spatial structure of the economy. We construct a model of spatial economy with many (more than two) regions connected by transport network. With this setting, we are able to deal with the case of non-uniform changes in transport costs in that access conditions for some regions are improved but those for other regions unchanged. We examine the effects of different link improvement policies on spatial structure of the economy, and evaluate alternative policies in terms of economic welfare. Mun (1997) investigates the effects of transport network improvements in multi-city economy, where agglomeration force is formulated as external economy of city size. The present paper uses more general model along the line of New Economic Geography (Fujita, Krugman, Venables (1999)) in that micro-foundation of agglomeration is explicitly formulated. With this formulation, we deal with a broader range of policy options.

One important feature of spatial economy is the possibility of multiple equilibria, which implies historical path dependency. We examine different paths of link improvements, and discuss welfare implications of alternative paths.

2. The model

2-1 Basic assumptions and setting

The economy consists of a fixed number \( I \) of regions, which are connected by transport network. Transport facilities are used for transportation of traded goods. Firms and households can migrate freely between regions and industrial sectors. There are two types of industries in the economy; foot-loose industry (F-sector) and local industry (L-sector). Technologies of firms in F-sector are independent of locations, but subject to increasing returns to scale, and they supply their products in monopolistically competitive market. There are \( M \) types of industries in the F-sector, which are different in the degree of scale economies, product differentiation, etc. Production technology of L-sector is constant returns and region-specific; each region has comparative advantage in production of single type of L-sector good. Therefore types of local goods are equal to the number of regions in the economy. L-sector goods are essential for consumers in all regions; this works as dispersion force. This treatment enables us to evaluate

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2 Forslid et. al. (2002) develop a general equilibrium model of spatial economy with many regions, and analyze the effects of trade cost changes. They focus on the effect of economic integration and merely deal with uniform changes in trade cost, so network effects discussed in this paper are out of considerations.
welfare effect by a single measure, i.e., utility level, since all workers are homogeneous and freely mobile between regions and industrial sectors. Input for transportation service is the traded good itself: the transportation cost is paid by a portion of the traded good as if it disappears in the process of transportation (so-called iceberg transportation technology). The intra-regional transportation cost is assumed to be zero. Each household seeks to maximize utility that depends on variety of F-sector goods consumption, and quantities of local goods. Each firm in F-sector seeks to maximize profit in monopolistically competitive market while market for L-sector is perfectly competitive. In equilibrium, commodities and labor markets are cleared, and all firms and households have no incentive to change locations.

2-2 Consumption

There are $M+I$ types of consumer goods in total; goods produced by F-sectors are indexed from 1 to $M$, and L-sector goods are from $M+1$ to $M+I$. Utility function of a household is specified as

$$U_j = \prod_{m=1}^{M} \left( X_j^m \right)^{\beta^m} \prod_{i=1}^{I} \left( x_{j}^{M+i} \right)^{\beta^{M+i}} \sum_{m=1}^{M+I} \beta^m = 1$$  \hspace{1cm} (1)

where $X_j^m = \left[ \int_0^{\rho^m} x_j^m(\theta) \rho^m d\theta \right]^{1/\rho^m}, \quad 0 < \rho^m < 1$ \hspace{1cm} (2)

$x_j^m(\theta)$: quantity of differentiated good of variety $\theta$ in sector $m$ consumed by a household in region $j$, $x_j^{M+i}$: consumption of local good produced in region $i$, $n^m$: total number of varieties (=firms) in sector $m$. The above specification implies that consumers seek varieties in consumption of differentiated good produced by firms in F-sector.

Budget constraint of a household is

$$w_j^m = \sum_{m=1}^{M} \left[ \int_0^{\rho^m} q_j^m(\theta) x_j^m(\theta) d\theta \right] + \sum_{i=1}^{I} q_j^{M+i} x_j^{M+i}$$ \hspace{1cm} (3)

where $q_j^m(\theta)$: consumer price of variety $\theta$ of good $m$ in region $i$, $w_j^m$: wage rate of worker employed by industry $m$ located in region $j$.

Maximizing utility subject to budget constraint, we have demand functions for goods, and indirect utility function as follows

$$V_j^m = w_j^m \prod_{m=1}^{M} \left( G_j^m \right)^{-\beta^m} \prod_{i=1}^{I} \left( q_j^{M+i} \right)^{-\beta^{M+i}}$$ \hspace{1cm} (4)

where $G_j^m$ is the price index given by
\[ G_j^m = \left[ \int_0^{\sigma^m} q_j^m(\theta)^{1-\sigma^m} d\theta \right]^{1/(1-\sigma^m)} \]  

where \( \sigma^m = 1/(1 - \rho^m) \) is elasticity of substitution.

2-3 Production

Each firm in F-sector produces a single variety of the differentiated good with increasing returns technology. Let \( y_i^m(\theta) \) be the quantity of output produced by a firm \( \theta \) of industry \( m \) (\( m = 1, 2, ..., M \)) located in region \( i \) \( (i = 1, 2, ..., I) \). Labor input for this firm is

\[ l_i^m = F^m + c^m y_i^m(\theta), \]

where \( F^m \) is fixed input independent of output level, representing the scale economy. \( c^m \) is labor required to produce one unit of output.

Profit of a firm is written as

\[ \pi_i^m(\theta) = p_i^m(\theta)y_i^m(\theta) - w_i^m(F^m + c^m y_i^m(\theta)). \]

And profit-maximizing price is

\[ p_i^m(\theta) = \frac{w_i^m c^m}{\rho^m} \]

All firms located in the same region face the same factor price and technology, thereby set the identical price for their products. So we denote by \( p_i^m \) the price in (8).

L-sector goods are produced in constant returns technology in that labor input is proportional to the quantity of output. Production technology is region-specific such that region \( i \) has comparative advantage in production of \( M+i \)-th good. There are many firms producing the local good in each region, and local goods produced in the same region are homogeneous. Therefore the markets for L-sector goods are perfectly competitive. It follows that price is equal to unit production cost, i.e.,

\[ p_i^{M+i} = w_i c^{M+i} \]

where \( c^{M+i} \) is labor input required for production of one unit of local good.

2-4 Market equilibrium

We suppose that there is free entry of firms in F-sector subject to monopolistic competition. So the firms’ profit should be zero in equilibrium. Substituting (8) to (7) and setting \( \pi_i^m(\theta) = 0, \quad (m = 1, 2, ..., M) \) we have
Let us denote by $L_i^m$ the number of workers in sector $m$ in region $i$. The labor market equilibrium requires $L_i^m = n_i^m l_i^m$, from which we obtain
\[ n_i^m = \frac{(1 - \rho^m) L_i^m}{F^m} \] (11)
where $n_i^m$ is the number of firms in sector $m$ in region $i$.

Inter-regional trade pattern is determined by spatial price equilibrium in which the possibility of positive profit for traders is eliminated. In other words, the consumer price of good $m$ produced in region $i$ and consumed in region $j$, $q_{ij}^m$ is equal to the mill price $p_i^m$ plus transport cost.
\[ q_{ij}^m = T_{ij}^m p_i^m \] (12)
where $T_{ij}^m = (1 + t_m d_{ij})$, and $t_m$ is the amount of good required for transporting unit distance, $d_{ij}$ is the shortest-path trip time between regions $i$ and $j$ along the network\(^3\). Accordingly the transport cost is equal to $p_i^m t_m d_{ij}$.

The clearing of the market for good produced by a firm in F-sector requires the following
\[ y_i^m (\theta) = \frac{F^m (\alpha^m - 1)}{e^m} \equiv \bar{y}^m, \] (10)

3 We assume that transport cost is proportional to trip time rather than physical distance. This is because our primary concern is on improvements of transport network; in most cases, they do not reduce physical distance, but trip times. Reductions of trips time typically lead to saving of wage payments for truck drivers.
where \( V_{jm} \) is the utility level attained by working for a firm in industry \( m \) located in region \( i \), which is given by (4).

### 3. Numerical analysis of alternative transport network improvements

It is not appropriate to adopt traditional comparative statics approach, since spatial structure of this economy may not change smoothly with transport improvements. We often observe discontinuous changes in spatial patterns. Thus we compute equilibrium solutions for a number of parameter sets that are constructed as possible combinations of parameters, then find out various patterns of spatial structure in equilibrium.

We conduct simulations for hypothetical system of 4 regions connected by 6 links network, as illustrated in Figure 1. Numbers in \( \langle i \rangle \) indicate the link codes, and service level of links are represented by time required to pass through, rather than physical distances.

There are 3 industries in F-sectors and 4 different local goods in L-sector. So the total number of industry types is \( M + I = 7 \).

Parameters given for each simulation are reduced to \( \rho^m (m = 1, \ldots, 4), \beta^m, \iota^m (m = 1, \ldots, 7) \), by normalizations of units. We construct 6804 parameter sets as possible combinations of parameter values. See Appendix A for normalizations and details of parameter sets.

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![Figure 1: Regions and transport network](image-url)
It is well-known that the model presented here produces multiple equilibria, so the solutions depend on initial states. Let $N_i$ be the population of region $i$, that is the sum of workers in all industries, i.e., $N_i = \sum_{m} L_i^m$. We specify the initial population distribution as follows

$$(N_1, N_2, N_3, N_4) = (0.55, 0.15, 0.15, 0.15)$$

and distribution of employments among industries within each region is given by

$$L_i^m = N_i / (M + 1), \quad L_i^{M+i} = N_i / (M + 1)$$

This setting holds for all simulations below.

We specify the dynamics of location adjustments toward equilibrium as follows,

$$\Delta L_i^m = -\delta, \quad \Delta L_i^{M+i} = \delta,$$

where $\Delta L_i^m$ is size of adjustment in the number of workers at $(m, i)$, and

$$\arg \max_{m, i} \{V_i^m\}, \quad \arg \min_{m, i} \{V_i^m\}, \quad \delta = \min \left\{ \varepsilon (V_i^m - V_i^{M+i}), L_i^m \right\}$$

The above process implies that workers in the lowest utility location move to the highest utility location at each step of adjustment.

### 3-1 Alternative link improvement plans

Suppose that spatial structure of the economy is initially core-periphery pattern where one region has relatively large population size and all types of industries in F-sector are located there. Given the initial distribution specified above, the core should be located at region 1 in initial equilibrium. Links in the transport network can be classified into two types: the link connecting the core and other region (type C) and the link connecting two non-core regions (type N). In Figure 1, links 1, 3, 5 are of type C, while links 2, 4, 6 are of type N. We compute the equilibrium solutions for the following two alternative link improvement plans, i.e.,

**Plan 1:** improvement of link 1 (type C), and

**Plan 2:** improvement of link 2 (type N).

We assume that the improvement reduces by one-third the time required to pass through the link. And it changes the inter-regional distance matrix, $\{d_{ij}\}$, of which each element is the shortest-path distance between $i$ and $j$ along the network.

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4 This does not mean that F-sector firms exist only in the core. Core-periphery patterns in multi-industry setting as in this paper include the case that some types of F-sector firms are located in peripheral regions.
[**Pattern A**]: Core move to region 3 or 4 for plan2

Properties: Utility level is identical for both plans
Size of core is increased

[**Pattern B**]: Core stays at region 1 for both plans

Properties: Utility level under plan 1 is always higher

B-1

- Plan 1
- Plan 2

size of core increased

$\frac{1335}{5426}$ (24.6%)

B-2

- Plan 1
- Plan 2

size of core decreased

$\frac{1786}{5426}$ (32.9%)

Figure 2 Patterns of spatial changes under alternative plans
For each plan, we first compute the equilibrium solution for the basic network without improvement (Figure 1), given the initial distribution of workers specified above. Then the inter-regional distance matrix is replaced by that for the network with link improvement, and compute the new equilibrium solution, given the equilibrium distribution of workers in basic case as the initial solution. Therefore we run the simulation program four times to examine two alternative plans, for each parameter set.

We conduct simulations for 6804 cases, and exclude cases that equilibrium are not attained within 90000 iterations, or workers are uniformly distributed across regions at equilibrium in basic case (i.e., core does not formed). Consequently, the number of effective cases is 5426.

We investigate the results of simulations from various aspects. It turns out that there are two distinct patterns A and B, as illustrated in Figure 2. Properties of each pattern are described as follows

**[Pattern A]**: Location of core is changed under plan 2, size of core expanded. In this case, spatial structure under one plan is a mirror images to other one, so welfare levels under two plans are indifferent. In both plans, the improved link connects core and other region. And the results suggest that this type of link improvement induces more agglomeration to the core.

**[Pattern B]**: Location of core is unchanged under both plans, size of core is always decreased under Plan 2, while size of core may either decreased or increased under plan 1. Utility level under Plan 1 is always higher than that under Plan 2. In other words, welfare is higher under the plan that may promote agglomeration.

Pattern B is more realistic; move of core as in Pattern A has been hardly observed as the result of transport system change. So we focus on this pattern and take a closer look at changes in industrial locations for different link improvement policies.

Figure 3 shows the typical result for Pattern B-1, which describes the distributions of workers by industrial sectors in four regions for different network improvement plans. Region 1 is the core in that there exist all types of industries and population size is the largest. With plan 1 that improves the link between regions 1 and 2, the size of core is increased and sizes of other regions are decreased. Region 2 loses F-sector employments (industry 3) that exists before the improvement. Firms producing F-sector good in region 2 no longer attract sufficient demand due to improved access to core region: region 2 is too close to the core. On the other hand, improvement of link between two peripheral regions under plan 2 induces dispersion of industrial locations from the core. Region 4 has two types of F-sector industries and gains population. With plan 2, spatial economy becomes 3-layered hierarchical system where region 1 is of the 1st rank, region 4 is of the 2nd rank, and regions 2 and 3 are of the 3rd rank.
Plan 1

Plan 2

Figure 3  Example of Pattern B-1
$(\rho^1, \rho^2, \rho^3) = (0.300, 0.600, 0.900), \quad (\beta^1, \beta^2, \beta^3) = (0.600, 0.300, 0.100), \quad \alpha = 0.600, \quad (t^1, t^2, t^3) = (2.000, 1.000, 0.500), \quad t^a = 0.300, \quad \gamma = 1.00$

Figure 4  Example of Pattern B-2
Figure 4 shows the result for Pattern B-2, under which size of the core is decreased in both plans. Note that industrial location in initial equilibrium are so concentrated that peripheral regions do not have F-sector employments. In this case, improvement under Plan 1 does not induce more concentrated industrial location patterns. Instead, improved access to core region causes expansion of local industry in region 2: consumers in region 1 demand more local good produced in region 2 since consumer price is decreased by the improvement. Likewise population sizes of regions 3 and 4 increase under Plan 2.

We look at the relations between parameter values and relative frequencies of patterns. Table A in Appendix B summarizes the results. The table indicates that Pattern B is more likely when parameters take the values so that agglomeration force is stronger. As discussed in Krugman (1991), agglomeration force is stronger when consumers seek more variety in consumption (smaller $\rho$), share of F-sector industry is larger (smaller $\alpha$), and overall level of transport cost is lower (smaller $\gamma$). In this case, lock-in effect of initial core is strong enough that the agglomeration there persists.

We also examine the following two types of plans, i.e.,

- Plan 3: improvement of link 4
- Plan 4: improvement of link 5.

The basic results are similar to the above case.

### 3-2 Alternative paths of link improvements

Suppose that two links (one is type C and the other is type N) are to be improved. We examine two alternative paths of link improvement, as shown in Figure 5.

- Path 1: first improve the link 1 (type C) and improvement of link 6 (type N) follows,
- Path 2: first improve the link 6 and improvement of link 1 follows.

We observe four patterns of spatial structure after the improvements, as illustrated in figure 6, patterns [I-1] and [I-2] are path-independent, and [D-1] and [D-2] are path-dependent.

- [Pattern I-1]: core location is unchanged.
- [Pattern I-2]: core moves to the region 2 where link 1 and 6 meet.
- [Pattern D-1]: core moves to region 4 under path 2 while core does not move under path 1, welfare levels are indifferent between two paths.
- [Pattern D-2]: core moves to region 2 under path 2 while core does not move under path 1, welfare level under path NC is higher.
Pattern [I-1] is likely to emerge when the lock-in effect is very strong. On the other hand, [I-2] is likely when the lock-in effect is very weak. In this case, firms and households easily change the location regardless of initial state, so they move to the region 2, the most convenient location in terms of accessibility. Patterns [D-1] and [D-2] are likely when the lock-in effect is moderate. In this case, lock-in effect is strong enough for the core to stay under path 1, but it is not too strong to prevent the move of the core under path 2. The result in the previous section suggests that location of core may move to region 2 or 4 when the link 6 is improved first. If core moves to region 4 (2), the pattern [D-1] ([D-2]) is realized.

4. Conclusion

Policy planners have regarded constructions of new transport links as a measure to control spatial distribution of economic activities. In countries like Japan and Korea that suffer from problems associated with concentration of firms and populations to capital region, it has been advocated that transport improvements induce dispersion of economic activities from core to peripheral regions.
[Pattern I-1]: Path-independent, core located at region 1

[Pattern D-1]: Path-dependent, utility same

[Pattern I-2]: Path-independent, core moves to region 2

[Pattern D-2]: Path-dependent, Utility level is higher for path2

Figure 6  Patterns of changes under alternative paths of link improvements
This paper shows that improvements of transport network may induce either concentration or dispersion depending on the choice of improved link. Improvement of the link between core and periphery is likely to induce more concentration, while improvement of the link between non-core regions induces dispersion. If the policy planner chooses the latter plan aiming at dispersions, the society should give up the higher welfare attainable under the former plan.

We also demonstrate that priorities of link improvements are another important factor that policy planners concerned with spatial structure should take into considerations.

References


Appendix A: Parameter sets for simulations

Following Fujita, Krugman, Venables (1999), we choose the units of measurements for variables to reduce the number of parameter sets for simulations, as follows
\[ F^m = \beta^m (1 - \rho^m), \quad \text{(A1)} \]
\[ c^m = \rho^m \quad \text{(A2)} \]
\[ c^{M+i} = 1 \quad \text{if good } M + i \text{ is produced in region } i \quad \text{(A3)} \]

Let us introduce new parameters as follows,

\[ \alpha = \sum_{i=1}^{I} \beta^{M+i} \]

\[ \bar{\beta}^m = \beta^m / \sum_{m=1}^{M} \beta^m, \quad (m = 1, \ldots, M) \]

where \( \alpha \) is expenditure share for L-sector goods, and \( \bar{\beta}^m \) represents the expenditure share of good \( m \) in consumption of F-sector goods. Using these definitions, the values of parameters are obtained as

\[ \beta^m = (1 - \alpha) \bar{\beta}^m, \quad (m = 1, \ldots, M) \quad \text{(A4)} \]
\[ \beta^{M+i} = \alpha^i, \quad (i = 1, \ldots, I) \quad \text{(A5)} \]
\[ t^m = \gamma T^m, \quad (m = 1, \ldots, M) \quad \text{(A6)} \]
\[ t^{M+i} = \gamma t^i, \quad (I = 1, \ldots, I) \quad \text{(A7)} \]

(A5) implies that consumer spends equal share of income for each local good. (A6)(A7) imply that we separate transport technology and sectoral variation in transport costs. \( \gamma \) represents overall level of transport cost, which uniformly affects transport costs of all sectors. And \( T^m \) is the relative transport cost of industry \( m \), of which the basic value is equal to unity. The values of parameters to be combined for making parameter sets are listed below,

\[ (\rho^1, \rho^2, \rho^3) = (0.3, 0.6, 0.9) \quad (0.3, 0.4, 0.9) \quad (0.3, 0.8, 0.9) \]
\[ (\bar{\beta}^1, \bar{\beta}^2, \bar{\beta}^3) = (0.333, 0.333, 0.334) \quad (0.1, 0.3, 0.6) \quad (0.6, 0.3, 0.1) \]
\[ \alpha = 0.4, \quad 0.6, \quad 0.8 \]
\[ (\bar{T}^1, \bar{T}^2, \bar{T}^3) = (1, 1, 1) \quad (0.5, 1, 2) \quad (1, 2, 1) \quad (2, 1, 0.5) \]
\[ \gamma = 0.001, 0.0025, 0.005, 0.0075, 0.01, 0.025, 0.05, 0.075, 0.1, \]
\[ 0.25, 0.5, 0.75, 1, 2.5, 5, 7.5, 10, 25, 50, 75, 100 \]

The total number of combinations amounts to \( 3^4 \times 4 \times 21 = 6804 \).
Appendix B  Parameters and frequency of patterns

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<td>628</td>
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<td>16.0%</td>
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<tr>
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<td>1877</td>
<td>1505</td>
<td>5426</td>
<td>100.0%</td>
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<td>942</td>
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<td>3121</td>
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<td>Pattern B-2</td>
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<td>398</td>
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<td>50</td>
<td>508</td>
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<td>1724</td>
<td>1863</td>
<td>5426</td>
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<th>0.01 ( \leq \gamma ) ( &lt; 0.1 )</th>
<th>0.1 ( \leq \gamma ) ( &lt; 1 )</th>
<th>1 ( \leq \gamma ) ( &lt; 10 )</th>
<th>10 ( \leq \gamma ) ( &lt; 100 )</th>
<th>TOTAL</th>
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