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Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

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World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Estimating Spatial Economic Impacts of Transport Infrastructure : Progress and Practical Availability of SCGE model Analysis

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Abstract

A SCGE analysis in the transportation planning was remarkably developed in the past for 20 years. The form of application could be divided into two groups; "the trial which measures the total benefit more correctly." and "the trial which obtains the regional economic effects". There were many SCGE analyses, but enough practical bases didn't exist yet about the reliability of the SCGE in japan. Therefore to inspect reproducibility of the effect by the policy implementation, we established a target as an effect of expressway, and we analyzed the trend of a correlation between the simulation and the actual data. First, we estimated the change rate of the production by reduction in travel time between regions using SCGE. Next, we calculated an actual change of seasonally adjusted industrial production index by prefecture, and we compared a simulation by SCGE and the actual changes. As a result, by the whole manufacturing, the simulation results by the SCGE and actual changes had a positive correlation, so we found out that estimation of the SCGE was highly reliable. When we aimed at a result according to the category of the manufacturing, the industry that to be easily capable of relocation had high reliability of prediction. But the industry that was difficult to relocate, or that had an immobilized business relation, the accuracy of prediction isn't so high. Based on the prediction of the SCGE, it had enough value to draft a regional future plan while considering an influence of the transport in advance.

Keywords: SCGE, RAEM-Light, Conduct of Ex-post Evaluation, expressway network, Correlation actual data and simulation data

1. Background and Objective

The validity of the infrastructure building is judged by a quantitative evaluation method, which is represented by a cost-benefit-analysis (CBA). In japan, Road Project Evaluations are compared the Three Benefits (benefits from travel

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time saving, operating cost saving and accident cost saving) with project cost for road development, maintenance and operation cost. When the Three Benefits are bigger than road project costs, the road project is corrected. However, there is a criticism that isn't possible to develop a really necessary road by CBA, or that isn't possible to measure a regional economic effect by only three benefits. When understanding that a result of the CBA is a social efficiency, it can be understood that two criticism opinions above-mentioned are major misunderstanding. Nevertheless, we aren't supposed to decide about propriety of an infrastructure building only about the social efficiency of CBA. As

What is the way of a judgement of an infrastructure building to choose an ideal society as well as the social efficiency? Or does the analytical method to support those argument exist? To answer these problems, a SCGE model was contrived and much research accumulation was done about the practical availability. As a result, reliable results are being obtained.

In this paper, we showed the feature of SCGE model analysis, and the predictability of the reginal economic effect analysis. Then we performed the practical availability analysis using SCGE model, in addition, we considered drafting method of a desirable infrastructure development project using a SCGE model.

2. Types and Characteristics of SCGE models

Economic effects of the infrastructure project had a long history. The origin of this study goes back to Jules Dupuit in 19th century, this research subject is important to the proceedings of infrastructure planning and the economics. A SCGE analysis was an abbreviation of Spatial Computable General Equilibrium analysis, and to measure the economic effect of the infrastructure, a traditional CGE analysis was expanded spatially. Then, a CGE analysis is the method to do policy evaluation quantitatively, which applied a mechanism as the consumer behavior theory, the producer behavior theory and the market equilibrium assumed by micro-economics to real economy. A CGE analysis was applied to a policy of customs duties by Shoven and Wally (1984). The analysis method was able to indicate influence of a policy as a change in an economic indicator variously. And the study which analyzed the expanse with spatial infrastructure effects were performed using a SCGE model at all over the world, for the last twenty years.

A CGE analysis was a general term for a practical analysis based on a general equilibrium theory in micro-economics. A market price was decided by solving equations of goods markets and production factor markets. The CGE analysis was capable of application to real society relatively, and there were used for various policy analyses. But when measuring an effect of infrastructure, those much was often inconvenient because we assumed that a household and a private firm were homogeneous as the precondition. Therefore household and private firm were defined according to the area. And general terminology of the model who expressed a mutual movement of goods as interregional trade was called a SCGE analysis. The try which measures the economic impacts of the infrastructure projects using a SCGE model had an origin in Roson (1995) and Brocker (1998). After that there have been a lot of studies. Anyway, there are two reasons that a SCGE was applied to measure the economic effects of the infrastructure projects.

The first one, when a perfect competitive market is supposed, it becomes possible to measure benefit of a transport project as a change in consumer's surplus. However, in the case of an imperfect competition market, it was indicated that a bias occurs to measurement of benefit of a transport project by Brocker (2011). It was the purpose of trying to measure correct benefit of a transport project by utilizing the SCGE model that considered an imperfect competition market. The various factors such as the unemployment and the uncertainty are related to imperfect competition. In recent years, the studies that increases the productivity by economy of agglomeration at the city or the region is performed extensively. For constructing the theoretical models, such studies were used results of New Economic Geography. There were accumulation of a lot of research and development at Europe in particular. The example by which CGEurope, RAEM was applied to a real policy analysis. However, these models have any problems as quantitative evaluation so that Graham (2011) pointed out.

The second, when evaluating the validity of the infrastructure investment, could that be judged by only total benefit? A judgement of the validity of the infrastructure project using a CBA is evaluated only the social efficiency, but argument about the social equality was not considered. And yet, in case of the large-scale infrastructure project which influences the country structure in the long run, the benefit is different depending on region. To aim the development balance of a country, the argument that it's better to consider regional maldistribution of benefit exists persistently.

In japan, to answer this problem, proceedings of infrastructure planning researchers have measured spatially benefit and spatially economic effect of an infrastructure project using a SCGE model. Such approaches often use SCGE model that assumed a prefect competition market basically, and the total benefit as the output of this model was known to almost accord with consumer's surplus measured with a CBA manual of a road project which is applied in japan. Because induction demand is calculated in the SCGE model, slightly big benefit may be measured than the consumer's surplus (or benefits from travel time saving). However, the SCGE model can estimate how much effect there is for which economic agents, for where region. The practical availability of the quantitative forecast using a SCGE model comes to be known little by little. In other words it was thought that I became able to argue how I should examine the infrastructure investment project that considered social equity or spatial equity by using the SCGE model analysis. Interest to a spatial distribution of infrastructure effect was not only Japan. The above-mentioned CGEurope model was used aggressively by an IASON project of European Commission, and this model was utilized for a transport planning in European Union. Furthermore, in late years a regional economy effect comes to be discussed as an economic ripple effects of the infrastructure project in Japan. (So called Stock Effects: long-term effects that grow economic for a long period through streamlined intercommunication and logistics, stimulated private investment, boosted tourism, and increased population and employment through infrastructure development.

When using a SCGE model analysis, the economic ripple effects by infrastructure projects was possible on the theory to know the spatial distribution of effects beforehand. If it's possible to obtain these effect beforehand, we become able to argue to utilize the effect of the infrastructure to the full. But enough practical bases didn't exist yet about the reliability of the estimation result of these SCGE analyses in japan. There was side which became obstruction of practical use of a SCGE analysis. In this study, for the view point of ex-post evaluation, we measured the effect of an expressway using SCGE model in japan for about ten years (the decade from 2005 to 2015). We analyzed how much an estimation of the SCGE model could reproduce an actual industrial active change according to region by industry. It's ex-post analysis, but attention is necessary for being not strict inspection because observation data doesn't exist when being expressway-less (counterfactual condition).

3. SCGE Models for Practical Use

As a SCGE model for practical use, to show the situation of the expressway network appropriately, the SCGE model was necessary to establish a small zoning. We thought the logit model used by transportation engineering should be applied more than the CES (Constant Elasticity of Substitution) function which is usually used by a CGE analysis to express small area trade of goods. As reasons for, when there is no inter-regional trade by the current state, the CES function is excluded from possibility that new trade will start .And it's difficult that the CES function establishes stable elasticity. Therefore the SCGE model of this study was different from a usual CGE model, a logit model was applied to the function of the inter-regional trade. And parameters included in its function were presumed statistically using data of freight transportation survey in japan. Model details are indicated in an appendix.

In a practical analysis, we set 199 areas except for the island part among the range of local living areas where Japan was divided into 207 as regional partition. And classification of industries established 16 industries indicated in table 1.

Table 1. Sectors of the SCGE model.

1. Agriculture, forestry and fisheries
2. Mining and quarrying of stone and gravel
3. Manufacture of beverages, tobacco and feed
4. Manufacture of textile mill products
5. Manufacture of pulp, paper and paper worked products
6. Manufacture of chemical and allied products
7. Manufacture of petroleum and coal products
8. Manufacture of ceramic, stone and clay products
9. Manufacture of iron and steel, non-ferrous metals and fabricated metal products
10. Manufacture of general machinery
11. Manufacture of electric machinery, electronic parts, devices and electronic circuits
12. Manufacture of transportation equipment
13. Miscellaneous manufacturing industries
14. Construction
15. Electricity, gas, heat supply and water
16. Services

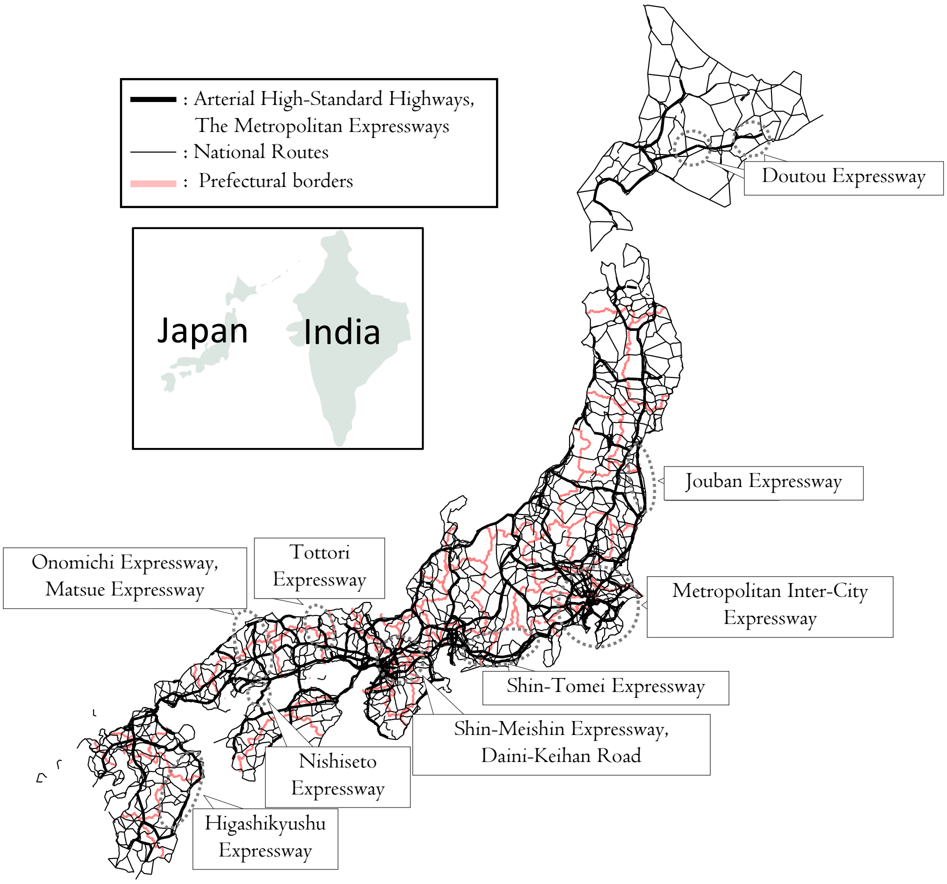

Fig. 1. Road Network in Japan (Arterial High-standard Highway and National Routes).

The basic economic information comes from report on prefectural accounts produced (2005) by the Cabinet Office. Moreover, we made social economy data in the small region as a benchmark using prefectural input-output table (2005), national population census (2005) and industrial statistics (2005) et al. Data about inter-regional trade used freight transportation survey in 2005. The transit time was estimated from a traffic assignment using a network including a small link.

A target expressway network of an analysis had been constructed during the period from 2005 to 2015. The total number of the link is more than 400 including a small link. A main one was surrounded with the gray dotted circle indicated in figure 1. The transit time (before-after) was estimated by traffic assignment in the condition of these networks. And that, ex post fact economic activity, we input a travel time in a SCGE model and estimated an economic condition. To know reproducibility of a SCGE model, we compared a production change in real economy (the actual data) with predicted value of a SCGE model (simulation data). So we compared a calculation result of the SCGE model (simulation data) and a change rate of seasonally adjusted industrial production index from METI by prefecture (actual data) at the same period. Basically, we should compare a period of the change rate of the industrial production index and an analysis year of the road network we analyzed by a SCGE model. But we used the change rate of industrial production index from 2015 to 2010 as actual data, because the drop in industrial production index was particularly sharp in the event of the worldwide recession (around 2008).

Figure 2 shows the change rate of production (all manufacturing sector) calculated by SCGE model as compared with actual industrial production index. A simulation data by the SCGE model in a vertical direction and an actual data (change rate of industry production index) in a lateral direction, the change rate of production by prefecture was plotted to create scatter diagram. In model characteristics, we obtained all results of the SCGE model were more than 1. On the other hand, the actual change rate of industrial production index were sometimes obtained less than 1 because it was affected by economic slump. If simulation data were equal to actual data, there were distributed in oblique line of 45 degrees. But a policy variable of the SCGE model was just an expressway in prediction period, so we couldn't get such result.

The purpose of this study was to estimate the ripple effects to the regional economic by expressway. An expressway made them reduce travel time between regions, these had an influence on firm activity through a supply chain and household's consumption. So we estimated these. In order to estimate the economic ripple effects of expressway with higher reliability, it was desirable that simulation results by the SCGE model and actual change rate of industrial production index have a positive correlation. Considering this, overall trends indicated that a positive correlation in figure 2, the SCGE model could mostly estimate the spatial change of production activities.

Next, we show a simulation results each by industry as a detailed analysis (figure 3 to 5). In a similar way, if these figure have a positive correlation, these SCGE analysis results mean highly reliable. "1. Manufacture of electric machinery, electronic parts, devices and electronic circuits", "2. Manufacture of general machinery", "3. Manufacture of transportation equipment" and "4. Manufacture of food, beverages, tobacco and feed" shows strong correlation (figure 3 and 4). On the other hand, "5. Manufacture of iron and steel, non-ferrous metals and fabricated metal products" and "6. Manufacture of pulp, paper and paper worked products" shows little correlation (figure 5). These industries of the former was smoothly relocation of factory. In terms of the latter industry, "5. Manufacture of iron and steel, non-ferrous metals and fabricated metal products" is large scale plant that needs time in move. And "6. Manufacture of pulp, paper and paper worked products" has high robustness of the business relations, it is difficult to be affected by development of transportation infrastructure. In other words, the industry that to be easily capable of relocation had high reliability of prediction, but the industry that was difficult to move factory, or industry that was fixed business relation, the accuracy of prediction of SCGE simulation was not so high. Though, a prediction result of the SCGE analysis is expressing the long-run equilibrium position. In the long-run, about the industry which judged that these had low predictability, there is a potential possibility which indicates a change like an estimation result of the SCGE model. Of course, we need to accumulate a long-term practical analysis to declare these results. When using a SCGE analysis for a policy judgement, it goes without saying that it's necessary to recognize the feature of such simulation results sufficiently.

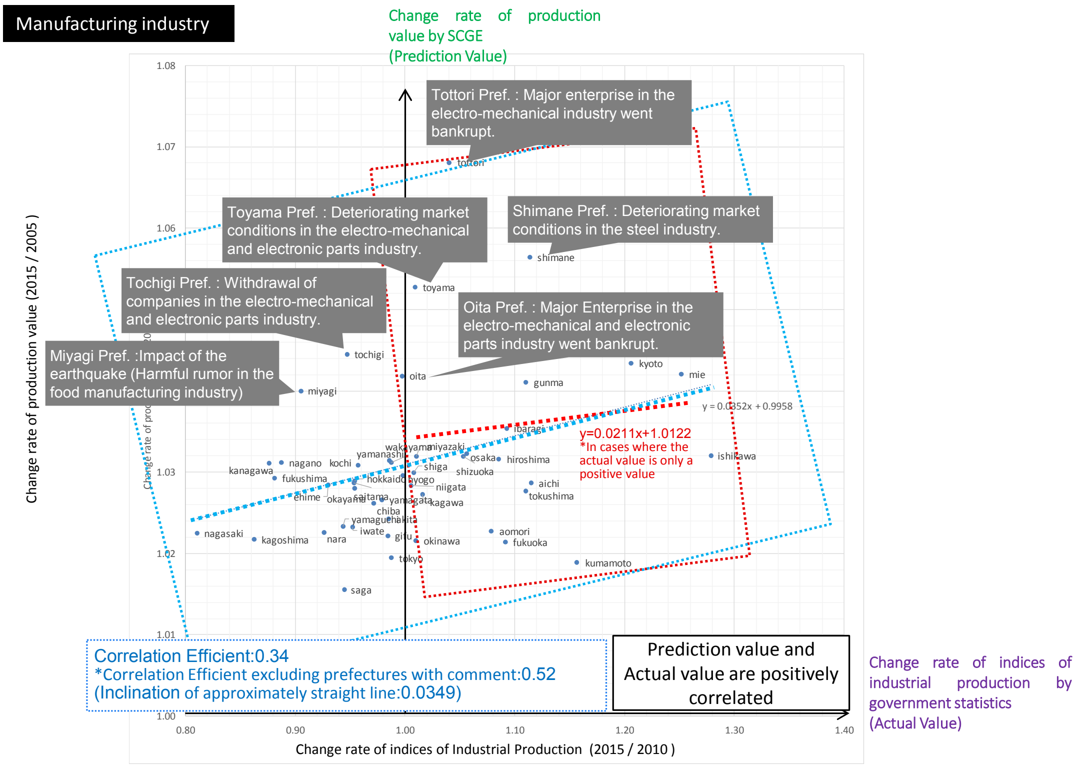

Fig. 2. Change Rate of Production as all Manufacturing Sectors (simulation data by the SCGE model and actual data)

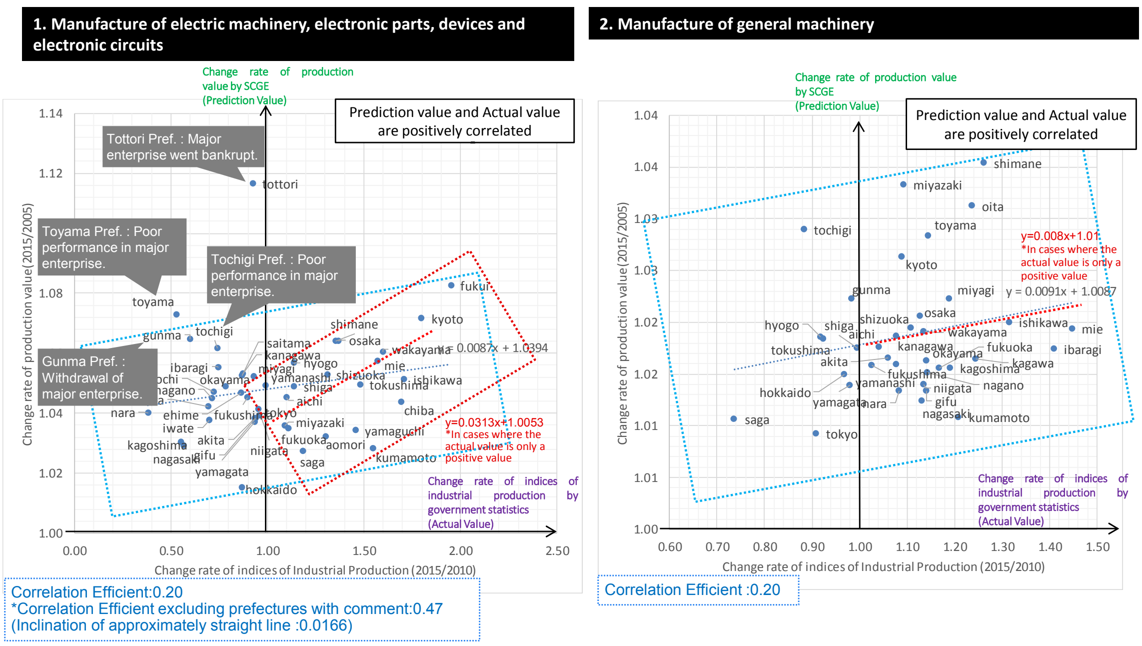

Fig. 3. Change Rate of Production (simulation data by the SCGE model and actual data)
(1) Manufacture of electric machinery, electronic parts, devices and electronic circuits;
(2) Manufacture of general machinery.

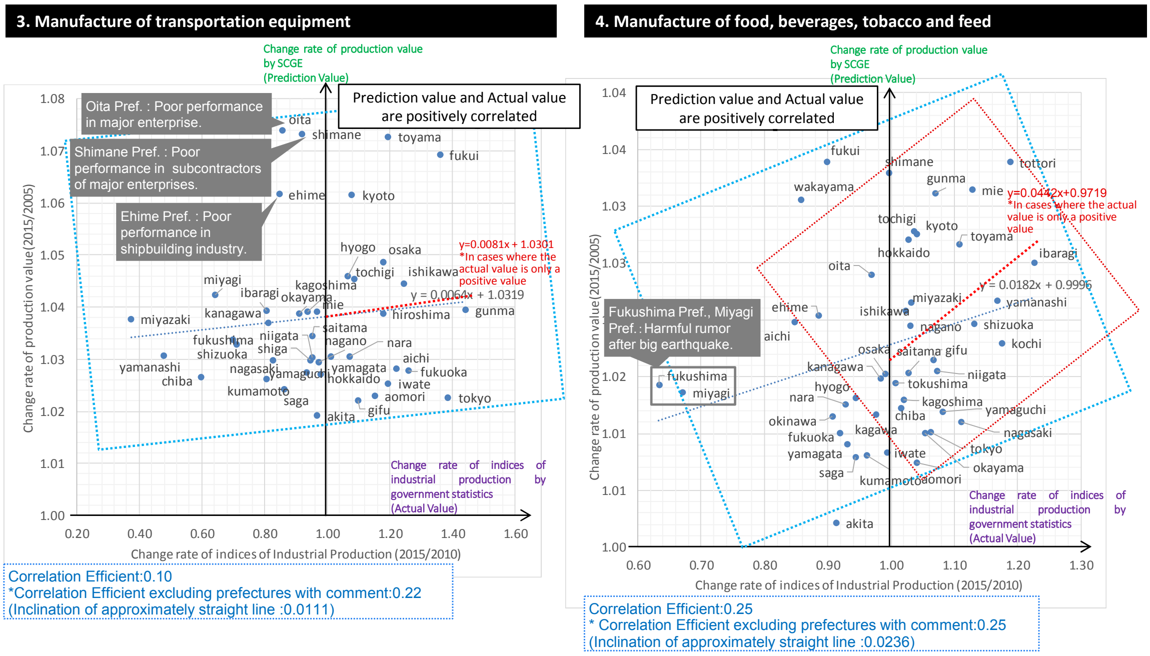

Fig. 4. Change Rate of Production (simulation data by the SCGE model and actual data)
(3) Manufacture of transportation equipment;
(4) Manufacture of food, beverages, tobacco and feed.

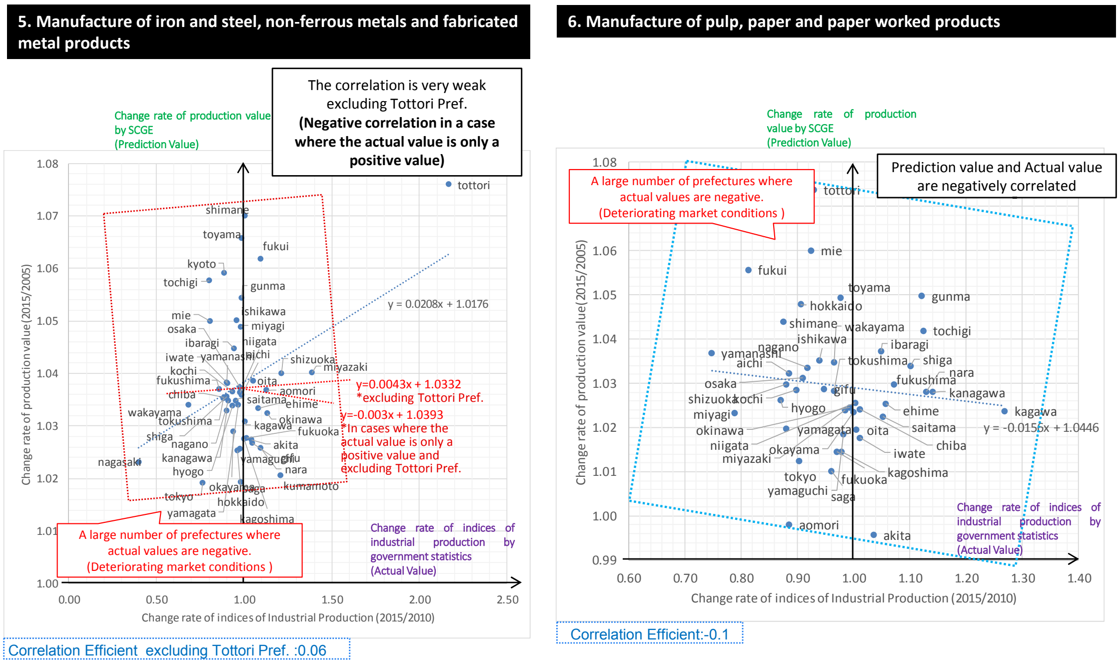

Fig. 5. Change Rate of Production (simulation data by the SCGE model and actual data)
(5) Manufacture of iron and steel, non-ferrous metals and fabricated metal products;
(6) Manufacture of pulp, paper and paper worked products.

4. Conclusions and Political Implications

In the past 20 years, an experimental trial made progress that is used for the evaluation of the transport infrastructure policy using SCGE model, and the application case is often reported by the researcher in the world. The form of application can be divided into two groups; “the trial which measures the total benefit amount of the transport infrastructure more correctly.” and “the trial which grasps the regional economic effects of using transport infrastructure”. In this study, we focus on the latter, we estimated spatial ripple effects (so-called the regional development effects) of road projects evaluation using the SCGE analysis. Then it was possible to get several knowledge through comparison with the actual measurement. When building the SCGE model by the local living areas, it became able to express in-depth trade relations of goods and services, and it could estimate change of industry production by region and by industry. Therefore it was possible to obtain its predictability is high relatively. But, for short-run, if the industries that was difficult to move a manufacturing plant and that had fixed trade relations, it could be obtained that was hard to predict.

A result of the SCGE analysis became possible to obtain the effects of transport infrastructure by industry and by region beforehand. When predictability was high, that has the enough value as the basic information to draft the planning which considered influence from the stage which makes a transport infrastructure plan. To estimate the ripple effects of roads by SCGE analysis, it’s possible to obtain how to change the industrial structure in region concerned potential beforehand. For example these mean the following; we can consider the agricultural equipment layout planning, business invitation policy and the attraction of tourists, and various departments in the administration becomes possible to argue a future plan by an identical frame. A final target of an infrastructure building is continuous improvement of the social economy carried on based on infrastructure. Therefore an infrastructure plan using a SCGE analysis is very important. A recent use of SCGE analysis; it was possible to calculate the economic damage that is at the time of accidents which considered influence of a supply chain (inter-regional trade). For example it achieved reproduction of the spatial economic damages and the production restoration caused by the Great East Japan Earthquake, using Dynamic SCGE model by Yamasaki (2018). Thus when it was possible to estimate spatial economic damage of disasters beforehand, they became able to obtain economical value of the network development which ensure redundancy of network. If so it became able to consider the value of the disaster prevention policy from a variety of perspectives. To indicate the value of the infrastructure, or to support various policies through infrastructure, accumulation of a further study is needed for accuracy improvement of a SCGE analysis.

Appendix A. Description of SCGE Model (RAEM-Light Model)

A.1. Model Assumptions

This SCGE model structure is illustrated in Fig. 6. The model in this paper has the following major assumptions;

- Multi-regional and multi-sectoral model for Japan.
- Private firms produce goods from input factors (labor and capital) and intermediate inputs.
- Transportation costs are described ice-berg-type, which transport of the tradable goods consumes a part of the goods itself.
- Labor market is closed in the region. Households own capital stock as mobile factor whose rent is common in all regions in the economy.

The following indices are used in the model:

Region : $I \in \{1,2 \cdots, i, j, \cdots, I\}$

Goods : $M \in \{1,2,\cdots,m,n\cdots,M\}$.

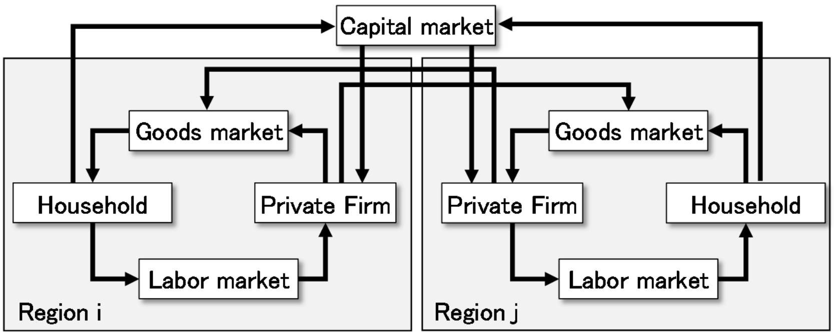

Fig. 6. Structure of SCGE Model.

A.2. Household Behavior

Representative households are each region, and consume composite goods in their own region and other regions. Utility function of a household is assumed to be Cobb - Douglas type, which is shown in Fig. 7.

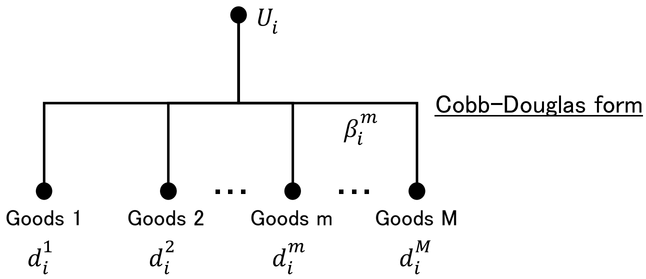

Fig. 7. Structure of Utility Function.

Regional households maximize the log linear utility function by choosing the level of consumption demand under the income constraint.

Household gains income from labor supply, capital stock which is owned evenly over all regions, and fixed regional income transfer.

We propose the following utility function and budget constraint:

$$\max.\ U_i(d_i^1, d_i^2, \cdots, d_i^M) = \sum_{m\in M} \beta_i^m \ln d_i^m$$
$$s.t.\ \ \bar{l}w_i + r\frac{\bar{K}}{T} + \frac{IT_i}{N_i} = \sum_{m\in M} p_i^m\, d_i^m \tag{1}$$

where U_i is utility in region i, d_i^m is consumption level per person for good m in region i, p_i^m is c.i.f. (cost, insurance, and freight) price of good m in region i, β^m is a parameter for good m ($\sum_{m\in M} \beta_i^m = 1$) , w_i is wage rate in region i, r is capital rent, $\bar{K}$ is national endowment of capital, $\bar{l}_i$ is individual endowment of labor ($\bar{l}_i = \bar{l}_i / N_i$)

in region i, IT_i is fixed regional income transfer, N_i is population in region i, and T is total population ($T = \sum_{i \in I} N_i$) .

The following demand function is derived from the first-order conditions.

$$d_i^m = \beta_i^m \frac{1}{p_i^m} \left(\bar{l}_i w_i + r \frac{\bar{K}}{T} + \frac{IT_i}{N_i} \right) \tag{2}$$

A.3. Private Firm Behavior

Private firm in region i produces a good m, which is shown in Fig.8.

The production technology is two level nested Leontief and Cobb–Douglas function. The upper Leontief technology describes the composition of intermediate inputs and value added.

$$Y_j^m = min. \left\{ \frac{v_i^m}{a_i^{0m}}, \frac{x_i^{lm}}{a_i^{lm}}, \cdots, \frac{x_i^{nm}}{a_i^{nm}}, \cdots, \frac{x_i^{Nm}}{a_i^{Nm}} \right\} \tag{3}$$

where Y_i^m is products for good m in region i, v_i^m is value added for good m in region i, $x_i^{n\,m}$ is intermediate inputs among n and m in region i, $a_i^{n\,m}$ is an input-output coefficient among n and m in region i, and $a_i^{0\,m}$ is the value-added ratio for good m in region i.

Then, the value added function is specified according to a Cobb-Douglas form:

$$v_i^m = A_i^m \, (l_i^m)^{a_i^m} \, (k_i^m)^{1-a_i^m} \tag{4}$$

where l_i^m is labor input for good m in region i, k_i^m is capital input for good m in region i, α_i^m is a share parameter for good m in region i, and A_i^m is an efficiency parameter for good m in region i.

Production sectors maximize profit under given production technologies.

$$max. \ v\alpha_i^m - w_i l_i^m + r k_i^m$$

$$s.t. \ y_i^m = A_i^m \, (l_i^m)^{a_i^m} \, (k_i^m)^{1-a_i^m} \tag{5}$$

where $v\alpha_j^m$ is value added for good m in region i ($= \alpha_{0i}^m q_i^m Y_i^m$) and q_i^m is f.o.b. (free on board) price for good m in region i.

From profit maximization, the derived demands for labor, capital, and the intermediate input are:

$$l_i^m = \frac{\alpha_i^m}{w_i} \, \alpha_i^{0m} \, q_i^m \, Y_i^m \tag{6}$$

$$k_i^m = \frac{1-\alpha_i^m}{r} \alpha_i^{0m} q_i^m Y_i^m \tag{7}$$

$$\chi_i^{nm} = \alpha_i^{nm} Y_i^m \tag{8}$$

Each production sector is a price taker. The private firm's production function technology has the property of constant returns to scale. Therefore the price of commodity produced by good m equals to the production cost for a unit output or the average cost,

$$q_i^m = \frac{\alpha_i^{0m} w_i^{\alpha_i^m} r^{1-\alpha_i^m}}{A_i^m (\alpha_i^m)^{\alpha_i^m} (1-\alpha_i^m)^{1-\alpha_i^m}} + \sum_{n\in M} \alpha_i^{nm} p_i^n \tag{9}$$

where q_i^m is f.o.b. (free on board) price for good m in region i and p_i^n is c.i.f. (cost, insurance, and freight) price for good m in region i.

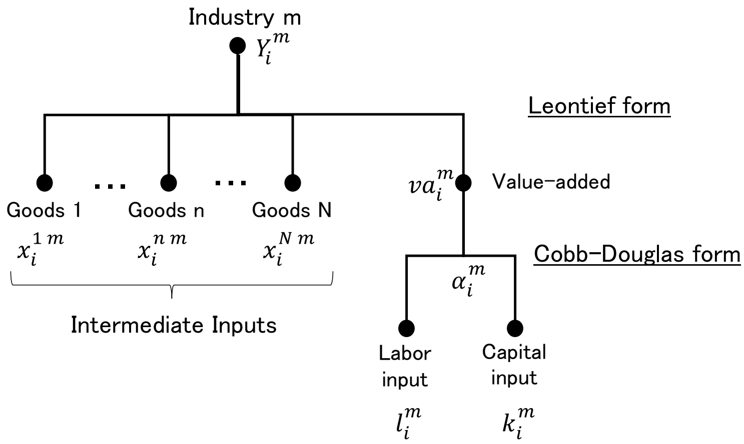

Fig. 8. Structure of Production Function.

A.4. Interregional Trade

We assume that the consumer demands minimum c.i.f. price goods with imperfect information. If a consumer who lives in region i chooses goods m made in region j as inputs, an error term is independently and identically Gumbel distributed. We then obtain a simple share type trade function as a Logit type choice function.

In addition, not only consumer but also private firms are used the logit type model of choice.

$$s_{ij}^m = \frac{y_j^m \; exp \left[-\lambda_j^m q_j^m \left(1+\varphi^m t_{i\,j}\right)\right]}{\sum_{k\in J} y_k^m \; exp \left[-\lambda_k^m q_k^m \left(1+\varphi^m t_{i\,k}\right)\right]} \tag{10}$$

where y_j^m is value added for good m in region j, q_i^m is f.o.b. (free on board) price for good m in region j, s_{ij}^m is interregional trade choice probability for good m among region i and j, t_{ij} is transport markup rate among region i and j, λ_j^m is a parameter of logit model for good m in region j and φ^m is a time value parameter for good m.

A.5. Market Equilibrium Condition

Each private firm produces commodities and services as much as consumers demand, and supply - demand balance for private firm's product always holds for each sector. The system of equations are,

$$X_i^m = \sum_{n \in N} \chi_i^{mn} + N_i \; d_i^m \tag{11}$$

where X_i^m is sum of demand for goods m produced in region i, $x_i^{n\,m}$ is intermediate inputs among n and m in region i, N_i is population in region i and d_i^m is consumption level per person for good m in region i.

The production technology in this model has a property of constraint return to scale. Therefore a private firm's supply equals demand. Input-Output balance of goods and demand-supply equilibrium of goods are represented by eq.12.

$$Y_i^m = \sum_{j \in J} \left(1 + \varphi^m t_{ij}\right) s_{ij}^m \; X_j^m \tag{12}$$

The c.i.f. prices are settled at the weighted average of f.o.b. prices.

$$p_i^m = \sum_{i \epsilon I} s_{ij}^m \; q_j^m \left(1 + \varphi^m \; t_{ij}\right) \tag{13}$$

The market clearing condition are as follows.
Labor market:

$$\sum_{m \in M} l_i^m = \bar{L}_i \tag{14}$$

Capital market:

$$\sum_{m \in M} k_i^m = \bar{K}_i \tag{15}$$

We showed only the important formula in this section. In practice we only have to solve simultaneous equations with respect to prices of input factors (wage rate and capital rent). For the detail of parameters setting method and the computational algorithm, see Ueda (2010) and Koike et al. (2009).

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