Construction of Computable General Equilibrium Model Considered Location Equilibrium to Evaluate Environmental Projects on Urban Transport

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Abstract

Environmental problems caused by automobiles are most serious among urban environmental problems. However automobiles play much important roles in the field of private or industrial transport, so urban environmental projects to control automobile use are afraid to give damages to socioeconomy through the increase of automobile using cost. So it is need to evaluate synthetically the economized environmental policies by calculating the economic loss due to executing these policies. In this paper, we build the computable general equilibrium (CGE) model consider location equilibrium to evaluate socioeconomic impacts when implementing the urban environmental projects. And we actually computed the impacts of some urban projects at Osaka in Japan and confirmed movements of our CGE model.

JEL classification : R12, R13, R52

Keywords : Automobile Environmental Problems, CGE Approach, Policy Evaluation

1. Introduction

Environmental problems caused by automobiles are most serious among some urban environmental problems. However automobiles play much important roles in the field of private or industrial transport, so urban environmental projects to control automobile use are afraid to generate damages to socioeconomy through the increase of automobile using cost. Recently, the concept of compact city is proposed for these urban problems, which is to decrease automobile trips through improving accumulation in the center of city by controlling to make suburban of the city. But to execute the environmental policies related to compact city is afraid to exert burdens to socioeconomy and, as result, to be generated the huge welfare loss, what is called deadweight loss [1]. So it is need to evaluate synthetically the economized urban policies by calculating the deadweight loss due to executing these policies. To such issues, we have worked on the research where we apply the computable general equilibrium (CGE) model (Muto, Morisugi and Ueda [2]). In the CGE model, the economic behaviors of household and industries and the mechanism of markets are formulated by mathematical programming [3], [4]. Hence the model allows us to grasp the change of agents' behaviors due to execute environmental policies, and measure the damage given to

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market economy. However, our CGE model was unsuitable to apply to political evaluation on urban environmental problems, because the elements on the spatial information were not considered in the model.

In this paper, we build the CGE model introduced spatial elements and location choice mechanism. The location choice mechanism means the agents' behavior deciding place of activity base, so can be composed the important spatial information ([5], [6], [7]). Actually, we constructed the combined model of CGE model and the Computable Urban Economic (CUE) model that is a kind of the location equilibrium model worked and developed on the research by us (Muto et al [8]). This combined model is possible us not only to grasp the economical influence extended through the markets, but also to catch the impacts to location choice of each agent.

2. Structure of CGE Model Considered Location Equilibrium

2.1 Outline of Model

In this model, we target the urban area divided in some zones. In each zone, there are households and firm m (m : show the kind of industry), and in whole urban area, there is real estate firm, who provide the land service (see Fig. 1). The markets are considered m goods, labor, capital and land markets. Among these markets, the ones of m goods, labor and capital are assumed to exist only one in whole urban area, and land markets exist for each zone [9].

2.2 Firms' behavior

In this model, the firms' behavior is formulated for one employed person. Framework of the behavior model is same type that traditional CGE model.

Firms produce commodities/services by inputting factors and intermediate goods. Its behavior model is built by the nested structure (in Fig. 2), that is, at first step, firms determine on input volume of the composite factor and each intermediate goods, and, at

Figure 1. Outline of agents' interaction for a zone

Figure 2. Outline of firms' behavior as one employed person

Table 1. Formulation of firm's behavior

Cost minimizing programs	Location probability, intermediate goods and factor input volume
<p><i>Location distribution</i></p> $\pi^{m*} = \max_{P_j^m} \left[\sum_j \xi_j^F \frac{1}{\sigma_j^F} (P_j^m \cdot \pi_j^m) \rho_j^F \right]^{\frac{1}{\rho_j^F}}$ <p>s.t. $\sum_j P_j^m = 1$</p>	$P_j^m = \frac{\xi_j^F \{ \pi_j^m \}^{\sigma_j^F - 1}}{\sum_j \xi_j^F \{ \pi_j^m \}^{\sigma_j^F - 1}}$
<p>Where, P_j^m: location choice probability of firm, π_j^m: firm's profit, (yielded by $\pi_j^m = p_m y_j^m - tc_j^m$), ξ_j^F, σ_j^F: parameters, $\rho_j^F = \frac{\sigma_j^F - 1}{\sigma_j^F}$.</p>	
<p><i>First step</i></p> $tc_j^m = \min_{P_C^m, z_j^{m-m'}, z_j^{m-T}} \left[fc_j^m \cdot pc_j^m + \sum_i (w t_{ji} \Pr_{ji}^T z_j^{m-T}) + \sum_{m'} p_{m'} z_j^{m-m'} \right]$ <p>s.t. $y_j^m = \min \left[\frac{pc_j^m}{a_m^0}, \dots, \frac{z_j^{m-m'}}{a_m^{m'}}, \dots, \frac{z_j^{m-T}}{a_m^T} \right]$</p>	$pc_j^m = a_m^0 y_j^m,$ $z_j^{m-m'} = a_m^{m'} y_j^m,$ $z_j^{m-T} = a_m^T y_j^m$
<p>Where, j: indicating the location zone of firm, pc_j^m: production capacity (input volume of composite factor), $z_j^{m-m'}$: intermediate goods input volume, z_j^{m-T}: transport service input volume, y_j^m: output volume, fc_j^m: unit cost of composite factor, t_{ji}: travel required time from zone j to i, $\Pr_{ji}^T$: probability chosen the zone of destination, p_m: the price of commodity, a_m^0: production capacity rate [production capacity for the unit output], $a_m^{m'}$, a_m^T: input coefficient in Leontief Matrix and tc_j^m: product cost.</p>	
<p><i>Second step</i></p> $fc_j^m = \min_{l_j^m, k_j^m, a_j^m} [w \cdot l_j^m + r \cdot k_j^m + h_j \cdot a_j^m]$ <p>s.t. $pc_j^m = \eta_j^m \{ l_j^m \}^{a_l^m} \{ k_j^m \}^{a_k^m} \{ a_j^m \}^{a_a^m} \quad [=1]$</p>	$D_{L_j}^m = \frac{1}{\eta_j^m} \left[\frac{a_l^m r}{a_k^m w} \right]^{a_l^m} \left[\frac{a_l^m h_j}{a_a^m w} \right]^{a_a^m},$ $D_{K_j}^m = \frac{1}{\eta_j^m} \left[\frac{a_k^m w}{a_l^m r} \right]^{a_k^m} \left[\frac{a_k^m h_j}{a_a^m r} \right]^{a_a^m},$ $D_{A_j}^m = \frac{1}{\eta_j^m} \left[\frac{a_a^m w}{a_l^m h_j} \right]^{a_l^m} \left[\frac{a_a^m r}{a_k^m h_j} \right]^{a_k^m}$
<p>Where, l_j^m, k_j^m, a_j^m: labor, capital and land input volume, respectively, w, r, h_j: labor wage, capital rent and land rent of zone j, respectively and η_j^m, a_l^m, a_k^m, a_a^m: parameters $[a_l^m + a_k^m + a_a^m = 1]$.</p>	

second step, they decide on input volume of each factor. And the firms' behaviors are formulated as cost minimizing programming under technology constraint. Those concrete formulations are shown collectively in table 1.

By solving the programming in table 1, we obtain the firms' production cost function tc_j^m . The profit is defined by total revenues minus total costs, so, the profit for one employed person is introduced like below,

$$\pi_j^m = p_m y_j^m - tc_j^m = \left[p_m - \left\{ gc_j^m a_m^0 + \sum_{m'} p_{m'} a_m^{m'} \right\} \right] y_j^m. \quad (1)$$

In equation (1), because m goods market is assumed to exist only one in whole urban area in this model, m goods price p_m is constant to all zones. And gc_j^m is difference for each zone, because travel required time and land rent are included in gc_j^m . So the profit π_j^m is difference for each zone. The location distribution is assumed to be determined according to this each zone's profit. The location choice probability function is adopted gravity type function shown in table 1.

2.3 Price vector of products

The price vector is yield similarly like below from the framework based on Leontief inverse matrix in traditional CGE approach,

$$\mathbf{p} = \mathbf{GC} \cdot [\mathbf{I} - \mathbf{A}]^{-1}. \quad (2)$$

Where, $\mathbf{p}$: commodity price vector, $\mathbf{GC}$: product cost vector, $\mathbf{I}$: unit matrix and $\mathbf{A}$: input coefficient matrix.

Product cost vector $\mathbf{GC}$ in (2), is defined by the one totaled the product cost for industry m and zone j like below by zone j . So the product price solved by (2) is constant to all zones.

$$\sum_j a_m^0 gc_j^m. \quad (3)$$

Figure 3. Outline of households' behavior

2.4 Households' behavior

In this model, we target the household who lives in zone i and works in zone j . Basically his behavior is formulated by same type that the traditional CGE model (Shoven and Whalley [10]), that is, he gains income by providing the input factors which consist of labor and capital, and determines the consuming volume of commodities/services where land service is included, so as to maximize his utility under the budget constraint. Hence the consuming behavior of the household should be illustrated in a nested structure, as shown in Fig. 3.

At the first stage, the household determines consumption levels of present goods and saving goods, at the second stage, he determines consumption levels of composite goods, leisure and total passenger transport service and, at the third stage, he determines consumption level of each commodity. Those concrete formulations are shown in table 2. As for the location distribution, the utility level of each zone's household is applied as location attrac-

Table 2. Formulation of household's' behavior

Utility maximizing programs	Location probability, commodity and service demand
<p><i>Location distribution</i></p> $V_j^H = \max_{P_H^H} \left[\sum_i \xi_i^H V_{ji}^H (P_{ji}^H \cdot V_{ji}^H)^{\rho_H^H} \right]^{\frac{1}{\rho_H^H}}$ <p>s.t. $\sum_i P_{ji}^H = 1$</p>	$P_{ji}^H = \frac{\xi_i^H \{V_{ji}^H\}^{\sigma_H^H - 1}}{\sum_k \xi_k^H \{V_{jk}^H\}^{\sigma_H^H - 1}}$
<p>Where, p_i^H: location choice probability of household, V_{ji}^H: utility level, ξ_i^H, σ_H^H: parameters, $\rho_H^H = \frac{\sigma_H^H - 1}{\sigma_H^H}$.</p>	
<p><i>First stage</i></p> $V_j^H = \max_{x_i^H, x_i^S} \left[\beta_H \frac{1}{\sigma_1} \{x_i^H\}^{v_1} + (1 - \beta_H) \frac{1}{\sigma_1} \{x_i^S\}^{v_1} \right]^{\frac{1}{v_1}}$ <p>s.t. $p_H x_i^H + p_C x_i^S = w[\Omega - \delta t_{ij}] + r k_s \quad (\equiv M_{ji}^1)$</p>	$x_i^H = \frac{\beta_H M_{ji}^1}{p_H \sigma_1 \Delta_1},$ $x_i^S = \frac{(1 - \beta_H) M_{ji}^1}{p_C \sigma_1 \Delta_1}$
<p>Where, x_i^H, x_i^S: consumption level of present goods and saving goods, respectively, p_H, p_C: price of present goods and saving goods, respectively, Ω, k_s: endowment of available time and capital, respectively, δ: unit commuting trip for a household, β_H, σ_1: parameters, $v_1 = \frac{\sigma_1 - 1}{\sigma_1}$ and V_{ji}^H: utility level.</p>	
<p><i>Second stage</i></p> $x_i^H = \max_{x_i^Z, x_i^S, x_i^T} \left[\beta_Z^2 \frac{1}{\sigma_2} \{x_i^Z\}^{v_2} + \beta_S^2 \frac{1}{\sigma_2} \{x_i^S\}^{v_2} + \beta_T^2 \frac{1}{\sigma_2} \{x_i^T\}^{v_2} \right]^{\frac{1}{v_2}}$ <p>s.t. $p_Z x_i^Z + w x_i^S + q_{Ti} x_i^T = M_{ji}^1 - p_C^* x_i^{S*} \quad (\equiv M_{ji}^2)$</p>	$x_i^Z = \frac{\beta_Z^2 M_{ji}^2}{p_Z \sigma_2 \Delta_2}, \quad x_i^S = \frac{\beta_S^2 M_{ji}^2}{w \sigma_2 \Delta_2},$ $x_i^T = \frac{\beta_T^2 M_{ji}^2}{q_{Ti} \sigma_2 \Delta_2}$
<p>Where, x_i^Z, x_i^S, x_i^T: consumption level of composite goods, leisure time and passenger transport service, respectively, p_Z: composite goods price, q_{Ti}: generalized transport price $[= p_T + w \{ \sum_j R r_{ij}^{HT} t_{ij} \}]$, $R r_{ij}^{HT}$: probability chosen the zone of destination for private trip, β_Z^2, β_S^2, β_T^2, σ_2: parameters and $v_2 = \frac{\sigma_2 - 1}{\sigma_2}$.</p>	
<p><i>Third stage</i></p> $x_i^T = \max_{x_i^m} \prod_m \{x_i^m\}^{\beta_m^3}$ <p>s.t. $\sum_m p_m x_i^m = M_{ji}^2 - p_C^* x_i^{S*} - q_{Ti} x_i^{T*} \quad (\equiv M_{ji}^3)$</p>	$x_i^m = \frac{\beta_m^3}{p_m} M_{ji}^3$
<p>Where, x_i^m: consumption level of m goods, p_m: m goods price and β_m^3: parameters.</p>	

tive, which is led from the programming in table 2.

2.5 Real estate firm behavior

In this model, as for the buying and selling of land, we treat as the one of real estate service supplied by real estate firm instead of treating directly land property. However the model must have the supply constraint for each zone, because the land area of zone has a limit.

So, real estate firm is assumed to produce real estate service according to land area of each zone by inputting factors and intermediate goods. By using rent of business land and residential land, the total revenue of real estate firm is led as below,

$$Y^A = \sum_j [h_j^F A_{Sj}^F + h_j^H A_{Sj}^H]. \quad (4)$$

Where, Y^A : total revenue of real estate firm, h_j^F , h_j^H : rent of business land and residential land, respectively, A_{Sj}^F , A_{Sj}^H : provided area of business land and residential land, respectively.

This revenue is distributed to intermediate goods and product factors. If its distribution ratio is assumed to base on intermediate coefficient and product capacity ratio, respectively, the volume of intermediate goods and product factors cost are yielded as below,

$$x_m^A = \frac{a_m^A Y^A}{p_m} \quad (5.1)$$

$$fc_j^A \cdot pc_j^A = a_0^A y_j^A. \quad (5.2)$$

Where, y_j^A : revenue of real estate for one employed person.

Next, from the product factors cost at each zone that is obtained in (5.2), input volume of each product factor is given like this,

$$L_j^A = \frac{D_{Lj}^A}{wD_{Lj}^A + rD_{Kj}^A + hD_{Aj}^A} fc_j^A pc_j^A \cdot E_j^A \quad (6.1)$$

$$K_j^A = \frac{D_{Kj}^A}{wD_{Lj}^A + rD_{Kj}^A + hD_{Aj}^A} fc_j^A pc_j^A \cdot E_j^A \quad (6.2)$$

$$A_j^A = \frac{D_{Aj}^A}{wD_{Lj}^A + rD_{Kj}^A + hD_{Aj}^A} fc_j^A pc_j^A \cdot E_j^A \quad (6.3)$$

Where, E_j^A : employed population of real estate firm.

2.6 Travel behavior

In this model, the business trips of firms, commuting trips and private trips of households are considered endogenously. As for commuting trips among these, traffic volume between zones (OD trips) can be yielded from below,

$$X_{ij}^{HC} = N_{ji} \cdot \delta. \quad (7)$$

Where, N_{ji} : population of household who lives in zone i and works in zone j , δ : unit commuting trip.

As for Business and private trips, generation trips are obtained like this,

$$Z_j^{FP} = E_j^m \cdot z_j^{m-T} \quad (8.1)$$

$$X_i^{HP} = N_i \cdot x_i^T. \quad (8.2)$$

Where, z_j^{m-T} , x_i^T : trip consumption volume for one person, and these are given in Table 1 and 2, respectively.

The Destination choice, traffic mode choice and route choice behavior of these trips are thought as well as CUE model [8].

3. Market equilibrium conditions

The markets in this model are considered on each commodity, labor, capital and lands. So the market equilibrium conditions of them are formalized as

$$\sum_{m'} a_m^{m'} Y^{m'} + x_m^A + x_m^H + x_m^G + x_m^I = Y^m \quad (9.1)$$

$$\sum_j \sum_m \{L_j^m + T_j^m\} = \sum_j N_j \left\{ \Omega - x_j^S - \sum_i (\delta t_{ji} + x_j^T t_{ji}) \right\} \quad (9.2)$$

$$\sum_j \sum_m K_j^m = \sum_j N_j k_s \quad (9.3)$$

$$\sum_m A_j^m = A S_j^F \quad (9.4)$$

$$N_j x_j^A = A S_j^H. \quad (9.5)$$

Where, $Y^{m'}$: total product volume of m goods, $a_m^{m'}$: input coefficient in Leontief Matrix, x_m^H , x_m^G , x_m^I : consumption volume of household, government and investment, respectively, T_j^m : total input time of business trip $\left(= a_{mj}^T y_j^m E_j^m \sum_i t_{ji} Pr_{ji}^T \right)$, L_j^m , K_j^m , A_j^m : total product factor input volume of each factor.

Equation (9.1) is m goods market condition and from (9.2) to (9.5) are the ones of labor, capital and business lands and residential lands market, respectively. There are simultaneous equations of equal number to unknown variables of the above equilibrium conditions, which are the prices of each commodity, wage, capital rent, rent of business lands and rent of residential lands. Because the Walras's Law exists, one equilibrium equation will be diffuse condition. So any price variables must be "numeraire", and the other prices must be solved by numerical approach. Here, the commodity prices have been solved already in equation (2), so the wage is set "numeraire" and left capital rent and land rents are computed from their equilibrium conditions. We adopt the Walras's Search as numerical method, which is to adjust successively the price according to the volume of excess demand.

From the result of equilibrium price calculation shown above, the utility level of households or the profit of firms for each zone are changed. So the populations of household and firm are reallocated based on the renewal utility level and profit, respectively, and the adjustment calculation of the prices, which are mainly land rents, is carried out again. By repeating those equilibrium calculations, before long, the location equilibrium is achieved.

4. Numerical simulation

4.1 Parameter setting

We implement numerical simulation where we set Osaka prefecture to objective area. When calculation this model, it is necessity to set parameters of product function and utility function. We adopt the calibration method for setting their parameters following general CGE model (Shoven and Whalley (1992)).

Here, we set the benchmark year in 1995, and used the input-output table in 1995 of Osaka prefecture and determined the parameters of the product and utility function. And we utilized the data of parson trip survey in Keihanshin area for travel behavior data, and the data of Osaka Statistic Year Book for location behavior data. The result of estimated parameters is shown in table 1.

4.2 Result of numerical simulation

We will apply this model to the travel required time reduction project between some zones and urban environmental policy of implementing the locating regulation at suburban area. The necessity of controlling the expansion of urban is pointed out by Wegener (2003) [11]. Here, we set simple case of dividing Osaka prefecture in 3 zones, which are Osaka City area, North area and South area.

As for the travel required time reduction project, we assumed that travel required times from North area and South area, respectively, to Osaka City area are reduced 10%. In Fig. 4, we show the result of changing ratio about population of residential people and employed people, utility level and GRP (Gross Regional Products) by implementing these projects. From the results, the populations both of residential and employed people are indicated to decrease at Osaka City area and to increase at South area. Though the populations of residential and employed people at North area decrease, the reduced ratios are smaller than the one at Osaka City area. So these results implicate to have possibility that this transport project causes expansion to suburban area. However, seeing the result of the utility level and GRP, they are going up at all zones. So it is understood for these projects to have brought a positive effect to socioeconomy at whole Osaka prefecture.

As for the locating regulation, we assumed to reduce land area both of residential and business 10% at north and south area. In Fig. 5, the results of main variable similar to the

Table 3(a). Result of setting parameters on product capacity function

Share parameters	Primary	Secondary	Tertiary	Transport	Real estate
Labor	0.1819	0.6837	0.6640	0.7152	0.0487
Capital	0.8174	0.3082	0.3128	0.2550	0.9442
Land	0.0008	0.0081	0.0232	0.0298	0.0071
Scale parameters					
Osaka city	1.483	210.86	209.48	346.42	0.349
North area	1.483	210.47	208.38	344.07	0.349
South area	1.482	209.41	205.37	337.70	0.347

Table 3(b). Result of setting parameters on utility function

First stage		Second stage		Third stage	
σ_1	1.113	σ_2	0.8	Primary	0.0098
Savings	0.1330	Composite goods	0.7809	Secondary	0.2432
Present goods	0.8670	leisure	0.1834	Tertiary	0.6075
		transport	0.0357	Real estate	0.1396

Figure 4. The result of transport projects

Figure 5. The result of locating regulation

previous one of transport project are shown. By implementing locating regulation, the populations both of residential and employed people are indicated to increase at Osaka City and to decrease at another area, though the population of employed people at South area increases. These results implicate that this locating regulation happen accumulation to center of city. As the result, though total travel trips are decreased, utility level and GRP fall down at suburban area. So it is understood that though the regulation project has a possibility of controlling the expansion of city it may bring economic loss.

5. Conclusion

In this paper, we constructed the CGE model considered location equilibrium in order to evaluate urban environmental policies related on automobiles. The characteristics of this model are measuring not only influence that the policies bring through the market mechanism, but also impacts to locating distribution of policies. And we implement the simple numerical simulation by using this model, and implicate that though the transport projects generate economic effects, it may expand suburban of city, and though the land regulation policies control expansion of urban, it may bring economic loss.

But we cannot clarify about the best policy in this research. In future, we will apply this model to more detailed analysis. To achieve the purpose, it is left as task to construct the dataset corresponding with this model and to make more exquisite the transport behavior model, and so on.

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