MIGRATION SPEED AND NETWORK EVOLUTION WITH COST BENEFIT RULES

Kyoto University Student member ○Mehmet Ali Tuncer
Kyoto University Student member Morimitsu Kurino
Kyoto University Regular member Kiyoshi Kobayashi

1. INTRODUCTION

This paper attempts to provide some simulation experiments for the policy driven development by revealing how city systems evolve through time in response to policy initiatives for network formation. By assuming that the government applies cost-benefit rules to improve railway network one by one, the paper illustrates that city systems will evolve in such a manner that population will indeed cluster in some dominant locations, and that they depend both on the geographical conditions and historical order of network improvement.

2. THE MODEL

An economic system of n cities, indexed by $i = 1, 2, \cdots, n$, is considered, where the cities are connected by a railway network. The economy produces one type of commodities consumed by the whole population. Perfect competition prevails in good markets. The population is homogeneous and freely mobile among cities. The total population is given exogenously and constant any point in time. For the representative household, living at a distance u_i from the CBD of city i, the composite commodity consumption, $x_i(u_i)$, is given by

$$x_i(u_i) = y_i - p_i(u_i) - c_i u_i \tag{1}$$

where y_i is income, $p_i(u_i)$ is the land rent per unit lot size at point u_i, and c_i is the cost of commuting per unit distance that is constant everywhere in the city. The indirect utility function is supposed to be

$$V_i(u_i) = y_i - p_i(u_i) - c_i u_i \tag{2}$$

Given the fixed lot size over the economy, the size of city i can be defined by the area of urban land use. Thus,

$$N_i = \int_0^{L_i} 2\pi u_i du_i = \pi L_i^2 \tag{3}$$

Then, the equilibrium utility levels of the representative households can be fully characterized by the three parameters, y_i, N_i, and c_i:

$$V_i = y_i - c_i \pi^{-\frac{1}{2}} N_i^{\frac{3}{2}} \tag{4}$$

Let us assume a constant return to scale technology and use the production function, Y_i, of the form

$$Y_i = N_i^{\alpha} \left\{ \sum_j N_j \left(\frac{R_{ij}}{N_j} \right)^{\xi} \right\}^{\gamma} \tag{5}$$

where Y_i is total output, R_{ij} is the inter-city communication frequency between city i and j, and α, ξ, g are parameters satisfying $\alpha + \xi g = 1$. Given the wage rent, w_i, and transportation cost between node i and j, d_{ij}, the firms' behavior is characterized by

$$w_i = \alpha \frac{Y_i}{N_i} \tag{6}$$

$$d_{ij} = \gamma \xi Y_i \frac{N_j d_{ij}^{-\frac{\xi}{1-\xi}}}{R_{ij} \sum_k N k d_{ik}^{-\frac{\xi}{1-\xi}}} \tag{7}$$

The household income is given by:

$$y_i = w_i + \frac{P_i}{N_i} \tag{8}$$

The population distribution among cities can be brought into equilibrium when no household has incentive to move. Thus the equilibrium of population distribution can be characterized by

$$V_1 = \cdots = V_n = \overline{V} \tag{9}$$

where $\overline{V}$ is the equilibrium utility level. Finally, the constant total population of the whole system is indicated by the following equation, where N is the exogenously given total population of the system.

$$\sum_{i=1}^{n} N_i = N \tag{10}$$

In the model described above, N, c_i, and d_{ij} are the exogenous variables whereas V_i, u_i, P_i, y_i, N_i and R_{ij} are endogenous variables determined by the equilibrium conditions.

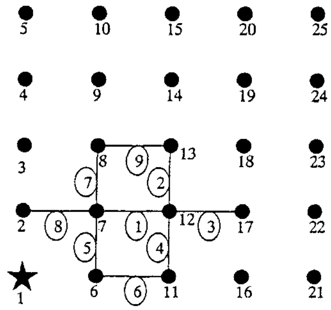
3. COST-BENEFIT RULES

The investment decision is taken by the central government, which controls the travel costs between the cities by improving the existing transportation links. We consider two kinds of cost-benefit rule. One is to be calculated by considering the new OD patterns of the network after the construction of a new link. By using the current values of inter-city communications, consumer surplus is calculated with the following equation and taken to be the benefit provided by the improved link:

$$B_l = \sum_{i=1}^{n} \sum_{j \neq i}^{n} \frac{1}{2} (R'_{ij} - R_{ij})(d_{ij} - d'_{ij}) \tag{11}$$

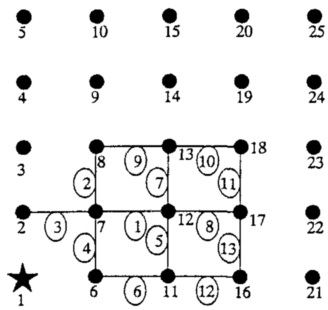
where B_l indicated the benefit due to the improvement of link l. In the second cost-benefit rule the decision is taken regarding the indirect equilibrium utility level. In this case the link which will provide the highest increase in the equilibrium utility level of the whole system is chosen to be constructed in the next stage of the evolution.

4. SIMULATION POLICY



$N_i = 70,\ N_\star = 820;\ N_{total} = 2500$

Fig. 1 Network Evolution $\lambda = 50.0$



$N_i = 70,\ N_\star = 820;\ N_{total} = 2500$

Fig. 2 Network Evolution $\lambda = 25.0$

The network of cities simulated is a simple grid system which lies on a flat ground. The network simulated which consists of 5x5=25 cities is shown in Fig.1. First. let us assume that the system adjusts instantly without time delay and the the network evolves in the following manner. Set the initial population patterns.Then, the link (connecting neighboring cities) is improved by decreasing its cost from its initial value of $d_{ij} = 1.0$ to $d'_{ij} = 0.7$. Following the improvement, the new utility levels of all of the cities are calculated and checked whether they are in equilibrium or not. If the equilibrium is not reached new populations are assigned to each and every city and this process is repeated until the equilibrium is obtained. At every stage of the evolution, the potential benefits due to possible link improvements are calculated by bringing the system into equilibria. Since the all links have the same length, the cost of construction of each links is assumed to be same, so, the link which provides the highest benefit is chosen to be constructed at the respective stage. The same procedure is repeated to determine the remaining links to be constructed.

Second, the system is assumed to be adjusted with time lags. The convergence to the equilibrium is regulated by the following population dynamics:

$$N_{t+1}(i) = N_t(i) + \lambda(V_i - \overline{V}) \qquad (12)$$

assuming the population moves toward the locations with above-average utility levels and away from those with below-average. Here $N_{t+1}(i)$ is the population of the i-th city to be used in the next iteration step, λ is the adaptation parameter reflecting the adjustment speed of convergence, $\overline{V}$ is the average utility level of the whole system calculated by taking the average of the utility levels of all the cities weighted by the population of each city, and V_i is the utility level of the ith city. The second term on the right hand side of (12) shows the change in the population of ith city, which is positive if V_i is greater than $\overline{V}$ and negative if V_i is smaller than $\overline{V}$.

5. RESULTS

For the benchmark case, the values of production function parameters are as follows: $\alpha = 0.9, \xi = 0.5$, and $g = 0.2$, the migration speed λ is taken as 50.0. As shown in **Fig. 1**, the numbers in the circles indicate the order of the links improved, the numbers show only the first 20 links improved though actually all of them are improved at the end of the simulation. This evolution pattern corresponds to the most centralized case where no cities disappear from the system. For this case both of the cost-benefit rules applied show the same evolution pattern. As it can be seen from the figure, the first 8 links improved refer to a very centralized evolution pattern. The evolution of the network starts from the center and evolves towards the edges of the network. The central city enjoys the largest share of the population during this process. **Fig. 2** shows the effect of the migration speed on the evolution pattern. As we decrease the speed of migration from 50 to 25 we end up with a larger final network, where 14 links are improved at the end of the process and the number of cities surviving the evolution process with population values greater than zero increased to 10 compared with the benchmark case.

6. CONCLUSION

The use of the step-by-step cost benefit analysis brings the system to highly centralized equilibrium points from which the system cannot go back to its initial pattern. This is especially true when the adjustment speed of the system is very high. The simultaneous cost benefit analysis of the entire network structure can be recommended to avoid the formation of highly centralized city system.