Evaluation of Toll Free Expressway Policy in Japan by using a General Equilibrium Model

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Abstract: This paper examines the effects of toll free policy for expressways which is to be introduced in Japan. A model that is developed by combining a general equilibrium model of a multi-city economy and deterministic user equilibrium traffic assignment model is applied for examining the effects of the toll free policy. In the model, cities are linked by a road network including toll expressways. It is shown that the toll free policy applied to all of the expressways in Hokkaido, Japan brings about the social welfare of 31.2 [billion JPY/year], and that applied to some part of expressways where traffic congestion rarely occurs brings about the social welfare of 41.2 [billion JPY/year]. The social welfares presented in this study are calculated from the utility levels of households in the economy.

Key Words: general equilibrium model, deterministic user equilibrium, toll free policy

1. INTRODUCTION

The effects of transport policy, e.g. benefits by a road project (or policy), have been measured based on accrual basis. Accrued benefit can be measured as the change in consumer surplus. For example, the accrued benefit by a road project in Japan is calculated from the decrease in travel time, the reduction in travel cost, and the decrease in traffic accidental cost. In general, transport policy, such as the construction of new expressways and change in expressway tolls, changes the locations of firms and households, and then brings about the changes in the spatial structure of the economy and people’s welfare level. Thus, the benefit by transport policy may be reasonable to be measured based on incidence basis. Incidence benefit can be measured as the change in national income or the utility level of households.

For addressing the incidence benefit by transport policy, general equilibrium models of an urban system are available. General equilibrium effects of inter-city transport investment are analyzed by Kanemoto and Mera (1985), Sasaki (1992), and Morisugi et al. (1995). On the other hand, urban economists have developed models which explain how the size of each city is determined in the system of cities, e.g. Henderson (1987), Kanemoto (1980), and Abdel-Rahman (1990). Krugman (1991a, 1991b) further analyzed industrial location by incorporating transport cost in the two-region model of interregional trade with scale economy. According to this model, the concentration of production activities may occur even when all regions are homogenous and no comparative advantage exists. Krugman (1993) extended the model framework to the setting of three regions scattered over two-dimensional
space and connected by a transport network. Fujita \textit{et al.} (1995) further developed the model so that the economy has multiple industrial sectors, and analyzed a dynamic process of city formation and development. The model is general since the location of each city is not a priori specified but endogenously determined. They demonstrated that, as the economy’s population size increases, the urban system organizes itself into a Christaller-type hierarchical system. Mun (1997) introduced many types of industry into the model of an urban system. In the model, some types of industry are subject to an agglomeration economy and the industrial structure of each city is endogenously determined. Recently, Koike \textit{et al.} (2009) analyses the effects of expressway network development on the spatial equity in Japan.

In this study, the short-term effects of the toll free policy for expressways which is to be introduced in Japan on the utility level of households are examined. The effects from the policy are measured as the incidence benefit. The benefit is calculated by using a model which is developed by combining two interactive models, i.e. the general equilibrium model of a multi-city economy proposed by Mun (1997) and deterministic user equilibrium (DUE) traffic assignment model. In the general equilibrium model, city size distribution (population), industrial location, inter-city trade patterns, wages, prices of goods, land rent, and the utility level of households are simultaneously determined given general travel time which reflects the toll free policy. General travel time represents the transportation cost of the goods. General travel time is determined by DUE model given the population of each region which is determined by the general equilibrium model.

2. GENERAL EQUILIBRIUM MODEL OF A MULTI-CITY ECONOMY

We apply the general equilibrium model proposed by Mun (1997) for measuring the incidence benefits by the toll free expressway policy. In this section, outline of the model is presented. One can access to Mun (1997) for the detailed explanation on the model.

Industrial firms locating in a large city enjoy the benefit of agglomeration economies, but pay higher wages. On the other hand, such high wage income in a large city attracts households as labor force, while they suffer high land rent and small housing space. The system attains equilibrium when the firm profits are zero, household utility levels are equal regardless of location, and all markets are cleared.

The setting and basic assumptions are as follows.

(a) Cities are developed at nodes in a transport network. The location of city \( i \) \((i = 1, \ldots, I)\) is specified exogenously. The number of cities, \( I \), is fixed.

(b) Firms and households can migrate freely between cities.

(c) Total population of the economy is fixed at \( T \). Thus, the following relation holds:

\[
\sum_{i=1}^{I} N_i = T , \tag{1}
\]

where \( N_i \) is the population of city \( i \). Everyone in the economy is employed by firms as a labor force.

(d) Land within the city is homogeneous and used for housing. This implies that firms use no land. The total supply of land in each city is fixed at \( H_i \) which is denoted as:

\[
N_i \cdot h_i = H_i , \tag{2}
\]
where \( h_i \) is the housing lot size of each household in city \( i \). Public ownership of land is assumed, i.e. land is owned by city government and rental revenue is distributed equally to each household in the city.

(c) The economy produces \( M \) types of goods; i.e. there exist \( M \) different industrial sectors. Inputs for production are labor and capital.

(f) Input for transportation service is the traded goods itself.

(g) The total amount of capital in the economy is fixed.

(h) Trades of capital and goods with the cities and countries which are situated outside of the economy are freely carried out. The balance of current account holds among the all cities and countries, i.e. the cities in the economy plus cities and countries outside the economy.

(i) The total amount of capital in the economy is fixed. Capital is equally owned by households, each of which receives a share in the capital rental revenue as income.

The production function is specified as the following linear homogenous Cobb-Douglas form:

\[
y^m_i = \delta^m \cdot G^m(N_i) \cdot (L^m_i)^{\alpha^m} \cdot (K^m_i)^{1-\alpha^m},
\]

where \( y^m_i, L^m_i \) and \( K^m_i \) are the amounts of output, labor and capital inputs for sector \( m \) in city \( i \), respectively. \( \alpha^m \) and \( \delta^m \) are the calibration parameters. \( G^m(N_i) \) is a function representing agglomeration economies, specified as:

\[
G^m(N_i) = N_i^{\sigma^m},
\]

where \( \sigma^m \) is a constant and takes the values within the range \( 0 \leq \sigma^m \leq 1 \). From the first-order conditions for profit maximization, the demand functions for labor and capital of sector \( m \) in city \( i \) are respectively given by:

\[
L^m_i = \frac{a^m}{w_i} \cdot q^m_i \cdot y^m_i,
\]

\[
K^m_i = \frac{1-a^m}{r} \cdot q^m_i \cdot y^m_i,
\]

where \( q^m_i \) is the free on board (FOB) price of goods \( m \); \( w_i \) is the wage rate in city \( i \); \( r \) is the rent of capital. Since the linear homogenous type production function is assumed, the profit of firm in sector \( m \) is zero if the output level is positive. Firm withdraws from the city if average cost \( (C^m) \) exceeds FOB price. Thus, we obtain the following conditions:

\[
q^m_i = C^m(N_i, w_i, r) \text{ if } y^m_i > 0,
\]

\[
q^m_i \leq C^m(N_i, w_i, r) \text{ if } y^m_i = 0,
\]

where

\[
C^m(N_i, w_i, r) = \frac{N_i^{-\sigma^m} \cdot w_i^{\alpha^m} \cdot r^{1-\alpha^m}}{\delta^m \cdot a^m \cdot (1-a^m)^{1-\alpha^m}}.
\]

Households in the economy have identical tastes and their utility functions are specified as:

\[
U(h_i, x^1_i, x^2_i, \ldots, x^M_i) = \alpha \cdot \ln h_i + \sum_{m=1}^{M} \beta^m \cdot \ln x^m_i,
\]

where \( x^m_i \) is the amount of goods \( m \) consumed by a household in city \( i \); \( \alpha \) and \( \beta^m \) are the positive parameters such that \( \alpha + \sum_m \beta^m = 1 \). Since personal income of a household, i.e. wages, redistribution of land rent, and a share of capital revenue, are spent for goods
consumption and housing cost, the budget constraint for a household in city $i$ is then:

$$w_i + \frac{p_i^b \cdot H_i}{N_i} + \frac{r \cdot \bar{K}}{T} = \sum_{m=1}^{M} p_i^m \cdot x_i^m + p_i^b \cdot h_i, \quad (11)$$

where $p_i^m$ is the cost insurance freight (CIF) price of goods $m$; $p_i^b$ is the residential land rent in city $i$; $\bar{K}$ is the total amount of capital in the economy. From the conditions for utility maximization, we obtain the following demand functions:

$$x_i^m = \frac{\beta^m}{1-\alpha} \cdot \frac{1}{p_i^m} \left( \frac{w_i + r \cdot \bar{K}}{T} \right), \quad (12)$$

$$h_i = \frac{\alpha}{1-\alpha} \cdot \frac{1}{p_i^b} \left( \frac{w_i + r \cdot \bar{K}}{T} \right). \quad (13)$$

Trade pattern between two cities can be determined by CIF price which is FOB price plus transportation cost. By following a logit-type random utility model (RUM), the probability of city $j$ demanding goods $m$ from city $i$ ($s_{ij}^m$) is given by:

$$s_{ij}^m = \frac{y_{ij}^m \cdot \exp \left[ - \bar{x}^m \cdot q_{ij}^m \cdot (1 + \omega^m \cdot \tilde{t}_{ij}) \right]}{\sum_k y_{ik}^m \cdot \exp \left[ - \bar{x}^m \cdot q_{ik}^m \cdot (1 + \omega^m \cdot \tilde{t}_{ij}) \right]}, \quad (14)$$

where $\omega^m$ is the amount of goods $m$ required to transport unit amount of the goods unit generalized travel time; $\tilde{t}_{ij}$ is the minimum generalized travel time from city $i$ to city $j$; $\bar{x}^m$ is the dispersion parameter for logit-type RUM. $\tilde{t}_{ij}$ is determined by DUE model which is to be explained in the next section. Thus, the amount of goods $m$ which is produced in city $i$ and is demanded in city $j$ is then:

$$z_{ij}^m = \left\{ N_j \cdot x_i^m \cdot (1 - \mu^m) + E_j^m \right\} \cdot s_{ij}^m, \quad (15)$$

where $\mu^m$ is the import coefficient which is exogenously given; $E_j^m$ is the amount of goods $m$ which is exported from node $j$ if the node contains an export node. CIF price in city $j$ of goods $m$ is given by:

$$p_j^m = \sum_i s_{ij}^m \cdot q_{ij}^m \cdot (1 + \omega^m \cdot \tilde{t}_{ij}). \quad (16)$$

The market equilibrium of this economy is described below.

Labor market:

$$\sum_{m=1}^{M} L_i = N_i. \quad (17)$$

Goods market (city of demand): $N_j \cdot x_j^m \cdot (1 - \mu^m) + E_j^m = \sum_{i=1}^{i} z_{ij}^m. \quad (18)$

Goods market (city of production): $y_j^m = \sum_{j=1}^{j} z_{ij}^m \cdot (1 + \omega^m \cdot \tilde{t}_{ij}). \quad (19)$

The balance of current account:

$$r \cdot \left( \sum_{j=1}^{j} \sum_{m=1}^{M} K_i^m - \bar{K} \right) = \sum_{i=1}^{i} \sum_{m=1}^{M} q_{ij}^m \cdot E_j^m - \sum_{i=1}^{i} \sum_{m=1}^{M} \mu^m \cdot p_i^m \cdot N_i \cdot x_i^m. \quad (20)$$

Household’s locational equilibrium: $U(h_i, x_1^i, x_2^i, \ldots, x_N^i) = u^*. \quad (21)$
3. DUE WITH VARIABLE DEMAND

In this section, the formulation of DUE with variable demand is presented. Consider a directed graph \( G(A, N) \) representing a transport network including a set of links \( A \) and a set of nodes \( N \). Let \( f^y \) denote the demand flow between OD pair \( ij \), i.e. travel demand from node (city) \( i \) to node \( j \), which is determined by the travel demand function of \( D_y(\tilde{t}_{ij}; N_i) \) which is the function of \( \tilde{t}_{ij} \) (the minimum generalized travel time between OD pair \( ij \)) given the population of city \( i \) \((N_i)\), and where \( \Omega \) is a set of OD pairs in the network. Each link in the network is associated with a travel time function \((\tau_a)\) where \( \tau_a \) is link flow which will be explained later. \( q_a \) is given by:

\[
q_a = \sum_{ij \in \Omega} \sum_{k \in K^y} \delta_{ak}^y \cdot f_k^y, \quad \forall a \in A,
\]  

where \( f_k^y \) is the flow on the \( k \)-th path between OD pair \( ij \); \( K^y \) is the set of paths serving between OD pair \( ij \); \( \delta_{ak}^y \) is a variable which equals to 1 if link \( a \) is associated with the \( k \)-th route between OD pair \( ij \) and 0 otherwise. Let \( t^k \) and \( \kappa_{ij} \) denote the travel time of \( k \)-th path between OD pair \( ij \) and the toll for the path, respectively. The generalized travel time of \( k \)-th path between OD pair \( ij \) is then:

\[
\tilde{t}_{ij}^k = t^k_{ij} + \frac{\kappa_{ij}}{\tau}, \tag{23}
\]

where \( \tau \) is the value of time.

The travelers in our model are assumed to choose the route following DUE principle with variable demand which can be formulated as:

\[
f_k^y \cdot (\tilde{t}_{ij}^k - \tilde{t}_{ij}) = 0 \quad \forall ij \in \Omega, \forall k \in K^y, \tag{24}
\]

\[
\tilde{t}_{ij}^k - \tilde{t}_{ij} \geq 0 \quad \forall ij \in \Omega, \forall k \in K^y, \tag{25}
\]

\[
f^y = \sum_{k \in K^y} f_k^y, \quad \forall ij \in \Omega, \tag{26}
\]

\[
f_k^y \geq 0 \quad \forall ij \in \Omega, \forall k \in K^y, \tag{27}
\]

\[
f^y \cdot (\tilde{t}_{ij} - D^{-1}_y(f^y; N_i)) = 0 \quad \forall ij \in \Omega, \forall k \in K^y, \tag{28}
\]

\[
\tilde{t}_{ij} - D^{-1}_y(f^y; N_i) \geq 0 \quad \forall ij \in \Omega, \tag{29}
\]

\[
f^y \geq 0 \quad \forall ij \in \Omega. \tag{30}
\]

Under separable link travel time condition, DUE principle with variable demand defined above can be formulated as the following equivalent optimization problem:

\[
\min Z_a = \sum_{a \in A} \int_0^{q_a} \tilde{t}_a(w)dw - \sum_{ij \in \Omega} \int_0^{f^y} D^{-1}_y(x; N_i)dx, \tag{31}
\]

\[
\text{s.t. } (21), (25), (26) \text{ and } (29),
\]

where \( \tilde{t}_a(q_a) \) is the general travel time of link \( a \). The general travel time considering tolls of expressway can be written as:

\[
\tilde{t}_a(q_a) = t^0_a(q_a) + \frac{\kappa_a}{\tau} = t^0_a \left(1 + \alpha \cdot \left(\frac{q_a}{c_a}\right)^{\beta}\right) + \frac{\kappa_a}{\tau}, \tag{32}
\]

where \( c_a \) is traffic capacity; \( \kappa_a \) is toll; \( \alpha \) and \( \beta \) are calibration parameters. The generalized
travel time of the $k$-th path between OD pair $ij$ is then:
$$
\tilde{t}_{ij}^k = \sum_{a \in A} \delta_{ik} \cdot \tilde{t}_a(q_a) \forall ij \in \Omega, \forall k \in K^{ij}. \quad (33)
$$

Given the population of city $i$ ($N_i$) which is determined by the general equilibrium model, the demand function can be given by:
$$
D_{ij} \left( \tilde{t}_i ; N_i \right) = \frac{N_i}{1 + \exp(f(\tilde{t}_i))}, \quad (34)
$$

where $f(\tilde{t}_i)$ is a linear function of $\tilde{t}_i$ with some calibration parameters.

### 4. PARAMETER ESTIMATION

For the model parameter estimation, Hokkaido which is the target economy in this study is divided into 14 regions as shown by Fig. 1. The regions shown in Fig. 1 will be addressed as the cities in the general equilibrium model.

#### 4.1 Production Function

Estimation method of the parameters used in the production function shown by Eq. (3), i.e. $\delta^m, \sigma^m, a^m$, is presented in this section. However, a linear regression model can be applied for parameter estimation, estimated parameters may be suffered from multicollinearity due to city scale effect. For the purpose of avoiding multicollinearity in estimating the parameters, consider the following equation which is obtained by dividing both sides of Eq. (3) by $L_i^m$:
$$
\frac{y_i^m}{L_i^m} = \delta^m \cdot (N_i)^{\sigma^m} \cdot \left( \frac{K_i^m}{L_i^m} \right)^{1-a^m}. \quad (35)
$$

Then, by taking logarithm of both sides of Eq. (35) we obtain:
$$
\ln \left( \frac{y_i^m}{L_i^m} \right) = \delta^m + \sigma^m \cdot \ln(N_i) + b^m \cdot \ln \left( \frac{K_i^m}{L_i^m} \right), \quad (36)
$$

where $\delta^m = \ln(\delta^m), b^m = 1 - a^m$. Thus, we can apply a linear regression model for the parameter estimation. Following Varian (1987), for the purpose of reducing estimation bias we calculate the amounts of labor demand as:
$$
L_i^m = a^m \cdot q_i^m \cdot y_i^m / w_i, \quad (37)
$$

which is obtained from utility maximization behavior. Since Eq. (37) does not contain the parameters $\delta^m$ and $\sigma^m$, three-stage least squares estimation needs to be applied for estimating the parameters which satisfy both Eqs. (36) and (37). $K_i^m$ needs to be obtained in Eq. (35). $K_i^m$ can be easily estimated as:
$$
K_i^m = q_i^m \cdot y_i^m - w_i \cdot L_i^m, \quad (38)
$$

where $r = 1$ since capital is assumed as the numeraire in the model.

#### 4.2 Trade Model

The trade model can be formulated as:
where
\[ \hat{\omega}_m = \lambda^m \cdot \omega^m. \] (40)

\( q^m_i \) in Eq. (38) can be calculated by using the parameters for the production function, as:
\[ q^m_i = C^m(N_i,w_i,r) = \frac{N_i^{-\alpha^m} \cdot w_i^{\alpha^m} \cdot r^{1-\alpha^m}}{\delta^m \cdot \alpha^m \cdot (1-\alpha^m)^{1-\alpha^m}}. \] (41)

Eq. (41) implies that the FOB price of goods \( m \) in city \( i \) equals to unit cost. The parameters for the trade model, i.e. \( \lambda^m \) and \( \omega^m \), can be then estimated by minimizing the following function:
\[ SQ = \sum_i \left[ \sum_j \frac{z^m_{ij}}{x^m_{ij}} - \sum_k \sum_l \frac{y^m_l \cdot \exp[- \lambda^m \cdot q^m_l + \omega^m \cdot q^m_l \cdot t^m_{lj} - \sum_k \sum_l (z^m_{ij} \cdot \exp[- \lambda^m \cdot q^m_k + \omega^m \cdot q^m_k \cdot t^m_{kj}])]}{y^m_k \cdot \exp[- \lambda^m \cdot q^m_k + \omega^m \cdot q^m_k \cdot t^m_{kj}]} \right]^2, \] (42)

where \( \bar{z}^m_{ij} \) is the aggregated freight weight of goods \( m \) which is traded from city \( i \) to city \( j \).

4.3 Utility Function and Import Coefficient

By the demand function of goods \( m \), we obtain:
\[ \bar{\beta}^m = \frac{\beta^m}{\sum_n \beta^m} = \frac{p^m_i \cdot x^m_i}{\sum_n p^m_i \cdot x^m_i}. \] (43)

The right hand side of Eq. (43) is the share of demand for goods \( m \) which is expressed in monetary unit. Since all goods’ shares are given by inter-industry table (input-output data), we can estimate \( \beta^m \).

The import coefficient \( \mu^m \) can be estimated as:
\[ \mu^m = \frac{IM^m}{TD^m}, \] (44)

where \( IM^m \) is the total amount of goods \( m \) which is imported from the area outside of the economy; \( TD^m \) is the total demand of goods \( m \) in the economy. Both \( IM^m \) and \( TD^m \) are given by inter-industry table.

4.4 Estimated Parameters

The number of industrial sectors assumed in this study is 20 (Table 1). Model parameters for the general equilibrium model were estimated by using the census data collected in 2005. The resultant parameters are shown in Table 1. In the model parameter estimation, \( \lambda^m \) was estimated at 0 in some industries which implies the inability to estimate \( \omega^m \). In specific industries, i.e. \( m = 4 \text{ - } 20 \), both \( \lambda^m \) and \( \omega^m \) could not be estimated due to the lack of data. In such cases, we determine these parameters such that those maximize the fitness of the model to observed data, e.g. wage in each city. The same manner is applied to the remaining parameter \( \alpha \) which is used in utility function.
Table 1 Estimated parameters.

<table>
<thead>
<tr>
<th>Sector No. Industrial sector</th>
<th>(a^m)</th>
<th>(c^m)</th>
<th>(\sigma^m)</th>
<th>(\lambda^m)</th>
<th>(\omega^m)</th>
<th>(\beta^m)</th>
<th>(\mu^m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Logging</td>
<td>0.085</td>
<td>0.157</td>
<td>0.206</td>
<td>0.209</td>
<td>2.099</td>
<td>0.0001</td>
<td>0.0978</td>
</tr>
<tr>
<td>2. Textile</td>
<td>0.149</td>
<td>0.117</td>
<td>0.288</td>
<td>0.360</td>
<td>0.606</td>
<td>0.0102</td>
<td>0.1689</td>
</tr>
<tr>
<td>3. Chemical</td>
<td>0.051</td>
<td>0.415</td>
<td>0.000</td>
<td>28.600</td>
<td>1.720</td>
<td>0.0314</td>
<td>0.1853</td>
</tr>
<tr>
<td>4. Plastics</td>
<td>0.101</td>
<td>0.251</td>
<td>0.161</td>
<td>1.310</td>
<td>1.443</td>
<td>0.0307</td>
<td>0.1056</td>
</tr>
<tr>
<td>5. Food manufacturing</td>
<td>0.135</td>
<td>0.355</td>
<td>0.129</td>
<td>0.265</td>
<td>2.647</td>
<td>0.0384</td>
<td>0.0997</td>
</tr>
<tr>
<td>6. Precision machinery</td>
<td>0.128</td>
<td>0.310</td>
<td>0.142</td>
<td>7.790</td>
<td>0.802</td>
<td>0.0115</td>
<td>0.1472</td>
</tr>
<tr>
<td>7. Ceramics</td>
<td>0.070</td>
<td>0.237</td>
<td>0.133</td>
<td>0.435</td>
<td>4.354</td>
<td>0.0008</td>
<td>0.0771</td>
</tr>
<tr>
<td>8. Beverage production</td>
<td>0.059</td>
<td>0.296</td>
<td>0.086</td>
<td>0.067</td>
<td>0.672</td>
<td>0.0187</td>
<td>0.1100</td>
</tr>
<tr>
<td>9. Publication printing</td>
<td>0.093</td>
<td>0.291</td>
<td>0.120</td>
<td>1.990</td>
<td>1.153</td>
<td>0.0030</td>
<td>0.0884</td>
</tr>
<tr>
<td>10. Apparel manufacturing</td>
<td>0.114</td>
<td>0.129</td>
<td>0.272</td>
<td>2.620</td>
<td>0.723</td>
<td>0.0314</td>
<td>0.1383</td>
</tr>
<tr>
<td>11. Nonferrous metal</td>
<td>0.106</td>
<td>0.330</td>
<td>0.000</td>
<td>0.024</td>
<td>0.238</td>
<td>0.0013</td>
<td>0.1426</td>
</tr>
<tr>
<td>12. Agriculture, forestry and fisheries</td>
<td>0.019</td>
<td>0.387</td>
<td>0.148</td>
<td>0.000</td>
<td>0.000</td>
<td>0.0160</td>
<td>0.9697</td>
</tr>
<tr>
<td>13. Mining</td>
<td>0.010</td>
<td>0.311</td>
<td>0.106</td>
<td>19.940</td>
<td>4.140</td>
<td>0.0001</td>
<td>0.0000</td>
</tr>
<tr>
<td>14. Building</td>
<td>0.011</td>
<td>0.360</td>
<td>0.100</td>
<td>4.000</td>
<td>0.010</td>
<td>0.1801</td>
<td>0.0000</td>
</tr>
<tr>
<td>15. Wholesale and retail</td>
<td>0.789</td>
<td>1.039</td>
<td>0.121</td>
<td>4.000</td>
<td>0.010</td>
<td>0.1252</td>
<td>0.4042</td>
</tr>
<tr>
<td>16. Finance, insurance and real estate</td>
<td>0.119</td>
<td>0.264</td>
<td>0.138</td>
<td>4.000</td>
<td>0.010</td>
<td>0.0970</td>
<td>0.0348</td>
</tr>
<tr>
<td>17. Transportation and communication</td>
<td>0.074</td>
<td>0.312</td>
<td>0.124</td>
<td>4.000</td>
<td>0.010</td>
<td>0.0444</td>
<td>0.3937</td>
</tr>
<tr>
<td>18. Utility</td>
<td>0.392</td>
<td>0.666</td>
<td>0.150</td>
<td>4.000</td>
<td>0.010</td>
<td>0.0174</td>
<td>0.0001</td>
</tr>
<tr>
<td>19. Service</td>
<td>0.803</td>
<td>1.509</td>
<td>0.121</td>
<td>4.000</td>
<td>0.010</td>
<td>0.2558</td>
<td>0.1455</td>
</tr>
<tr>
<td>20. Civil service</td>
<td>0.214</td>
<td>0.437</td>
<td>0.125</td>
<td>4.000</td>
<td>0.010</td>
<td>0.0867</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

5. BENEFIT

Since the short-term effects of the toll free policy are the main concern in this study, neither the change in the location of households nor the variable transport demand in DUE is considered. This implies that utility levels of households in a city are all equal, however, households in different cities can have different utility levels. Let \(p^i_S = (p^i_1(S), p^i_2(S),..., p^i_{m}(S),...)\) denote the vector of prices in city \(i\) when project state is \(S\), i.e. if project state is before \(S = B\), otherwise \(S = A\). Each household in city \(i\) chooses the amounts of goods consumed by maximizing the utility function \(U(h_i, x^i_{1},..., x^i_{M})\) subject to the income
constraint which is denoted by \( p_i^S(S) \cdot h_i + \sum_m p_i^m(S) \cdot x_i^m = z_i^S \). The indices that express the change in utility level in monetary value are compensating variation (CV) and equivalent variation (EV). CV and EV are defined respectively as:

\[
V(p^A_i, z^A_i - CV_i) = u^B_i, \\
V(p^B_i, z^B_i + EV_i) = u^A_i,
\]

where \( u^S_i = V(p^S_i, z^S_i) \) is the utility level when project state is \( S \); \( V(\ ) \) is indirect utility function. CV and EV in city \( i \) are then calculated by using the definitions of relating variables, respectively as:

\[
CV_i = Y_i^A - \exp \left[ u^B_i - \bar{v} + v(p^A_i) \right],
\]

\[
EV_i = \exp \left[ u^A_i - \bar{v} + v(p^B_i) \right] - Y_i^B,
\]

where

\[
\bar{v} = \alpha \cdot \ln \left( \frac{\alpha}{1-\alpha} \right) + \sum_m \beta^m \cdot \ln \left( \frac{\beta^m}{1-\alpha} \right),
\]

\[
v(p^S_i) = \alpha \cdot \ln p_i^S(S) + \sum_m \beta^m \cdot \ln p_i^m(S),
\]

\[
Y_i^S = w_i^S + \frac{r \cdot \overline{K}^S}{T}.
\]

6. RESULTS

Productions from the two industry sectors, i.e. Agriculture, forestry and fisheries, and Mining are determined depending strongly on land and natural resources. Production from civil service is determined politically. Since productions from these industry sectors are determined regardless of the economy, these productions are given exogenously in the model. Export nodes (cities) from which the goods are exported to outside of the economy are Ishikari (domestic), Oshima (domestic) and Iburi (abroad). Total capital \( \overline{K} \) which is used to calculate CV or EV cannot be calculated from the census data. However, total capital can be estimated from Eq. (20), as:

\[
\overline{K} = \sum_{i=1}^l \sum_{m=1}^M K_i^m - \sum_{i=1}^l \sum_{m=1}^M q_i^m E_i^m + \sum_{i=1}^l \sum_{m=1}^M \mu^m p_i^m N_i x_i^m. 
\]

We assumed further that the size of each household is equal and each household has an employee. Thus, the number of households is the same as the number of employees in the economy.

As mentioned earlier, since the short-term effects of the toll free policy are the main concern in this study, neither the change in the location of households nor the variable transport demand in DUE model is considered. The change in the location of firms, on the other hand, is considered since that can occur shortly after the toll free policy. Fig. 2 shows the road network addressed in this study in which expressways are depicted by the thick lines, i.e. red lines and blue lines. We consider two toll free plans. The first plan (plan 1) makes the entire expressways toll free. The second plan (plan 2) makes the expressways depicted in blue lines toll free. The expressways targeted by plan 2 do not carry large traffic volumes, i.e. traffic congestions rarely occur on these expressways. Plan 2 is now under practice as a pilot.
program.

Fig. 3 shows the dispersion between two wages which are the actual wage and the estimated wage by the general equilibrium model. As is often the case in the general equilibrium model, the coefficient of correlation is calculated as 0.7 which is actually not so high, since the scale of the estimated wage is not equal to that of actual one. However, the estimated wage tends to follow the actual wage.

Fig. 4 shows the distribution of regional benefits (CVs) by plan 1 in which the distribution of regional population is also presented. As shown in the figure, the population of Ishikari region is the biggest among all the regions and the populations in the other regions are less than half of Ishikari region. Thus, the population and the economy in Hokkaido now can be regarded as the overconcentration in Ishikari region. In plan 1, two benefits of Ishikari region and Shiribeshi region are calculated at negative values. This comes mainly from the location change by the firms from these two regions to the other regions due to the toll free. In plan 1, CIF prices of the goods decrease in all regions, and then the wages also decrease in all regions. Accordingly, the region which enjoys positive benefit has the positive income effect in total. Total benefit in Hokkaido by the plan is calculates as 31.2 [billion JPY/year].

Fig. 5 shows the distribution of regional benefits by plan 2. Different from plan 1, all regions enjoy positive benefits in this plan. Total benefit in Hokkaido by the plan is calculated as 41.2 [billion JPY/year] which is 10 [billion JPY/year] higher than that by plan 1. Similar to the case of plan 1, wages in all regions decrease. In contrast to plan 1, all regions enjoy the positive income effect by plan 2.
7. CONCLUSIONS

In this study, the effects of the toll free expressway policy which is under consideration in Japan are examined by targeting the road network in Hokkaido. The effects are measured as the incidence benefits by using a model which is developed by combining both the general equilibrium model and DUE model. Different from the traditional models which have been used in the field of cost benefit analysis for infrastructure investments, the incident benefits may be more reasonable than the accrued benefit since the incidence benefits are calculated from the utility levels of households via economical activities. In this regard, the accrued benefit calculated from the traditional models may be underestimated one. In general, the direct effects of transport policies or measures on a transport network can be estimated as the changes in generalized travel costs by transport network models. Therefore, the effects can be transformed into the incidence benefits by applying general equilibrium models. A cost benefit analysis method for the infrastructure investment to transport network which reflects the economical activities as well as the travel behaviors by the travelers in the network is required for calculating the reasonable benefits. The framework presented in this paper can be regarded as one of the alternative methods for the traditional cost benefit analysis for the infrastructure investment to transport network.

However, the framework for calculating the benefits presented in this study still has some challenges for a future study. The utility function assumed in this study reflects only the amounts of goods consumed, wage and housing level into account. The reduction in the travel costs for commuter and leisure trips as well as the modal choice behavior in a multi-modal transport network are also important factors in measuring the benefit by transport policy. In addition to that, the production function defined in the present study does not reflect the intermediate inputs which are also important factors in economical activities. The introduction of the intermediate inputs to the production function is required. These are the tasks for a future study.

REFERENCES


