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Economic Impacts of a New Road Network in San-en Region, Japan - A Spatial Computable General Equilibrium Model -

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1. Introduction

Japan's economy is entering a new phase of economic growth through the so-called "lost 15 years" since 1990. Particularly Tokyo and Aichi prefectures have been drawing attention as engine of new economic growth in Japan. Although the recovery of Japan's economy has resulted in an increase in the demand for traffic, construction of new roads has been located in a serious situation. It is attributed to a decreasing trend in the Japanese population and aging. Thus the Japanese national budget will be being reduced in the future.

Due to this situation, stricter economic assessment of new construction of roads has been required than before. Taking into account these backgrounds, this article aims to present a model integrating the concepts of economic equilibrium and transport network equilibrium. And then setting San-en region in Aichi prefecture as a study area where the demand for traffic has been increasing, this study aims to measure the economic benefit of construction of new roads in this area as well.

A representative study having the purpose like this is one by Anas (1984), however, his study focuses on theoretical consideration lacking empirical treatment. As an empirical study, Muto, Ueda, Yamaguchi, and Yamasaki (2004) can be pointed out. Our model basically follows their specification. Muto's model explicitly incorporates the induced and generated traffics, leading to a more realistic analysis. The present paper is interpreted as an intermediate report on measuring the benefit of construction of new roads in San-en region, and focuses on explanation of whole structure of the model.

2. Spatial Computable Equilibrium Model

2.1 Assumptions of the Model

Main assumptions in the model are summarized as follows:

- (1) The study area is assumed to be a metropolitan area where it is divided into I zones.
- (2) There exist households, firms which are defined by per employee, absentee landlords in each zone. Moreover there is a unique government sector in the study area.
- (3) Only the land market is considered. Land use is characterized by residential and business uses.

2.2 Behaviors of Economic Agents

Households and firms are assumed to be able to change their locations in this model. They choose their location, consume or produce commodities, and generate trips. In the subsequent context, we describe the behaviors of households and firms.

(1) Location Equilibrium Model

1) Households Location Choice Behavior

Households choose their residential zone. This behavior is specified as the following optimization problem.

$$S^H = \max \left[\sum_{i=1}^I P_i^H v_i^H - \frac{1}{\theta^H} \sum_{i=1}^I P_i^H \ln P_i^H \right] \quad (1)$$

$$\text{subject to } \sum_{i=1}^I P_i^H = 1 \quad (2)$$

where

S^H : maximized expected utility in household location choice behavior

P_i^H : household location choice probability for zone i

v_i^H : household indirect utility value in zone i

θ^H : logit parameter in household behavior

Solving this optimization problem, one can obtain the household location choice probability.

$$P_i^H = \frac{\exp \theta^H v_i^H}{\sum_{k=1}^I \exp \theta^H v_k^H} \quad (3)$$

Substituting formula (3) into formula (1), the household maximized expected utility value is obtained.

$$S^H = \frac{1}{\theta^H} \ln \sum_{k=1}^I \exp \theta^H v_k^H \quad (4)$$

Here v_i^H is derived from the following household consumption behavior.

$$v_i^H \equiv \max z_i^{\alpha_z} a_i^{\alpha_a} x_i^{\alpha_x} f_i^{\alpha_f} \quad (\alpha_z + \alpha_a + \alpha_x + \alpha_f = 1) \quad (5)$$

with respect to z_i, a_i, x_i , and f_i

subject to

$$z_i + r_i a_i + q_i x_i + w f_i = w \left[T - \sum_{j=1}^I n_{ij} t_{ij} / N_i \right] + y_i \quad (6)$$

where

z_i : composite good consumed by a household in zone i (numeraire good)

a_i : land size used by a household in zone i

x_i : private trip by a household in zone i

f_i : leisure demand by a household in zone i
 r_i : residential land rent in zone i
 q_i : generalized price of private trip by a household in zone i
 w : wage rate prevailing in the study area (exogenous variable)
 T : total available time endowed by a household
 y_i : dividend income to a household in zone i
 n_{ij} : the number of households residing in zone i and working in zone j
 t_{ij} : commuting time between zones i and j
 N_i : the number of households residing in zone i

Solving the utility maximization problem formulae (5) and (6), household demand functions are obtained.

$$z_i = \alpha_z [w(T - \sum_{j=1}^I n_{ij} t_{ij} / N_i) + y_i] \quad (7)$$

$$a_i = \alpha_a [w(T - \sum_{j=1}^I n_{ij} t_{ij} / N_i) + y_i] / r_i \quad (8)$$

$$x_i = \alpha_x [w(T - \sum_{j=1}^I n_{ij} t_{ij} / N_i) + y_i] / q_i \quad (9)$$

$$f_i = \alpha_f [w(T - \sum_{j=1}^I n_{ij} t_{ij} / N_i) + y_i] / w \quad (10)$$

Substituting equations (7) to (10) into the utility function, one can obtain the indirect utility function per household.

$$v_i^H = \alpha_z^{\alpha_z} \left[\frac{\alpha_a}{r_i} \right]^{\alpha_a} \left[\frac{\alpha_x}{q_i} \right]^{\alpha_x} \left[\frac{\alpha_f}{w} \right]^{\alpha_f} [w(T - \sum_{j=1}^I n_{ij} t_{ij} / N_i) + y_i] \quad (11)$$

Household location probability can be obtained by substituting equation (11) into equation (3).

2) Firms Location Choice Behavior

Firms' location choice behavior is derived from replacing the household indirect utility function by firm's profit in formula (1).

$$P_i^F = \frac{\exp \theta^F \pi_i^F}{\sum_{k=1}^I \exp \theta^F \pi_k^F} \quad (12)$$

where

P_i^F : probability of location in zone i by a firm
 θ^F : logit parameter in firm's location behavior
 π_i^F : profit of a firm in zone i

The firm's profit π_i^F in formula (12) is obtained by the following profit maximization problem.

$$\pi_i^F \equiv \max Z_i - R_i A_i - Q_i X_i - w L_i - \sum_{j=1}^I n_{ij} p_{ij} / E_j \quad (13)$$

with respect to A_i and X_i

subject to

$$Z_i = m A_i^{\beta_A} X_i^{\beta_X} \quad (0 < \beta_A + \beta_X < 1) \quad (14)$$

where

Z_i : output of composite good

R_i : land rent of business area
 A_i : input of land in a firm
 Q_i : generalized price of business trip
 X_i : input of business trip in a firm
 L_i : labor input in a firm
 p_{ij} : commuting cost between zones i and j
 E_j : the number of workers in zone j
 m, β_A, β_X : technological parameters in a firm

This specification implies that firms pay household commuting cost. Solving this profit maximization problem, we get the demand functions for business land and business trip per firm.

$$A_i = \left[\frac{m\beta_A}{R_i} \left(\frac{\beta_X}{\beta_A} \right)^{\beta_X} \left(\frac{R_i}{Q_i} \right)^{\beta_A} \right]^{\frac{1}{1-\beta_A-\beta_X}} \quad (15)$$

$$X_i = \left[\frac{m\beta_X}{Q_i} \left(\frac{\beta_A}{\beta_X} \right)^{\beta_A} \left(\frac{Q_i}{R_i} \right)^{\beta_X} \right]^{\frac{1}{1-\beta_A-\beta_X}} \quad (16)$$

Moreover substituting these demand functions into formula (13), the profit function in zone i is obtained.

$$\begin{aligned} \pi_i^F = & m \left[\frac{m\beta_A}{R_i} \left(\frac{\beta_X}{\beta_A} \right)^{\beta_X} \left(\frac{R_i}{Q_i} \right)^{\beta_A} \right]^{\frac{\beta_A}{1-\beta_A-\beta_X}} \left[\frac{m\beta_X}{Q_i} \left(\frac{\beta_A}{\beta_X} \right)^{\beta_A} \left(\frac{Q_i}{R_i} \right)^{\beta_X} \right]^{\frac{\beta_X}{1-\beta_A-\beta_X}} \\ & - R_i \left[\frac{m\beta_A}{R_i} \left(\frac{\beta_X}{\beta_A} \right)^{\beta_X} \left(\frac{R_i}{Q_i} \right)^{\beta_A} \right]^{\frac{1}{1-\beta_A-\beta_X}} - Q_i \left[\frac{m\beta_X}{Q_i} \left(\frac{\beta_A}{\beta_X} \right)^{\beta_A} \left(\frac{Q_i}{R_i} \right)^{\beta_X} \right]^{\frac{1}{1-\beta_A-\beta_X}} - wL_i - \sum_{j=1}^I n_{ij} p_{ij} / E_j \end{aligned} \quad (17)$$

2.3 Transportation Equilibrium Model

The transportation behavioral model aims to solve the probabilities for destinations, modal split, and route choice in private trip (9) and business trip (16). This model is described as follows:

$$S_i^D = \max \left[\sum_{j=1}^I ZH_j^D (\Phi_{ij,k,r}^K, \Phi_{ij,k}^S, P_{ij}^D) - \frac{1}{\theta^D} \sum_{j=1}^I (P_{ij}^D \ln P_{ij}^D) \right] \quad (18)$$

with respect to $\Phi_{ij,k,r}^K$, $\Phi_{ij,k}^S$, and P_{ij}^D

subject to

$$\sum_{j=1}^I P_{ij}^D = 1 \quad (19)$$

$$\sum_{k=1}^2 \Phi_{ij,k}^S = P_{ij}^D \quad (20)$$

$$\sum_r \Phi_{ij,1,r}^K = \Phi_{ij,1}^S \quad (21)$$

$$\Phi_{ij,1,r}^K \geq 0 \quad (22)$$

$$x_a = \sum_{j=1}^I \sum_r X_{ij,1} \Phi_{ij,1,r}^K \delta_{ij,ar} \quad (23)$$

$$ZH_j^D = \sum_{k=1}^2 ZH_k^S - \frac{1}{\theta^S} \sum_{k=1}^2 (\Phi_{ij,k}^S \ln \frac{\Phi_{ij,k}^S}{P_{ij}^D}) \quad (24)$$

$$ZH_k^S = \sum_r ZH_r^K - \frac{1}{\theta^K} \sum_r (\Phi_{ij,k,r}^K \ln \frac{\Phi_{ij,k,r}^K}{\Phi_{ij,k}^S}) \quad (25)$$

$$ZH_r^K = -\Phi_{ij,1,r}^K p_{ij,1} - w \sum_a \int_0^{x_a} t_a(\omega) d\omega \quad (26)$$

where

P_{ij}^D : choice probability for destination j

$\Phi_{ij,k}^S$: choice probability for transportation mode k ($k=1$: automobile transportation, $k=2$: public transportation)

$\Phi_{ij,1,r}^K$: probability of automobile transportation choosing path r

x_a : traffic volume of automobile transportation on link a

$X_{ij,1}$: traffic volume of automobile transportation between zones i and j

$\delta_{ij,ar}$: matrix of link-path incidence

$p_{ij,1}$: travel cost of automobile trip between zones i and j

t_a : travel time of automobile trip on link a

$\theta^D, \theta^S, \theta^K$: logit parameters

Formula (18) expresses an objective function for choosing destination j , and ZH_j^D and ZH_k^S depict objective functions for choosing traffic mode and path, respectively. The first term in ZH_r^K stands for an expected price of trip, while the second term represents the integration of the link cost function in a user equilibrium traffic assignment model. Solving these optimization problems, the choice probability in each stage is obtained.

• choice probability for destination j

$$P_{ij}^D = \frac{\exp[\theta^D S_{ij}^S]}{\sum_{j=1}^J \exp[\theta^D S_{ij}^S]} \quad (27)$$

where

$$S_{ij}^S = \frac{1}{\theta^S} \ln \sum_{k=1}^2 \exp[\theta^S S_{ij,k}^K]$$

$$S_{ij,1}^K = \frac{1}{\theta^K} \ln \sum_r \exp[\theta^K q_{ij,1,r}^K]$$

$$S_{ij,2}^K = -q_{ij,2}^K$$

$$q_{ij,1,r}^K = p_{ij,1} + w \cdot t_{ij,1,r}$$

• choice probability for transport mode k

$$P_{ij,k}^S = \frac{\exp[\theta^S S_{ij,k}^K]}{\sum_{k=1}^2 \exp[\theta^S S_{ij,k}^K]} \quad (28)$$

• **choice probability for path r**

$$P_{ij,1,r}^K = \frac{\exp[-\theta^K q_{ij,1,r}^K]}{\sum_{k=1}^2 \exp[-\theta^K q_{ij,1,r}^k]} \quad (29)$$

Here S_{ij}^S implies the maximized expected utility value in choosing traffic mode. Since only the automobile and public transports are considered as traffic modes, $S_{ij,2}^K$ expresses the generalized price for public transportation services, while $S_{ij,1}^K$ depicts the maximized expected utility value in choosing path for automobile transportation. $q_{ij,k,r}^K$ implies the generalized price of traffic mode k . From the optimization problem (18), the generalized prices of private and business trips, q_i and Q_i , are derived as follows:

$$q_i = \sum_{j=1}^I \exp[S_{ij}^S - S_i^D] \quad (30)$$

where

$$q_{ij}^D = \sum_{k=1}^2 q_{ij,k}^S \exp[S_{ij,k}^K - S_{ij}^S]$$

$$q_{ij,k}^S = \sum_r q_{ij,k,r}^K \exp[-q_{ij,k,r}^K - S_{ij,k}^K]$$

2.4 Distribution of Commuting Trip

In the preceding section, we showed private and business trip models. In this section, in turn, we attempt to derive a commuting trip model. The number of households in zone i , N_i , and that of employees in zone j , E_j , are calculated by location choice probabilities (3) and (12) as follows:

$$N_i = P_i^H N \quad (31)$$

$$E_j = P_j^E E \quad (32)$$

where

N : the number of total households (exogenous variable)

E : the number of total employees (exogenous variable)

The commuting trip is treated as usual traffic distribution, taking into account the number of households, N_i , as generation side and the number of employees, E_j , as attraction side. Applying the double constrained gravity model, the distribution of commuting trip can be denoted as follows:

$$n_{ij} = \mu_i N_i \cdot \nu_j E_j \cdot q_{ij}^{-\rho} \quad (33)$$

$$\mu_i \equiv \frac{1}{\sum_{j=1}^I \nu_j E_j \cdot q_{ij}^{-\rho}} \quad (34)$$

$$\nu_j \equiv \frac{1}{\sum_{i=1}^I \mu_i N_i \cdot q_{ij}^{-\rho}} \quad (35)$$

where

n_{ij} : the number of households residing in zone i and working in zone j

q_{ij} : average generalized transportation price between zones i and j

μ_i, ν_j : constraint parameters

ρ : parameter on distance

2.5 Behavior of Absentee Landlords

Absentee landlords supply land following the supply functions as depicted in formulae (36) and (37). Land is assumed to be supplied as residential use or business use.

$$a_i^{HS} = \bar{a}_i^{HS} \left[1 - \frac{\sigma_i^H}{r_i}\right] \quad (36)$$

$$A_i^S = \bar{A}_i^S \left[1 - \frac{\sigma_i^F}{R_i}\right] \quad (37)$$

where

a_i^{HS} : land supply for residential use

\bar{a}_i^{HS} : available land size for residential use

σ_i^H : parameter in residential land supply

A_i^S : land supply for business use

\bar{A}_i^S : available land size for business use

σ_i^F : parameter in business land supply

2.6 Equilibrium Conditions

(1) Location Equilibrium Conditions

Households and firms location probabilities are expressed by formulae (3) and (12). Thus the location equilibrium conditions for households and firms are denoted as equations (38) and (39).

$$N = \sum_{i=1}^I N \cdot P_i^H \quad (38)$$

$$E = \sum_{i=1}^I E \cdot P_i^F \quad (39)$$

(2) Market Equilibrium Conditions

In this model, the market which is explicitly considered is only land market. The equilibrium conditions for land market are as follows:

$$\text{Equilibrium condition for residential land: } a_i^{HS} = N_i a_i \quad (40)$$

$$\text{Equilibrium condition for business land: } A_i^S = E_i A_i \quad (41)$$

In our model, if the equilibrium land rent in each zone is found, economic and transport network equilibria are obtained. By the way, finding the simultaneous economic and transport network equilibrium solution needs a lot of iterations by a usual computation algorithm. Instead, for the sake of reducing computation time, we adopt the Walrasian search algorithm. That is, the equilibrium land rents are obtained through equilibrating each land market in order.

2.7 Definition of the Benefit in the Model

In this model, the study area is divided in some zones, and households and firms location behaviors are taken into account as well. Therefore some device is necessary to define the benefit of a new construction of road networks. The fundamental concept in defining the benefit is the equivalent variation (*EV*). That is, the benefit is measured by pecuniarily valuating a change in household utility by employing the price system before a project. In our model, there are two possible ways to define the benefit. That is, they are the benefit of the whole study area which is independent of division of the area, and the benefit which is defined by zone. The former is said to be

non-contingent EV and the later is called EV by zone. The non-contingent EV is defined by maximized expected utility value (4) which stands for the average utility value over the whole study area. This is expressed as follows:

$$\frac{1}{\theta^H} \ln \left[\sum_{i=1}^I \exp \theta^H v_i^H (r_i^A, q_i^A, y_i^A + NCEV) \right] = \frac{1}{\theta^H} \ln \left[\sum_{i=1}^I \exp \theta^H v_i^H (r_i^B, q_i^B, y_i^B) \right] \quad (42)$$

where

$NCEV$: non-contingent EV

A, B : suffixes denoting the states before and after a project, respectively

y_i^A, y_i^B : household incomes in zone i before and after a project, respectively

Since the non-contingent EV is independent of division of the area, the social net benefit based on the non-contingent EV , SNB^N , is defined by multiplying $NCEV$ by the number of households in the study area plus a change in profits of the absentee landlords.

$$SNB^N \equiv N \cdot NCEV + \sum_{i=1}^I \Delta \pi_i^L \quad (43)$$

where

$\Delta \pi_i^L$: a change in profits of absentee landlords by a project

Next EV by zone is defined based on the indirect utility level by zone.

$$v_i^H (r_i^A, q_i^A, y_i^A + ZCEV_i) = v_i^H (r_i^B, q_i^B, y_i^B) \quad (44)$$

where

$ZCEV_i$: EV by zone

Since EV by zone is defined for a household in each zone, the benefit in each zone is calculated by multiplying EV by zone by the number of households in each zone. However since the household choice of residential location is internalized in our model, EV by zone differs depending on the situation when one takes the number of households before or after a project. Particularly when one considers the number of households before a project, the utilities of households who relocate their residential places after the project are not taken into account at all. Moreover when one takes the number of households after a project, the benefit could be overestimated or underestimated. For treating this problem rigorously, one should take into account the household relocation during the project term. The following formula reflects such a problem.

$$ZSNB_i = \int_{A \rightarrow B} [N_i(\tau) dZSNB_i(\tau) + d\pi_i^L(\tau)] \quad (45)$$

The integration in formula (45) implies a line integral from the beginning of a project, A , to the end of the project, B . This line integral differs depending on the process of a project in general. Here assuming that the project is implemented being proportional to time passing, we approximate formula (45) by formula (46).

$$ZSNB_i = N_i(A)ZCEV_i + \frac{1}{2} (N_i(B) - N_i(A))ZCEV_i + \Delta \pi_i^L \quad (46)$$

where

$N_i(A)$ and $N_i(B)$: the numbers of households in zone i before and after a project, respectively

In this study, we define the social net benefit in each zone by formula (46).

3. Concluding Remarks

In this paper, we have shown a full model for measuring the economic impacts of a new road network construction in San-en region, Japan. Our model heavily depends on Muto, Ueda, Yamaguchi, and Yamasaki (2004), however, this paper gives another attempt to value the economic impacts of a new road network construction in a different region. Construction of the computer model and numerical simulations are now being implemented. Hence the numerical valuation of the road construction in the study area will be presented in the near future. Areas worth examining include an extension of our model into a full equilibrium model. Finally, this study is financially supported by the Grant-in-Aid for Scientific Research (C)(2) of the Ministry of Education, the Government of Japan (No.16510021), and a project by Center for Collaborative Regional Planning and Design in Toyohashi University of Technology.

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