Measurement of Transportation Infrastructure Development Impacts by using Dynamic Spatial Computable General Equilibrium Model

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Abstract

Transportation infrastructure, such as high speed rail- and expressway, create huge economic impact across the nation. To measure such economic impacts, the computable general equilibrium (CGE) analysis has been widely used recently. However, such an impact arises through a long period of time, so that measurements of economic impacts in dynamic form are strongly required. Therefore, we employed Ban's model which is an expanded spatial CGE model in dynamic form. We modified it to measure accumulated economic impact of transportation infrastructure development up to present.As a case study, we estimated the economic impact of development of Shinkansen Railways and National Expressways in Japan using our modified model. By comparing base run and alternative run in which efficiency parameters of transportation were set 0.8 times of those in base run for case without project.The results show, first, that GDP growth by transportation infrastructure development was about 6 trillion yen and the gross regional product (GRP) growth was mostly accumulated in Kanto and Kinki regions in 2030. Second, the amount of GDP growth is drawn by a fitted curveto the past from the estimated future GDP. Third, if same development of transportation infrastructure for all regions in the whole country is assumed, the amount of GRP growth is higher in metropolitan areas and lower in provincial areas. Fourth, labor does move from provincial areas to metropolitan areas.

Keywords:CGE, GDP, high speed railway, expressway, economic impacts

1. Introduction

Recently, computable general equilibrium (CGE) analysis has been widely used to measure transportation infrastructure development impact in quantitative form. Reason why CGE has been used is that benefit incidence and GDPcan't be measured by applying classical cost and benefit analysis, even itallows to measureaccrued benefit (timesaving benefit or consumer surplus). Also, GDP can be measured by using econometric analysis, but we can't measure benefit incidence.On the other hand, CGE analysis can represent supply-demand equilibrium condition which is related to market mechanism. Thus, CGE allow us to compute accrued benefit, benefit incidence and GDP which will be created from transport infrastructure development by using theoretically uniformed model.

However, widely-used CGE model is delivered in static form to compute equilibrium condition at some point in time. So accumulation of capital by transportation infrastructure development

can't be calculated by using this type model. That is reason why dynamic model in which the accumulation of capital is included is necessary.

Thus, in this study, Ban's model to enlarge dynamic and spatial CGE model was employed and economic effect of transportation infrastructure development to accumulate from past to present was estimated.

2.Outline of Dynamic Spatial Computable General Equilibrium Model

2.1 Dynamic of CGE model

Typically,capital stock level of static CGE model is treated as exogenous variables. Capital stock level of dynamic CGE model is treated as endogenous variables. Dynamic CGE model is expressed Ramsey Growth Model. Capital of this model is determined so as tomaximizetotal present value of utility over infinity year. The model of one sector is as follows.

$$V = \max_{C_t} \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^t u(C_t) \qquad (1)$$

$$Y_t = f(K_t, L_t) \qquad (2)$$

$$I_t = Y_t - C_t \qquad (3)$$

$$K_{t+1} = I_t + (1-\delta) K_t \qquad (4)$$

$$L_t = (1+n)^t L_0 \qquad (5)$$

V : presentvalue of utility over infinity year
$u(C_t)$: instantaneous utility of t year
C_t : household consumption of t year
ρ : rate of time preference
Y_t : income of t year
K_t : capital of t year
L_t : labor of Efficiency unit of t year
I_t : investment of t year
δ : rate of capital depreciation
n : rate of laborgrowth rate

Equation (1) expresses that the representative householdconsumes so as to maximizeutility present value.Equation (2) expresses that income(=output) is a function of capital and labor. Equation (3) expresses that investment is income net ofconsumption. Equation (4) expressesthat t+1 year capital is the t year investment plus t year capital net of depreciated. Equation (5) expresses t year labor.

Equation (6) to equation (8) is the first order conditions for equation (1) to equation (5).

$$P_t = \left(\frac{1}{1+\rho} \right)^t \frac{\partial u(C_t)}{\partial C_t} \qquad (6)$$

$$PK_t = (1-\delta) PK_{t+1} + P_t \frac{\partial f(K_t, L_t)}{\partial K_t} \qquad (7)$$

$$PK_t = P_{t+1} \qquad (8)$$

P_t : price level of consumption at t
PK_t : price levsl of capital stock at t

2.2 Dynamic Spatial of CGE model (Ban's model)

Bandevelopeddynamic spatialCGE model (Ban's model). Ban's model is based on Ramsey Growth Model and takes into account trade between regions. This model can estimate GDP in the future. Calculation of model adopts GAMS/MPSGE program.

Ban's model is composed ofproduction structure, consumption structure of household and consumption/investment structure of government. Composition of goods or production factor is expressed by CES function. Division of goods is expressed by CET function.

a) Production structure

[1st step]

Composite production factor is composed of capital and labor (Fig.1). Capital and labor is demanded to its own region and other regions. Accordingly, capital rent and wage rateis paidto its own region and other regions.Intermediate input goods is composed of domestic goods and import goods.

[2nd step]

Outputof product is composedof "composite production factor" and "intermediate input goods".

[3rd step]

Product is divided consumer goods for domestic market and consumer goods for export market.

b) Consumption structure of household

[1st step]

Composite goods is composed of domestic goods and import goods(Fig.2).

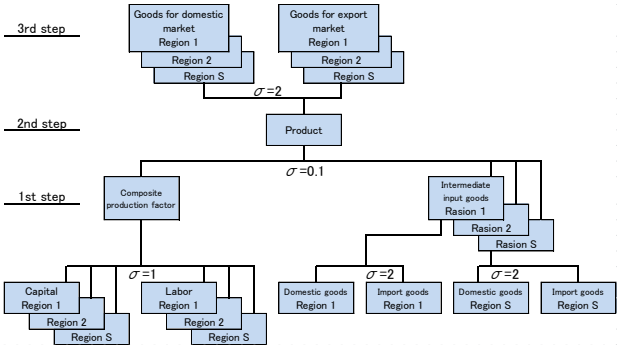

Fig. 1 Production structure

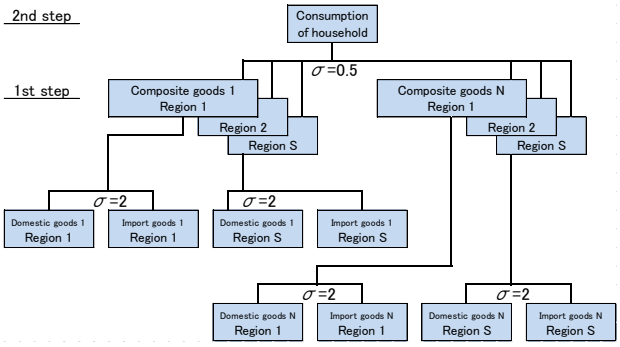

Fig. 2 Consumption structure of household

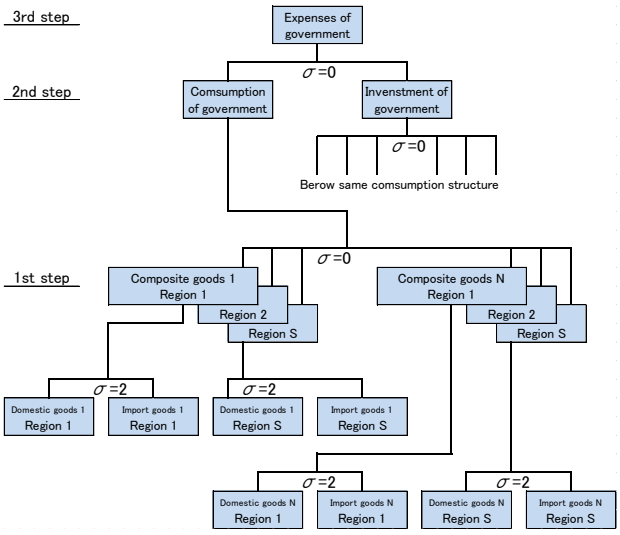

Fig. 3 consumption/investment structure of government

[2nd step]

Consumption of household is composed of composite goods in all regions.

c) consumption/investment structure of government

Consumption of government is the same structure as investment of government in 1st step and 2nd step(Fig.3).

[1st step]

Composite goods is composed of domestic goods and import goods.

[2nd step]

Consumption of government or investment of government is composed of composite goods in all regions.

[3rd step]

Expenses of government are composed of consumption of government and investment of government.

2.3Expression of the time savingin CGE model

Muto et al. express the time saving by expressway construction in CGE model in such a way that production activity level of transportation sector is decreased with respects to capital and labor. When with developingtransportation, transportation service needs capital and labor less than without developing.The study adopts this method.

3.Expression of high-speed transportation network (Shinkansen and expressway) development

The study uses theinterregional input-output tableof 2000 made byArai et al.The assumption is that a development of a high-speed transportation network uniformly reduces the traveling time by 20% between all regions.

a) Benchmarkequilibrium (with developing)

High-speed transportation network has been developed up to 2000 from the past which is the actual.

b) Imaginaryequilibrium (without developing)

This case assumes that the high speed transportation network has not been developed up to 2000 from the past.It is ofimagination. This imaginary benchmark is set a 20% decreasethe

efficiency parameters of the transport sectorfrombenchmark equilibrium.

Equation (9) and (10) the expressed that composite production factor is composed capital and laborin the transportation sector.

$$p_{tpts}{}^{f} f_{tpts} = \min_{l_{tpts,s},k_{tpts,s}} \left(\sum_{s} wl_{tpts,s} + \sum_{s} rk_{tpts,s} \right) \quad (9)$$

$$s.t. \quad f_{tpts} = \gamma_{tpts} \left(\sum_{s} \alpha_{tpts,s}{}^{l} l_{tpts,s}{}^{\frac{\sigma-1}{\sigma}} + \sum_{s} \alpha_{tpts,s}{}^{k} k_{trpt,s}{}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \quad (10)$$

$p_{tpts}{}^{f}$: Price of composite production factor in transportation sector
f_{tpts} : Amount of composite production factor in transportationsector
w :wage rate
$l_{tpts,s}$: Labor of transportation sector in s region
r : Capital rent
$k_{tpts,s}$:Capital of transportation sector in sregion
γ_{tpts} :Efficiencyparameterof transportation sector
$\alpha_{tpts,s}{}^{l}$:input sharecoefficient of labor of transportation sector
$\alpha_{tpts,s}{}^{k}$: input share coefficient of capital of transportation sector
σ : The elasticity of substitution of labor and capital

Equation (9) expresses cost minimization. Equation (10)expressesproduction function. Efficiency parameter in imaginary equilibrium is set 0.8times efficiency parameter in benchmark equilibrium as shown by equation (11).

$$\gamma_{tpts}{}^{wo} = 0.8\gamma_{tpts}{}^{w} \quad (11)$$

$\gamma_{tpts}{}^{wo}$:Efficiency parameter in imaginary equilibrium (without developing)
$\gamma_{tpts}{}^{w}$:Efficiency parameter in benchmark equilibrium (with developing)

Calculation of model uses GAMS/MPSGE software from 2000 to 2050. The parameter settings are shown in Table 1.

Table 1 The parameter settings

Ramsey Growth Model	
Rate of time preference : ρ	0.05
Rate of Labor increase : n	0.001
Rate of capital wastage : δ	0.04
The elasticity of substitution intertemporal : σ^{t}	0.5
Productive structure of company	
The elasticity of substitution capital and labor : σ	1
The elasticity of substitution domestic goods and import goods : σ	2
The elasticity of substitution composite production factor and intermediate input goods : σ	0.1
The transform elasticity of substitution Product : σ	2
Consumption structure of household	
The elasticity of substitution domestic goods and import goods : σ	2
The elasticity of substitution composite goods : σ	0.5
consumption/investment structure of government	
The elasticity of substitution domestic goods and import goods : σ	2
The elasticity of substitution composite goods : σ	0
The elasticity of substitution of consumption of government and investment of government : σ	0

Table 2 Amount and rate of GDP increase

Year	GDP without developing [Trillion yen]	GDP with developing [Trillion yen]	Amount of GDP increase [Trillion yen]	Rate of GDP increase [%]
2000	484.4	488.8	4.4	0.91
2030	497.7	503.7	6.0	1.21
2050	507.4	513.9	6.5	1.28

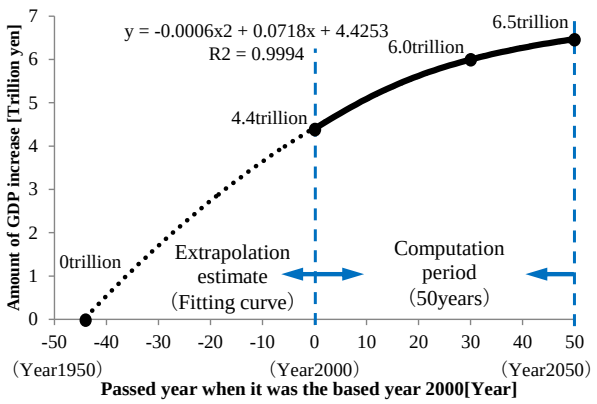

Fig. 4 Amount of GDP increase

4.Results

4.1 Amount of GDP increase

Amount of GDP increase is calculated GDP with developing minus GDP without developing. Amount of GDP is 6.0 trillion yen in 2030, 6.5 trillion yen in 2050 (Table 2, Fig. 4). Rate of GDP increase is 1.21% in 2030, 1.28% in 2050. Amount of GDP rises year after year. It is amount of GDP increase in the past is estimated to use fitting curve of amount of GDP increase from 2000 to 2050. Year of amount of GDP increase to equal 0 is estimated in 1956. This year is beginning increase GDP. So it is near the opening time of the high-speed transportation network.The amount of GDP increase in the past is expressed dotted lineon Fig.4. Amount of GDP increase in the past is 3.6 trillion yen in 1990, 2.7 trillion yen in 1980, 1.7 trillion yen in 1970 (Table 3).

4.1 Amount of GRP(Gross Regional Products) increase

O f amount of GRP increasethe largest is the Kanto, next Kinki and Chubu. It is small in Hokkaido, Tohoku and Shikoku (Fig. 5).Metropolitan areasarelarger than provincial areas'amount of GRP increase.

Rate of GRP increase is larger in Kanto and Kinki, smaller Hokkaido, Tohoku and Shikoku (Fig. 6).This study development of high-speed transportation network level is the same across the country. But rate of GRP increase appearshigh in metropolitan areas.

4.2Change of the real wage rate

Real wage rate of 2030 is as Fig.7. Real wage rate increaseslargerin Kanto, Kinki and Chubu. It decreases in Hokkaido.

4.3Change of the labor input by regions

Development of high-speed transportation network changes labor input amount change by regions. Household is assumed not to move residencebetween regions in the model.So labor input amount change by regions expresses that household move to offer labor between regions.

Labor input amount change by regions of 2030 is as Fig.8. It increases in Kanto, be flat in Kinki, decreases in other regions. It expresses to move labor from other regions to Kanto by development.

Table 3 Amountof GDP increase in the past

Year	Amount of GDP increase in the past [Trillion yen]
1960	0.5
1970	1.7
1980	2.7
1990	3.6

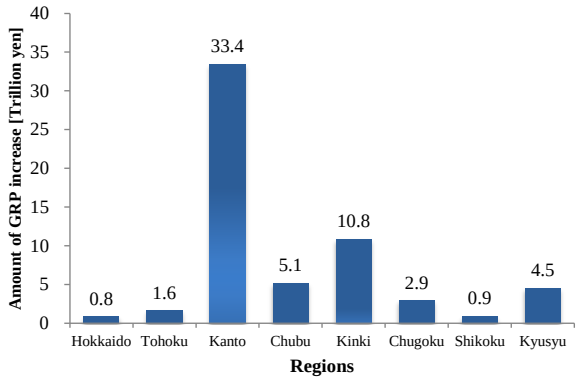

Fig. 5 Amount of GRP increase

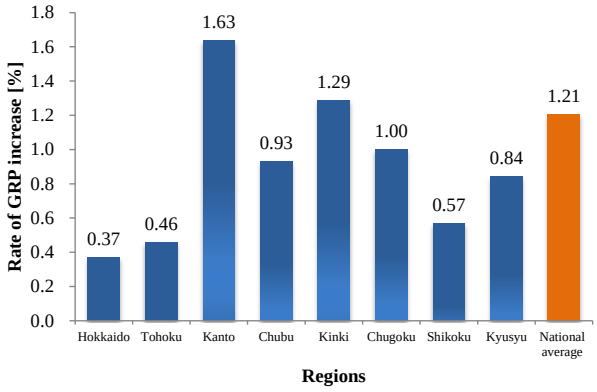

Fig. 6 Rate of GRP increase

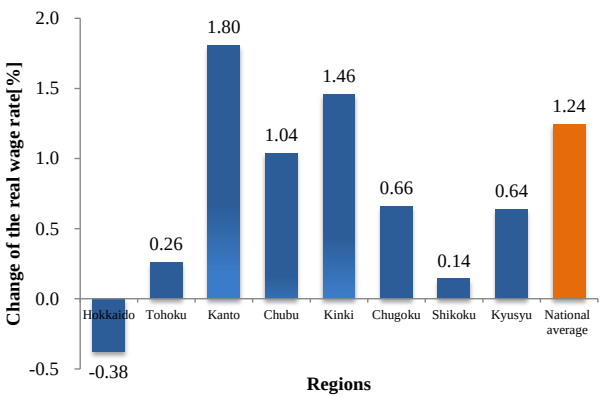

Fig. 7 Change of the real wage rate

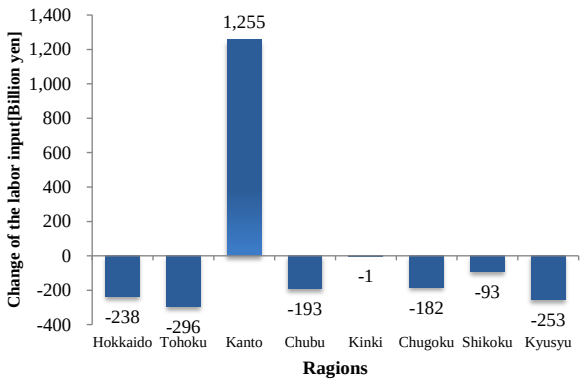

Fig. 8 Change of the labor input by regions

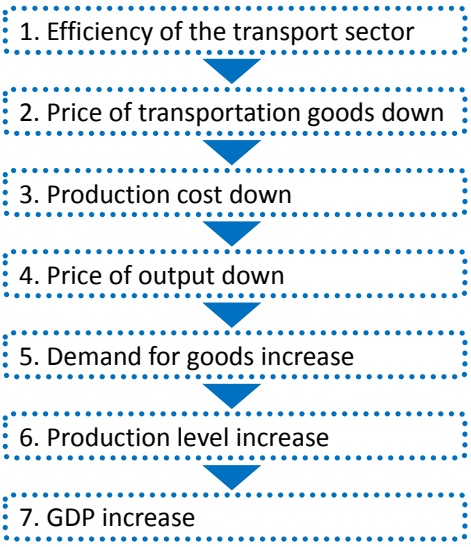

Fig. 9 Process to increase the GDP

4. Discussion

Image to increase the GDP is as Fig.9. 1st, Efficiency of the transport sector reducesinput level of the labor and capital. 2nd, the reduction in labor and capital inputs leads to price of transportation goods (service) down. 3rd, production sectors can use inexpensive transportation goods (service). So production cost is down. 4th, by decrease in production cost, price of that output is down. 5th, the decreasing in price of goods leads to increase in demand of household final goods and company intermediate input goods. 6th, production levelis increase. 7th, byincreasing production volume, GDP increases.GDP increases from the efficiency of the transport section by such a process.

5. Conclusion

The study employs Ban's model and incorporates traveltime saving by developinghigh-speed transportation network into the model. And the study estimates amount of GDP increase by the following ways.

a) Assuming that travel time to reduce 20% by developing high-speed transportation network, Amount of GDP increase is estimated 6.0 trillion yen in 2030.
b) Using fitting curve of amount of GDP increase, amount of GDPin the past is estimated.
c) Thesame developing levelacross the country in timesaving rate leads tohigh rate of GRP increase in metropolitan areas, low in provincial areas.
d) Real wage rate increases large in Kanto, decreases in Hokkaido.
e) Labor moves from other regions to Kanto by development.

Development of high-speed transportation network level is set as the same across the country. Rate of GRP increase appearshigh in metropolitan areas and low in provincial areas. In fact, developingconcentrates in metropolitan areas, and be scantyprovincial areas. Therefore Rate of GRP increase in metropolitan areasislarger than GDP, in provincial areas smaller than GDP. This suggests overconcentration of metropolitan areas and decline of provincial areas.

As the future research issue, the different degree of decreasing travel time be set for different kinds of transportation.

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