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Road Infrastructure and Urban Growth

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1. Introduction

Urban Economists have devoted to analyze the system of cities theoretically over the last two decades or so. Henderson ([6]) argued that an equilibrium or optimal city size is reached when the marginal social benefits due to economies of scale equal the marginal social costs due to diseconomies of scale such as high housing or commuting costs, and showed the formation of the hierarchical urban system of cities. Furthermore, Abdel-Rahman ([1]) introduced the monopolistic competition theory developed by Dixit and Stiglitz ([4]), and applied increasing return to scale to urban system model. Tabuchi ([9]) combined the monopolistic competition theory with the location theory (Alonso [2] ~~(1964)~~), and showed the impacts of transportation cost on urban concentration and dispersion in a two-city system framework. Because of ignoring a spatial distribution of cities, these types of models do not provide explanation for the spatial hierarchy of cities.

On the other hand, the central place theory (e.g., Christaller [3] ~~(1966);~~ and Losch [7] ~~(1954)~~) explains the system of cities spatially. While this theory shows hierarchical distribution of cities, it lacks the economical foundations. More precisely, this type of model cannot show how the distribution of cities emerges from the economic interaction of households or firms. Although Wang ([10]) improved the central place theory by introducing economic factors such as consumption and production, his research do not provide an urban growth such as emergence of new cities.

Fujita and Mori ([5]) and Mori ([8]) analyzed the spatial formation of urban system by using monopolistic competition theory. Their research had economical foundations and clarified the spatial urban growth with hierarchical distribution of cities such as the central place theory. Fujita and Mori ([5]) showed how the increase in population size evolves the urban systems, and Mori ([8]) clarified that the most important factor for formation of megalopolis is the lower transportation cost. It can be said that the population size and the transportation cost are determined in the market. For this reason, their study did not consider the role of administration such as government or local government, and their study could not explain how a construction of a road infrastructure exerts agglomeration force for urban system. In this paper, we add a road infrastructure radiating from cities in Fujita-Mori model, and shows that the agglomeration force for cities increases with the number of roads. This extension shows that the construction of the road infrastructure brings concentration of population and economy in the urban area rather than rural area. This result gives the planner of road infrastructure a useful direction toward optimal road construction.

This paper is organized as follows: next section discusses the model, and section 3

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In the transportation of i-goods for the distance d, only a fraction $e^{-\tau_i d}$-units actually arrives. Then the price of M-goods at location y produced by the firm locating at x is given by $p_M(y\,|\,x)=p_M(x)e^{\tau_M|y-x|}$.

Since M-goods are assumed to have monopolistic brands, M-goods are produced at the point where the marginal costs and marginal revenue are equal, that is, the following condition must be ~~met~~. satisfied

$$p_M\left(1-\frac{1}{1+\gamma}\right)=a_M W(x), \tag{6}$$

where $1+\gamma$ is the price elasticity of the M-goods, and $W(x)$ is the wage rate at x. Then the prices of M-goods are given as $p_M(x)=a_M W(x)/\rho$.

The profit of the M-firm locating at x can be obtained as

$$\pi(x)=p_M(x)Q-W(x)L=a_M\gamma^{-1}W(x)(Q-\gamma f/a_M). \tag{7}$$

Because there are many potential firms producing M-goods, and they enter the market until they prospect to earn profit, the profits of the firms become zero. As a result, by using (7), the equilibrium output of each M-goods, and labor input of each M-firm are obtained as $Q^*=\gamma f/a_M$, and $L^*=f(1+\gamma)$, respectively.

Suppose that all the M-goods are produced in the single city at $x=0$ whose agricultural hinterlands lie on the v roads radiating form the city, and those lengths are l. Because directions are not concerned and roads have no hierarchy, we determine one road as a base-road and the others as sub-roads arbitrarily, and suppose that the base-road and the sub-roads are on the interval $[0,\ l]$ and $[-l,\ 0]$, respectively. Figure 1 explains the urban system. In the figure, dots mean the central cities, and the lines radiating from the dots are roads. By using the number of roads radiating from the central city, v, we call the urban system as v-road system as shown in figure 1.

The price of the A-good produced at the location y is given by $p_A(y)=e^{-\tau_A|y|}$. We define $p_A(0)$ as the price of the A-good at the central city and normalized to be 1. In the production of A-good, since there are so many potential workers, the competition for the agricultural land becomes so fierce that the profits of producing A-good equal the land rent of agricultural land. Then the land rent at each location is then given by

$$R(y)=\max\{p_A(y)-a_A W(y),\ 0\}. \tag{8}$$

The agricultural fringe (A-fringe), l, is the location where the land rent is zero, and, by using $p_A(y)$ and (8), we can obtain the wage of the A-fringe as $W(l)=a_A^{-1}e^{-\tau_A l}$.

The necessary condition for the stable urban system is the equality of utilities of A-workers and M-workers at location y. Let $p_M(\omega/y)$ be the price of M-good indexed ω at location y produced in the city, and p_A be the price of A-good at location y, the equilibrium wage rate at y, given the A-fringe distance l, can be obtained as

$$W(y)=a_A^{-1}e^{-a_M(\tau_A+\tau_M)l}e^{(a_M\tau_M-a_A\tau_A)|y|} \quad \text{for } y\in[0,\ l], \tag{9}$$

Under the wage rate obtained by (9), the utilities of A-workers and M-workers are equal and the stable urban system is ensured.

Since the wage at location y is $Y(y)=a_A W(y)+R(y)=p_A(y)$, the excess supply of A-

goods at location y is given by $1-[\alpha_A Y(y)/p_A(y)]=1-\alpha_A=\alpha_M$. Considering that the transporting A-good requires some portion of decaying, the supply of A-good to the city is given by $\alpha_M v\int_0^l p_A(y)dy=v\alpha_M(1-e^{-\tau_A l})/\tau_A$. The necessary condition for attaining market equilibrium of A-good is that the equality of the supply and the demand for A-good, $\alpha_A W(0)N_M$, where $N_M=N-N_A=N-va_A l$ is the number of M-workers, and $N_A=va_A l$ is the number of A-workers. Then the market clearing condition for the A-good is given by

$$(\alpha_A/a_A)e^{-\alpha_M(\tau_A+\tau_M)l}(N-va_A l)=v\alpha_M(1-e^{-\tau_A l})/\tau_A. \tag{10}$$

Let $D(x)$ be the potential demand for the M-goods produced at x, and, by using (7), the potential profit for the firm is given by

$$\pi(x)=a_M\gamma^{-1}W(y)(D(x)-Q^*). \tag{11}$$

We define the market potential function of M-good produced at x as

$$\Omega(x)=D(x)/Q^*. \tag{12}$$

The implication of the market potential function is as follows. $\Omega(x)\geq 1$ means that the potential profit of the firm at x is $\pi(x)\geq 0$, and, in the same way, $\Omega(x)<1$ means that the potential profit of the firm at x is $\pi(x)<0$. For attaining the locational equilibrium, the necessary conditions for the market potential function are

$$\Omega(x)\leq 1 \qquad \text{for all } x, \text{ and } \Omega(0)=1. \tag{13}$$

The implications for the above conditions are as follows. The former condition implies that the potential profit of the firms is less than zero, and the latter condition implies that the profit of the firms in the city is zero as mentioned earlier.

By using (2) and (4), the market potential function can be written as

$$\Omega(x)=\frac{(1-\rho)/f}{W(x)^{\gamma+1}}\left\{\frac{\alpha_M W(0)N_M}{nW(0)^{-\gamma}}e^{-\gamma\tau_M|x|}+\int_o^l\frac{\alpha_M p_A(y)e^{-\gamma\tau_M|y-x|}}{nW(0)^{-\gamma}e^{-\gamma\tau_M|y|}}dy+(v-1)\int_{-1}^0\frac{\alpha_M p_A(y)e^{-\gamma\tau_M|y-x|}}{nW(0)^{-\gamma}e^{-\gamma\tau_M|y|}}dy\right\}. \tag{14}$$

2.2 Agglomeration and Dispersion

By using (10) and defining a function as $F=(\alpha_A/a_A)e^{-\alpha_M(\tau_A+\tau_M)l}(N-va_A l)-v\alpha_M(1-e^{-\tau_A l})/\tau_A$, we can obtain the relation between the number of roads, v, and the A-fringe, l, as follows.

$$\frac{\partial l}{\partial v}=-\frac{F_v}{F_l}<0. \tag{15}$$

The above relation shows that, under the constant population, increase in the number of roads decrease the A-fringe. This is because that the increase in the number of roads can increase the supply of the A-good from near agricultural hinterland around the city. By using (9), we can also obtain the following relation,

$$\frac{\partial W(y)}{\partial v}>0. \tag{16}$$

This relation shows that the construction of the roads raise the wage rate at y under the constant population

large central city brought by the road infrastructure to the emerging new cities raise the supply of the A-good. It can be conclude that the large overpopulated cities such as Tokyo can be benefited from the policy dispersing the overpopulation of the central city to peripheral cities.

We can conclude as follows. Construction of the road infrastructure increases the supply of the A-goods, and, as a result, the social welfare increases. Since the increased population in the city brought by the road construction decreases the social welfare, it is necessary to restrain the population at the optimal level. In other word, the policy of urban growth control can play an important role in maintaining optimal social welfare. When the new cities emerge at the periphery, the overpopulation can be dispersed to the new cities, and then the social welfare increases. Then the policy stimulating the migration can maintain the social welfare.

6. Conclusion

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In this paper, we added the road infrastructure to the urban system model (Fujita and Mori [5] ~~(1997)~~), and analyzed how the number of roads radiating from central city affects the urban growth. As a result, we showed that at the early stage of urban formation, i.e., monocentric urban structure, the construction of roads increased in the supply of the A-good in the city, and it also increased the population of city rapidly. Because of increase in population of city, new frontier cities emerge, and the location of emergence of cities is farther from central city as the number of roads increased. Though increase in population of frontier cities was not so large, that of central city was quite large. This result represents the current serious problem of urban concentration and decrease in population of rural area. This is because ~~that~~ the construction of roads improves the connectivity between central cities and rural area, and, though it gives rural area some benefits, it increases the supply of A-good in the central city, and it also stimulates the urban concentration. As population grows, population of the central city gets larger, and that of the frontier cities gets smaller with the number of roads. This model showed that the construction of road infrastructure is not always effective in measures of stimulating rural economy. In section 4, we showed by analyzing the social welfare that the benefit of road construction is larger, the number of roads increases. That is, the construction of road infrastructure is more effective in the large overpopulated cities, such as Tokyo, than in small cities.

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Because of assuming that the city has no space, this model cannot consider the traffic congestion. Introducing traffic congestion into our model would explain the mechanism of dispersion force of urban formation, and it also gives us optimal construction of road network.

References

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