A MODEL FOR ANALYSING THE IMPUTATION OF COMMUTERS' BENEFITS TO LAND PROPERTY VALUES

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1. INTRODUCTION

Financing urban transport projects is one of the most critical issues in almost all cities of the world. Generally, full public financing and user charges cannot be called sufficient in providing facilities to maintain urban economic activities.

Therefore, we have examined and tried to apply financial policy options which capture benefits not only directly imputed as user benefits, but also indirectly imputed as an increase in land values, the profitability of enterprises and the welfare level of households. The alternatives of financial policy options should be examined on the following bases(1):

a) balance between received benefits and burdens for each interest group
b) equity between interest groups
c) compensation of time lags between fund-raising and expenditure demand

The measurement methods of benefits should provide information to meet the above examination. To examine the alternative financial policy options on the basis of benefit principle, therefore, a model should be equipped with the following functions:

a) It can estimate the total amount of generated benefits.
b) It can identify the share of benefits imputed to each interest group by region.
c) These values can be calculated in each time period.

Existing relevant methods are limited to the following three categories: (i) the property value method, (ii) partial equilibrium models of the land market and (iii) general equilibrium models. Each of these methods cannot solely meet the above requirements, as will be described in Chapter 3.

This study first derives a theoretical relationship between benefits generated by urban transport improvements and benefits imputed to each interest group by region, and next, develops a practical model to measure each type of benefit.

2. DEFINITION OF BENEFITS CAUSED BY TRANSPORT IMPROVEMENTS

2.1 Benefits generated by transport improvements

Transport improvements generate direct benefits for users of the new or improved facilities in the form of savings in travel time and cost. Also the users in the existing competing rail lines or roads will take indirect benefits by the release of congestion due to the diversion of passengers and traffic to the new facilities.

Benefits are generated not only for the direct users but also for secondary users and non-users. These users and non-users newly move to the improved area, demanding benefits due to external economies associated with agglomeration and specialization of tertiary industries. As shown in Figure 1, through generation of these additional benefits, the total amount of benefits grows as time goes by.

In this study, we define the term "generated benefits" as including both direct user benefits and indirect benefits additionally generated to users and non-users.

2.2 Imputation of the benefits

The benefits also spread outside the transport market; namely, land property values increase through the growth of the locational demand due to the improvement of locational utility and profitability in the surrounding area of the improved facilities.

This study gives attention to estimating the total amount of the benefits and to identifying the extent to which generated benefits are changed into land property values. For this purpose, it is necessary to define two phenomena; inducement and transfer, which are associated with changes of the state of the benefits. Inducement is defined as the generation of additional benefits due to external economies through the locational interdependency between households, offices, and shops. Transfer is defined as the change of benefits generated for users into the increase of land property values.

In the following chapter, we will take an overview of existing studies associated with the measurement of benefits, by looking at how they analyze the mechanism of inducement and transfer.

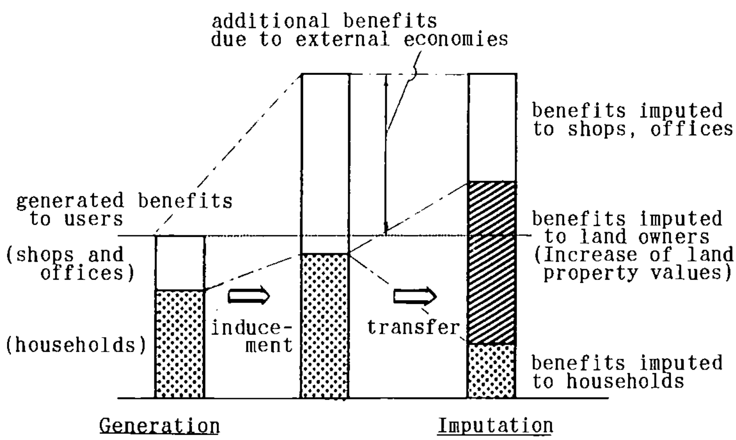

Figure 1 Generation and imputation of benefits due to transport improvements

3. OVERVIEW OF EXISTING MEASUREMENT METHODS

Until now, many measurement methods have been developed. As mentioned in chapter 1, these methods could be categorized into three groups.

The first group applies the property value method(2),(3),(4) which is based on the "Capitalization Hypothesis" and estimates the benefits at the final stage of imputation. This method has the merit of easily measuring the benefits by region and it was proved that this method can be adequately applied in the situation in which the transport facilities of interest are regarded as local public goods. However, this method measures only the benefits finally imputed to land owners and lacks the function to identify to what extent the generated benefits are transferred to land property values in a mid-stage of imputation. Therefore it cannot provide any information in examining the financial policy options on the basis of equity between interest groups and compensation of time lags between fund-raising and expenditure demand described in chapter 1.

The second group attempts to explain through partial equilibrium analysis of the land market how the direct user benefits due to the improvements are transferred to land rents, from the viewpoint of partial equilibrium analysis in a static manner. Mohring(5)'s pioneering work has substantially influenced successors such as Pines and Weiss(6) and Wheaton(7). This method mainly focuses on the theoretical explanation of transfer in a highly simplified mono-centric city. In addition, it does not consider the inducement of benefits. Therefore it seems difficult to apply this method to real transport improvements in estimating when and to what extent the benefits are imputed to land owners.

The last group uses the general equilibrium analysis(see Morisugi (8), Kanemoto and Mera(9)). This method can measure benefit imputation considering not only transfer, but also inducement by formulating the increase of generated benefits through interdependency between different types of activities. However, it has some practical problems; namely, it cannot identify the detailed imputation to each interest group by region. Additionally, as well as the former two groups, it is not equipped with a function to forecast how the imputation of benefits will change as time goes by.

From the above overview, it can be seen that there are few measurement methods of benefits which can be applied in examining policy options for financing transport projects on the basis of the benefit principle. The shortcomings of most existing methods are summarized as a)inability to estimate to what extent user benefits are transferred to land property values and b) inability to express the state of benefits in a mid-stage until the final stage of imputation.

4. THEORETICAL RULE FOR BENEFIT GENERATION AND IMPUTATION

4.1 Assumptions on modelling

In this study, we assume that the benefit imputation is balanced between interest groups and between regions at the equilibrium in which the number of transport users who have located there and land prices are balanced. This state of equilibrium is described through formulating the locational behavior of transport users(hereafter, we deal with households, who are considered to be the typical transport users).

To formulate households' behavior and to derive a theoretical rule for benefit generation and imputation, the following assumptions are made:

1) The urban areas include work-place zones and residential zones.
2) Households within the whole region are distinguished only by their work place.
3) All sites in the same residential zone are indiscriminate in their attributes.
4) Households can migrate freely and their relocations are costless.
5) The total amount of households, employees and the supply of residential lands are given exogeneously.

4.2 Equilibrium conditions

The state of equilibrium in each time period is described through formulating the locational choice of households. Here, the locational choices of households are determined as the simultaneous outcome of the locational utility maximization and competition at each site; namely, the following conditions are achieved at the equilibrium:

(a) Each household achieves the maximum locational utility at the current site.

(b) At each site, land price is determined as the maximum bid price and this site is occupied by the household with the maximum bid land price.

Based on the assumptions in 4.1, conditions (a) and (b) are respectively expressed as follows:

(a): For a household(discriminated by work-place zone j)

$$X_{ji} = \gamma_j^* \quad \text{if} \quad T_{ji}^* \geq 0 \qquad (1)$$
$$X_{ji} \leq \gamma_j^* \quad \text{if} \quad T_{ji}^* = 0 \qquad (2)$$

(b): For a site(discriminated by residential zone i)

$$b_{ji} = \alpha_i^* \quad \text{if} \quad T_{ji}^* \geq 0 \qquad (3)$$
$$b_{ji} \leq \alpha_i^* \quad \text{if} \quad T_{ji}^* = 0 \qquad (4)$$

where X_{ji} : locational utility for a household (j) to a site in zone i
b_{ji} : bid land price of a household (j) to a site in zone i
T_{ji}^*: amount of households (j) in zone i
γ_j^* : maximum level of locational utility which a household (j) can achieve
α_i^* : maximum level of bid land price achieved at a site in zone i, namely land price
(the superscript * means the value determined at the equilibrium)

Furthermore, if we specify the locational utility function as the locational surplus function (5), we can combine these two optimization conditions (a) and (b) into one equilibrium equation. Here, locational surplus is defined as net locational utility, which is obtained by deducting land price burden from land-use value at each site.

$$X_{ji} = W_{ji} - \ell_{ji} P_i \qquad (5)$$

where W_{ji} : land-use value of a site(for the area ℓ_{ji}) in zone i perceived by a household (j)

P_i : land price of the site in zone i
ℓ_{ji} : amount of land consumption by household (j)

The land-use value is defined as the gross locational utility of each site for each household, which is determined in monetary terms according to locational attributes of each site such as transport service level. By applying equation (5), equation (1) can be rewritten as follows:

$$W_{ji} - \ell_{ji} P_i = \gamma_j^* \quad \text{if} \quad T_{ji}^* \geq 0 \tag{6}$$

Additionally, since the maximum level of bid land price α_i^* is equal to market land price P_i, equation (3) are rewritten as follows:

$$b_{ji} = \alpha_i^* = P_i \quad \text{if} \quad T_{ji}^* \geq 0 \tag{7}$$

Then, equations (6) and (7) can be arranged in the following forms:

$$W_{ji} = \ell_{ji} \alpha_i^* + \gamma_j^* \quad \text{if} \quad T_{ji}^* \geq 0 \tag{8}$$
$$\ell_{ji} b_{ji} = W_{ji} - \gamma_j^* \quad \text{if} \quad T_{ji}^* \geq 0 \tag{9}$$

Equation (8) shows an equilibrium relationship; namely, the sum of land property value and the level of locational surplus of each household is always equal to land-use value. Here, it is noteworthy that land-use value W_{ji} is only perceived by households and therefore is latent as opposed to land price α_i^* which is determined through land market. Equation (9) shows that by means of the concept of locational surplus, the bid price function can be specified as a linear combination of land-use value and the level of locational surplus.

Here, the change of land-use value(in equation (9)) ΔW_{ji} due to transport improvement can be proved to be equivalent to the CV(compensating variation) measure. This change is regarded as generated benefits to each household, which includes not only the savings in commuting time and cost but also other locational benefits such as the increase of accessibility to shopping places and schools(10).

4.3 Rule for benefit generation and imputation

As mentioned in the previous section, generated benefits by transport improvements are estimated by changes of land-use values which are brought to households. From the equilibrium condition (8) we can derive the following rule for benefit generation and imputation:

$$\Delta W_{ji} = \Delta(\ell_{ji} \alpha_i^*) + \Delta\gamma_j^* \tag{10}$$

The above relationship is obtained by deducting the values of equation (10) before and after the improvement. This represents that the generated benefit measured by a change of land-use value for each household is divided into two elements, namely change of land property values $\Delta(\ell_{ji} \alpha_i^*)$ and change of the level of locational surplus $\Delta\gamma_j^*$. The former is imputed to a land owner and the latter to a household commuting to work place zone (j). We call this relationship "The Rule for Benefit Generation and Imputation".

The mechanism of benefit transfer is shown in Figure 2. The shares of benefits imputed to land owners and to households are determined by the outcome of the balance between the total amount of located households and land prices, in other words the balance of locational choice of each household (j)

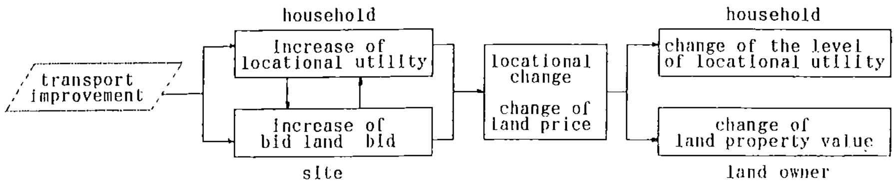

Figure 2 Mechanism of the balance of benefit imputation

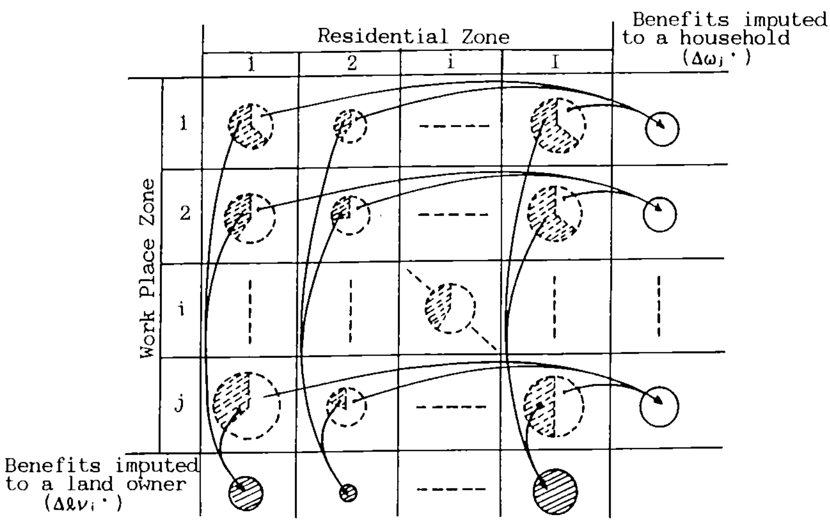

Figure 3 The rule for benefit generation and imputation

and locational competition at each site (i). Figure 3 illustrates the quantitative relationship in which the generated benefits are assigned to land owners and households. The size of a circle in each cell of the matrix represents the amount of generated benefit, of which the shaded part is imputed to a land owner and unshaded part is remaining to a household. When we focus on the successive change of equilibrium, we can obtain this matrix in each time period.

5. MEASUREMENT MODEL OF THE IMPUTATION OF USER BENEFITS TO LAND

The benefits due to transport improvements can be measured by applying the above-mentioned rule. In this chapter, we develop a method to forecast the shift of equilibrium of the land market and to estimate the benefits imputed both to land owners and to households.

5.1 Stochastic equilibrium condition

Prior to obtaining a measurement model, the rule for generation and imputation of the benefits is extended under the condition of imperfect information and when behavior of households varies randomly. We consider first the following random variations of locational surplus and bid land price:

$$\mathcal{X}_{ji} = X_{ji} + \varepsilon_{ji} \tag{11}$$

$$\mathscr{b}_{ji} = b_{ji} + \eta_{ji} \tag{12}$$

where, $\mathcal{X}_{ji}, \mathscr{b}_{ji}$: random locational surplus and random bid land price
X_{ji}, b_{ji} : strict components, $\varepsilon_{ji}, \eta_{ji}$:random components

Supposing that both the additive random terms ε_{ji} and η_{ji} are independently and identically Gumbel distributed (I.I.G.D), we can obtain the following inclusive values ($\{\omega_j\}, \{\nu_i\}$) which represent the expected maximum level of locational surplus for each household and that of bid land price at each site respectively.

$$\omega_j = 1/\beta \ln \sum_i \exp(\beta X_{ji} + \ln(H_i/\ell_{ji})) \tag{13}$$

$$\nu_i = 1/\beta^b \ln \sum_j \exp(\beta^b b_{ji} + \ln E_j) \tag{14}$$

where β, β^b are variance parameters of ε_{ji} and η_{ji}.

In the above equations, the amount of land supply $\{H_i\}$ and the number of employees $\{E_j\}$ are considered to express size effects of the number of alternatives and the number of bidders respectively. The expected values $\{\omega_j\}$, $\{\nu_i\}$ can be also expressed as the following optimization equations:

$$\omega_j = 1/E_j \max_{T_{ji}} \{ \sum_i T_{ji} X_{ji} - 1/\beta \sum_i (T_{ji} \ln \frac{T_{ji}}{E_j H_i/\ell_{ji}}), \text{ s.t. } \sum_i T_{ji} = E_j \} \tag{15}$$

$$\nu_i = 1/H_i \max_{T_{ji}} \{ \sum_j T_{ji} (\ell_{ji} b_{ji}) - 1/\beta^b \sum_j (T_{ji} \ln \frac{T_{ji}}{E_j H_i/\ell_{ji}}), \text{ s.t. } \sum_j T_{ji} \ell_{ji} = H_i \} \tag{16}$$

At the equilibrium it is considered that each household has achieved the expected maximum locational surplus ω_j, and that at each site land price is determined as the expected maximum bid land price ν_i, hence we can obtain an equilibrium condition as follows by unifying requisites for maximizing equations (15) and (16):

$$W_{ji} - 1/\beta \ln \frac{T_{ji}^*}{E_j H_i/\ell_{ji}} = \ell_{ji} \nu_i^* + \omega_j^* \tag{17}$$

(the superscript * means the value determined at the equilibrium)

Compared with equation (8), equation (17) includes an additional term which represents the random effect. Due to this effect, households perceive higher land-use value for the site and consequently higher land prices or a higher level of surpluses are formed than under deterministic conditions. Consequently we can obtain "The Rule for Benefit Generation and Imputation" under stochastic conditions as follows:

$$\Delta W_{ji} - 1/\beta \, \Delta(\ln \frac{T_{ji}^*}{E_j H_i/\ell_{ji}}) = \Delta(\ell_{ji} \, \nu_i^*) + \Delta\omega_j^* \tag{18}$$

5.2 Measurement model

The values of land prices and locational surpluses in equation (18) can be forecasted by means of the following optimization model, which has the requisite for maximizing as shown in equation (17):

(a) Measurement model of the benefits

$$\min_{\omega_j, \nu_i} \{1/\beta \sum_i \sum_j (E_j H_i / \ell_{ji}) \exp(\beta(W_{ji} - \omega_j - \ell_{ji}\nu_i)) + \sum_i H_i \nu_i + \sum_j E_j \omega_j \quad \text{s.t. } \nu_i \geq 0 \} \tag{19}$$

Equation (19) gives land prices $\{\nu_i^*\}$ and the level of locational surpluses $\{\omega_j^*\}$ in each time period of time, given the number of employees $\{E_j\}$ and land supply $\{H_i\}$. As a result of solving equation (19), land prices $\{\nu_i^*\}$ and locational surpluses $\{\omega_j^*\}$ are expressed respectively in the following form:

a_1) Equilibrium land price

$$\nu_i^* = 1/\beta^b \sum_j \exp(\beta^b (W_{ji} - \omega_j^* + (1/\beta - 1/\beta^b) \ln \frac{T_{ji}^*}{E_j H_i / \ell_{ji}}) + \ln E_j) \tag{20}$$

a_2) Equilibrium locational surplus

$$\omega_j^* = 1/\beta \sum_i \exp(\beta(W_{ji} - \ell_{ji}\nu_i^*) + \ln(H_i/\ell_{ji})) \tag{21}$$

where T_{ji}^* represents the locational distribution of households at the equilibrium.

By considering the dual problem of the measurement model(19), we obtain the following model for predicting residentail locations $\{T_{ji}\}$ at the equilibrium:

(b) Prediction model of residential locations

$$\max_{T_{ji}} \{ \sum_j \sum_i W_{ji} T_{ji} - 1/\beta \sum_j \sum_i T_{ji} (\ln \frac{T_{ji}}{E_j H_i / \ell_{ji}} - 1) \quad \text{s.t. } \sum_i T_{ji} = E_j , \sum_j T_{ji} \ell_{ji} \geq H_i \} \tag{22}$$

As a result of solving equation (22), T_{ji}^* is expressed in the following form:

$$T_{ji}^* = A_j B_i E_j (H_i / \ell_{ji}) \exp(\beta W_{ji}) \tag{23}$$

where A_j, B_i : valancing factors

By substituting predicted values at each state of equilibrium by models (19) and (22) for ω_j^*, ν_i^* and T_{ji}^* in the rule for benefit generation and imputation (18), the following relationship is obtained.

$$\sum_j \sum_i (T_{ji}^t W_{ji}^t - T_{ji}^{t-1} W_{ji}^{t-1}) + \sum_j \sum_i 1/\beta(- T_{ji}^t \ln \frac{T_{ji}^t}{E_j^t H_i^t / \ell_{ji}} + T_{ji}^t \ln \frac{T_{ji}^{t-1}}{E_j^{t-1} H_i^{t-1} / \ell_{ji}})$$

$$= \sum_j (H_i^t \nu_i^t - H_i^{t-1} \nu_i^{t-1}) + \sum_i (E_j^t \omega_j^t - E_j^{t-1} \omega_j^{t-1}) \tag{24}$$

In the above relationship, the left side represents the total amount of generated benefits during period t under imperfect information and when the behavior of households varies. The first term on the right side corresponds to the amount of benefits transferred to land property values and the second

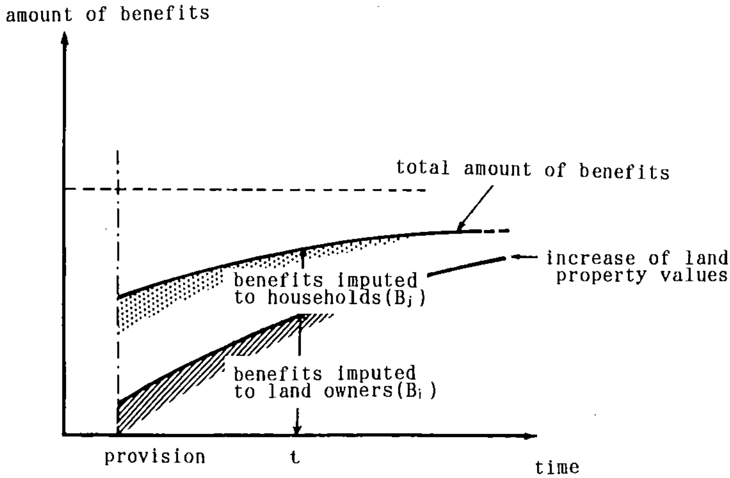

Figure 4 Successive change of imputation of the benefits

term to the benefits left to households. The measurement by property value method which identifies the benefits imputed only to land is provided as a special solution by our model assuming that the improved area along the transport facility is small and opened. As shown in Figure 4, we can find a successive change of imputation of the benefits through applying this model in each time period.

5.3 Model estimation

It is necessary to specify the land-use value function W(·) and to estimate the coefficient parameters of W(·) and the variance parameters β in order to apply the measurement models (19),(22) and (24).

These values can be respectively obtained through maximum likelihood estimation with respect to the equilibrium land price model (20) for coefficient parameters and the equilibrium location model (23) for β. However, both models are mutually dependent and therefore it is impossible to calibrate each parameter individually. In this study, we adopt a recursive maximum likelihood method for both models.

First, we suppose the following linear model as a land-use value function:

$$\begin{aligned} W_{ji} &= W(t_{ji}, d_i, C_i, Z_i, R_i) \\ &= a_t \cdot t_{ji} + a_d \cdot d_i + a_C \cdot C_i + a_Z \cdot Z_i + a_R \cdot R_i \end{aligned} \tag{24}$$

where
t_{ji} : level of travel service between site i and zone j
d_i : distance to the nearest railway station
C_i : accessibility to shopping places
Z_i : other attributes(vector) of site i
R_i : zoning regulations

Table 1 shows the estimated values of parameters in the Nagoya metropolitan area (see Figure 5) based on the 1170 data of land prices at the announced value sites and locational distribution of 2,757,000 households in 1980. This result shows, for example, that the effects of a 10 minute commute on land-use value is nearly equivalent to the effects of being located 1 km away from the rail station.

Table 1 Results of estimation of land-use value function

(10 thousand yen)

Variables description		Parameter (t-value)	
t	travel time to work place(in 10min)	a_t	-0.933 (-63.9)
c	accessibity to shopping place	a_c	-0.0274(-6.2)
d	distance to nearest station(in 1km)	a_d	-0.989 (-11.5)
Z	gas supply (dummy)	a_Z	0.866 (23.2)
	sewerage supply (dummy)		1.76 (17.2)
	land readjustment(dummy)		0.220 (12.5)
R	zoning for neighborhood commercial	a_R	3.08 (17.9)
	zoning for restraining development		-1.33 (-24.7)
variance parameter of bid land price		β^b	0.102 (49.7)
variance parameter of locational surplus		β	0.331 (65.2)

Number of sumples 1170

The goodness of fit of the model shows 0.98 in multiple correlation coefficient for the amount of households by zone and 0.87 for land prices by announced value site.

Although the previous discussion is limited to the benefits generation to households and their transfer to land property values in residential use, the model can be easily extended to involve also the benefits generation to shops, offices or enterprises and their transfer to land property values in commercial use by formulating the inducement of benefits due to locational interdependency between different types of activities.

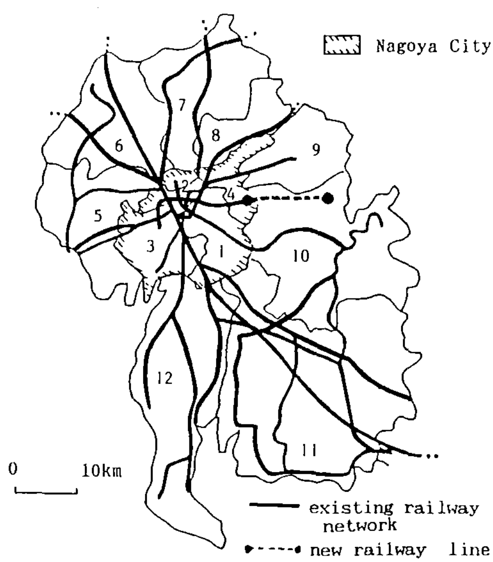

Figure 5 Railway network in the Nagoya metroplitan area

6. CASE STUDIES

In order to examine the applicability of the measurement model, it was applied to a new 15 km long suburban railway in the Nagoya metropolitan area, which reduces travel time by 20 minutes between zone 4 and 10 (see Figure 5).

We examined two cases. In the first case, the new line is not connected with existing radial lines in zone 4, and in the second case, connected directly in zone 5. Therefore, in case 2, the 15 minutes which are necessary for changing trains in case 1 are additionally saved.

In measuring benefits, we also consider benefits generated to shops and offices and those imputed to land in commercial use. The simulation is conducted every five years during three periods.

Figures 6(a) and 6(b) show the change of the total amount of benefits in each period imputed to each interest group, namely land owners and transport users including households and enterprises in each case. The generated benefits are imputed to users, as an increase of locational surpluses (Figure 7(a) and 7(b)) and to land owners as an increase of land property values(Figure 8(a) and 8(b)). These results show that most benefits are transferred to land property values with an accompanying increase in the number of households and enterprises located in zone 4 and 10 near the new line. Furthermore, according to the estimated result of the coefficients of the land-use value function $W(\cdot)$ in Table 1, these benefits are imputed to land owners as special benefits, which diminish by approximately 10 thousand yen/m^2 per each 1km away from a rail station.

However, the above results also show that not all generated benefits by the transport improvement are transferred to land property values. This result is different from that calculated by the property value method which is based on the capitalization hypothesis. The shares of benefits imputed to land are identified as 82% in case 1 and 70% in case 2 in the last(third) period. This shows that the extent to which generated benefits are transferred to land property values varies depending on the characteristics of the transport improvement of interest. Namely, in case 1, the new line is regarded as local public goods of which passengers are almost local inhabitants and therefore the benefits are mostly imputed to land property values in its area. But, in case 2, because the line is well connected to the existing network, the other passengers also use the line and consequently the user benefits are spillt over to households and enterprises in other areas without transferring to land property values.

7. CONCLUDING REMARKS

In this paper, we first enumerated requirements for a measurement model of the benefits to provide information in examining financial policy options. Then we developed a theory which formulates generation and imputation of benefits, and a practical model to measure the benefits imputed to each interest group by region. As a result of application to practical cases of transport improvements, it is shown that this model can identify the benefits imputed not only to land owners but also those remaining to households and enterprises as users of transport facilities in each time period. Therefore it is possible to apply this model when examining financial policy options on the basis of equity between interest groups. Furthermore it was shown that model can express the differences in the mechanism of imputation corresponding to the characteristics

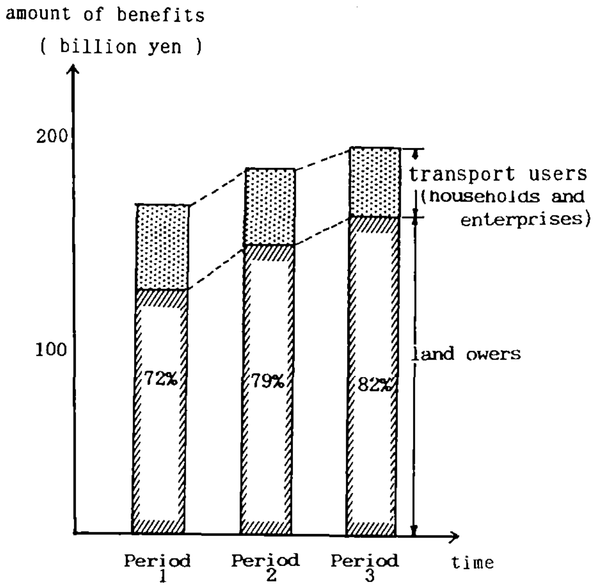

Figure 6(a) Change of the share of each benefits imputed to transport users and land owners (case 1)

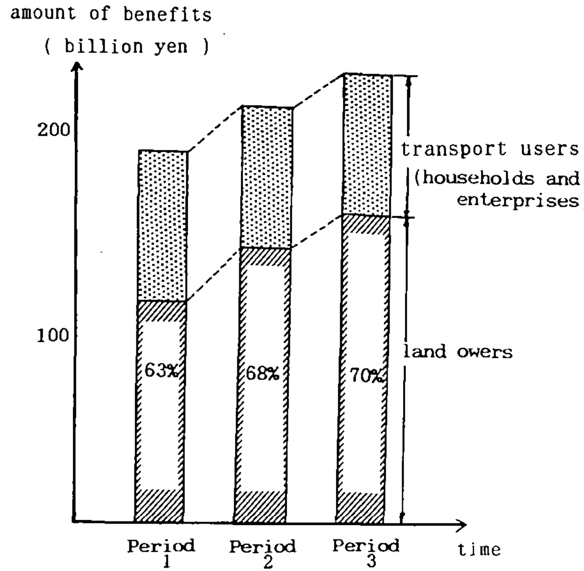

Figure 6(b) Change of the share of each benefits imputed to transport users and land owners (case 2)

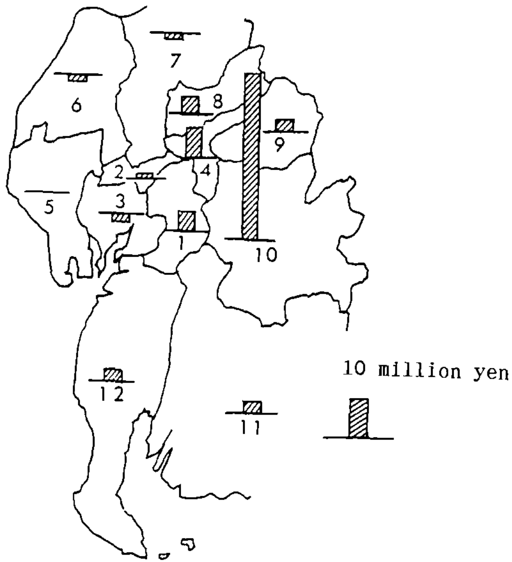

Figure 7(a) Regional distribution of the benefits imputed to land owners(case 1)

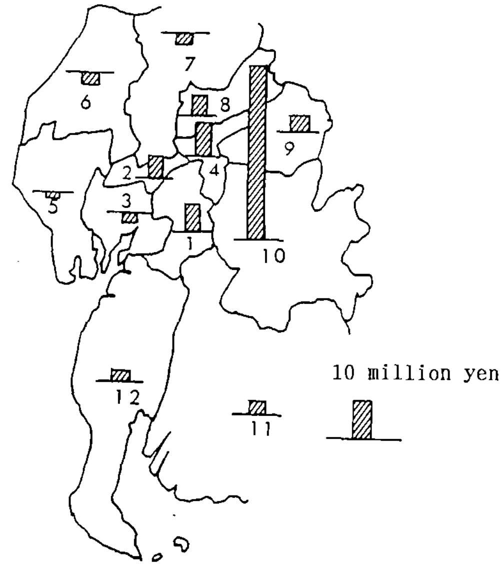

Figure 7(b) Regional distribution of the benefits imputed to land owners(case 2)

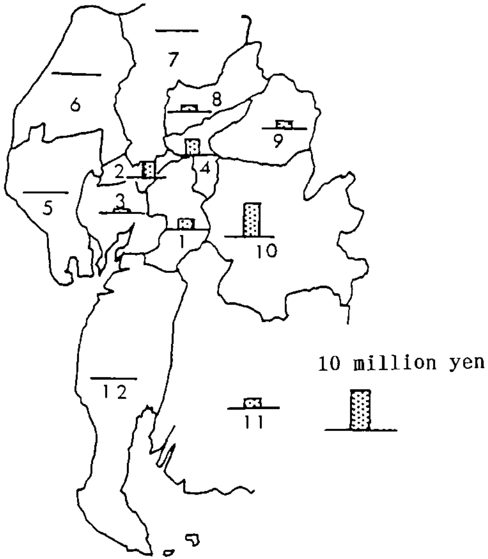

Figure 8(a) Regional distribution of the benefits imputed to transport users (case 1)

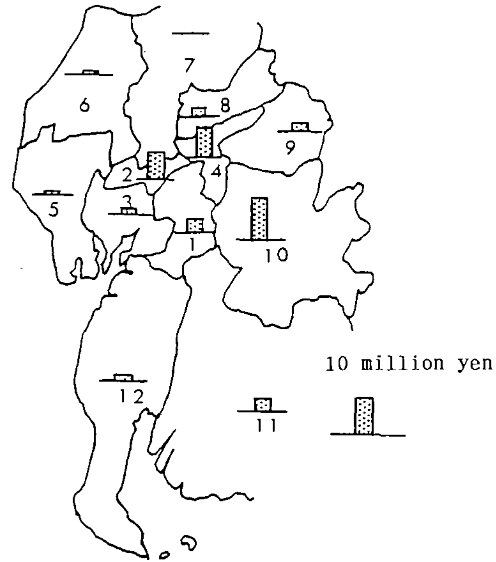

Figure 8(b) Regional distribution of the benefits imputed to transport users (case 2) measurement models, such as the property value method, partial equilibrium models and general equilibrium models.

The functions included in this measurement model are summarized as follows:

1) Both the total amount of benefits and the share of benefits imputed to each interest group by region can be identified theoretically. This function is derived from the rule for benefit generation and imputation, which is deduced by analytically formulating a simple equation of locational equilibrium with the concepts of land-use value and locational surplus.

2) The imputation of benefits can be estimated under more relatively general assumptions than those used in the property value method, such as a small-open city.

3) By simulating the equilibrium of the land market in a quasi-dynamic manner, it is possible to forecast the imputation of benefits in each time period.

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