SPATIAL BENEFIT INCIDENCE OF ECONOMIC EFFECTS OF ROAD NETWORK INVESTMENTS

CASE STUDIES UNDER THE USUAL AND DISASTER SCENARIOS

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ABSTRACT

Road networks can be considered to be local public goods. Hence, their spatial benefit incidence should be equal to their cost burden in each region. An analysis of benefit incidence should include not only the usual scenario but also a disaster scenario, because the redundancy effect is expected to reduce the amount of economic damage incurred during a disaster. Our research group has developed a Spatial Computable General Equilibrium model (RAEM-Light), which can be applied to small spatial regions. The model has some innovative features and can explicitly describe the spatial behavior of producers and consumers. It is endogenously determined by using econometric production and consumption functions. The model does not depend on input–output data and is therefore well suited for analyzing detailed areas where official input–output data are not available. This paper focuses on a road network in the Chugoku area in Japan. The RAEM-Light model was applied to analyze the development and maintenance stages of road networks under a usual and a disaster scenario for an existing road network and a proposed new network. The benefit incidence under the usual scenario showed the spatial incidence of the economic effects of road investment, including spill-over effects. The benefit incidence under the disaster scenario showed the spatial incidence of economic effects as a reduction in economic damage. These two spatial benefit incidences differed with the measurement viewpoint even within the same stage, indicating that the regional cost burden will also differ, depending on the investment aim. Clarification of the spatial benefit incidence of road investments will contribute to a more efficient and reasonable allocation of the cost burden for each region in Japan's increasingly decentralized society. Furthermore, the information should also prove useful to regional decision-makers in reaching consensus.

KEYWORDS

Road Network Investment, Spatial Benefit Incidence, Spatial Computable General Equilibrium

1. BACKGROUND AND OBJECTIVES

1.1 Road Networks as Local Public Goods

In general, public goods are classified as national public goods if the benefits accrue to everyone in the nation and local public goods if the benefits are limited to those living in a particular locality or region. The entire road network is generally recognized as a national public good. In practical studies of road networks, however, the national road network is usually considered to be subdivided into sections. In this case, the subdivided road networks are recognized as local public goods. When considering road networks as local public goods, the spill-over effect should be considered, because one road network influences not only its own locality but also other localities through spatial economic relationships.

In economic theory, an efficient supply for local public goods requires that the marginal cost of the goods be equal to the marginal benefit of the goods (including spill-over effects). To satisfy this efficiency condition for local public goods, spill-over effects should be internalized by forming economic units of a size sufficient for most of the consequences of any action to occur within the economic unit (e.g., a local government). In the real world, however, there are several types of local public goods that have different benefit incidence scales (e.g., roads, libraries, and parks) in the same local government unit, and it is therefore impossible to satisfy the efficiency condition by resizing the scale of local governments. This indicates that it is not necessary to optimize the unit scale, but it is necessary to optimize the allocation of the costs of local public goods among local governments.

1.2 Road Network Costs in Japan

After World War II, Japan developed many road networks that were controlled by the central government, and these networks obviously contributed to rapid economic expansion as the population increased. But Japan's population is aging, and Japan is faced with becoming a more decentralized society. When investments in public goods are considered in this period of systematic change, it is necessary to clarify the benefits and cost burdens for local government in order to reach consensus about investment in local public goods. Currently, the central government pays about 70% of the total cost of developing new roads and the relevant local government pays about 30%. The central government then pays 55% of total road maintenance costs, while the relevant local government pays 45%.

As Japan becomes more decentralized, these levels of cost sharing will no longer be appropriate. From a risk-management viewpoint, the potential for damage from disasters (e.g., earthquakes) exists. The optimum allocation of the maintenance cost burden must therefore consider spatial externality effects if we are to implement an effective planning strategy that protects local governments from having to bear inordinate cost burdens. This optimization is very important, considering the recent budget constraints of local governments.

1.3 Economic Effects of Road Network Investments

The economic effects of road network investments can be categorized in two stages, the development stage and the management stage. For each stage, we study two scenarios, the usual scenario and the disaster scenario (Table 1). Although each type of road investment has economic effects, they have different characteristics. Spatial economic effects, such as the spill-over effect, are different, particularly for the development stage.

Table 1 - Economic Effects of Road Investments under the Usual and Disaster Scenarios

Stage	Case	Effects
Development	Usual	The effect of saving origin–destination (OD) travel time by developing additional roads. In general, this factor is measured in evaluations of road network development.
	Disaster	If several road networks are developed in the same OD sector, the redundancy effect reduces disaster damage.
Maintenance	Usual	Investment in routine maintenance allows expressway service (high-speed travel) to continue by reducing routine damage, such as pavement deterioration.
	Disaster	Investment in maintenance, such as improving earthquake resistance, increases sustainable and secure use by reducing disaster damages.

1.4 Methodology for Analyzing the Spatial Incidence of Economic Effects

To analyze the impacts of road investment on regional development, we need models that describe the causal relationships between the service quality offered by the transport system and regional economic functioning. Several models are available that deal with aspects of the broad issue of the economy-wide effects of transportation, including Land Use Transportation Interaction (LUTI) or Lowry-type models, Multiregional Input/Output (I/O) models, non-spatial Computable General Equilibrium (CGE) models, and Spatial Computable General Equilibrium (SCGE) models.

Spatial models have evolved to include more behavioral richness and regional detail. I/O models have evolved into LUTI models and SCGE models with variable or endogenous coefficients, imposing mathematical consistency between several economic subsystems, including transportation, trade, consumption, and production. A crucial feature of present-day SCGE models is that market-related efficiency measures—and changes therein—can be explicitly derived for the purpose of welfare analysis. The current, more sophisticated, LUTI models (e.g., Hunt and Abraham, 2003) show many similarities with Krugman-type SCGE models (e.g., Venables and Gasiorek, 1996) because they have incorporated random utility-based location choice and trade modeling. The main difference between these I/O-based models and Krugman-type CGE models is that the former describe trade and location choice using discrete choice primarily as a distribution mechanism for total demand, whereas the latter propel changes in total demand itself, using continuous choice models or production functions. See Andersen et al. (1998) for an early account of the mathematical relationship between these model types and Knaap and Oosterhaven (2003) for a more recent and broad comparison of LUTI and SCGE models.

Although the main focus of SCGE models has been on the economic effects of changes in transport network performance, applications of these models go well beyond the field of transportation and infrastructure (see Van den Bergh et al., 1996 for a list other applications).The earliest example of a full and empirically developed SCGE model in Europe was the CGEurope model (Bröcker, 1998). The SCGE model RAEM was constructed and applied in the Netherlands by Knaap and Oosterhaven (2000). Empirically less comprehensive SCGE models have been developed in Denmark (the BROBISSE model; Caspersen et al., 2000), Sweden (Hussain and Westin, 1997; Nordman, 1998, Sundberg, 2002), Norway (the PINGO model; Ivanova et al., 2002), and Italy (Roson, 1995). An overview of this work can be found in the work of Sundberg (2005). Krugman-type SCGE models have been developed in the USA (e.g., Löfgren and Robinson, 1999), and relevant research has also been performed by Lakshmanan and Anderson (2002). In Japan, SCGE models have been developed to analyze the potential damage to the Japanese economy due to major earthquakes (Koike et al., 2000; Ueda et al., 2001; Mun, 1997). Miyagi (2001) used an SCGE model to appraise the indirect economic impacts of a large expressway project.
The RAEM-Light model described in this paper was originally developed by Japanese and Dutch researchers who used it to study the effects of increasing levels of traffic congestion in the Netherlands (Koike and Thissen, 2005, Tavasszy et al, 2002) and the effects of expressway network projects in Japan (Koike et al., 2008). The model has several innovative features. The spatial behavior of producers and consumers is explicitly described and is endogenously determined by using econometric production and consumption functions.

In this study, we used the RAEM-Light model to analyze the development and maintenance stages of road networks under a usual and a disaster scenario for an existing road network and a proposed new network. We measured the spatial benefit incidence of economic effects of the road investments as a means of providing information for deciding how to share the cost burden of building and maintaining road networks.

2. DESCRIPTION OF THE RAEM-LIGHT MODEL

2.1 Formulation of the model

The RAEM-Light model developed by Koike et al. (2008) is a multiregional, multisectoral model for economic activities of households and firms, as well as equilibrium in goods, labor, and capital markets. A spatial price equilibrium is formulated to determine trade patterns. There are four basic assumptions:
(1) The number of households is fixed in each region.
(2) Private firms produce goods from input factors (capital and labor) and intermediate inputs.
(3) There are iceberg-type transportation costs. We chose this well-known approach because of its convenience, but see Tavasszy et al. (2002) for a discussion of the possible adverse effects of this assumption.
(4)Total capital is owned by all households by a national dividend scheme.

Fig. 1 is a diagram of the market used in this model.

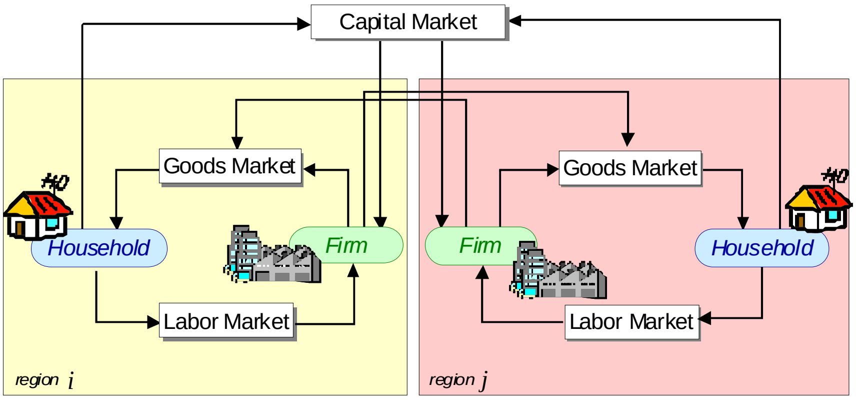

Figure 1 - Each Market in the RAEM-Light Model.

The following indices are used in the model:

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

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

Population: $\mathbf{N} \in \{N_1, N_2, \cdots, N_i, \cdots, N_I\}, \quad \sum_{i \in \mathbf{I}} N_i = T$.

The model formulation is shown in Table 2.

Table 2 – Model Formulation

Category	Formulation
Firm behavior	The production function is specified in accordance with a Leontief form: $y_i^m = \min\left\{ \frac{v_i^m}{a_i^{0m}}, \frac{x_i^{1m}}{a_i^{1m}}, \cdots, \frac{x_i^{mm}}{a_i^{mm}}, \cdots, \frac{x_i^{Mm}}{a_i^{Mm}} \right\},$ (1) where y_i^m is production, v_i^m is value added, x_i^{Mm} is intermediate inputs, a_i^{Mm} is an I/O coefficient, and a_i^{0m} is value-added ratio. The value-added function is specified in accordance with a Cobb-Douglas form: $v_i^m = A_i^m \left(L_i^m\right)^{\alpha_i^m} \left(K_i^m\right)^{1-\alpha_i^m},$ (2) where L_i^m is labor input, K_i^m is capital input, α_i^m is a share parameter, and A_i^m is an efficiency parameter. From first order conditions for market equilibrium, input factor demand functions and the average cost function are determined: $L_i^m = \frac{\alpha_i^m}{w_i} a_{0i}^m q_i^m y_i^m$ (3) $K_i^m = \frac{1-\alpha_i^m}{r} a_{0i}^m q_i^m y_i^m$ (4) $cv_i^m = \frac{w_i^{\alpha_i^m} r^{1-\alpha_i^m}}{A_i^m \left(\alpha_i^m\right)^{\alpha_i^m} \left(1-\alpha_i^m\right)^{1-\alpha_i^m}}$ (5)

	where, w_i : wage level, r : capital rent, q_i^m : f.o.b. price, cv_i^m : value added per product unit.
Household behavior	The utility function and budget constraint are as follows: $$\max U_i\left(d_i^1, d_i^2, \cdots, d_i^M\right) = \sum_{m \in M} \beta^m \ln d_i^m \quad , \qquad (6)$$ $$s.t.\ \bar{l}_i w_i + r\frac{\bar{K}}{T} = \sum_{m \in M} p_i^m d_i^m$$ where U_i is utility, d_i^m is consumption of good m , β^m is a parameter, $\bar{K}$ is national endowment of capital, $\bar{l}_i$ is individual endowment of labor ($\bar{l}_i N_i = \bar{L}_i$), $T = \sum_i N_i$ is total population, and p_i^m is c.i.f. price. The following demand functions are derived from first order conditions: $$d_i^m = \beta_i^m \frac{1}{p_i^m}\left(\bar{l}_i w_i + r\frac{\bar{K}}{T}\right) \qquad (7)$$
Interregional trade	The trade model is based on the approach of discrete choice modeling of spatial interactions assuming independent random utilities (see e.g. Erlander and Stewart(1990) for the explanation and interpretation of random utility methods in spatial analysis). We assume that the consumer demands minimum c.i.f. price goods with imperfect information. C.i.f. price is Cost, insurance and freight – the price of goods include the full shipping cost, as opposed to the f.o.b. (free on board) price, which exclude shipping costs. Now, if a consumer who lives in region j chooses m goods made in region i as inputs, the following equation is satisfied: $$q_i^m\left(1+\tau^m t_{ij}^m\right) + \varepsilon_{ij}^m < q_k^m\left(1+\tau^m t_{kj}^m\right) + \varepsilon_{kj}^m, \quad for\, all\, k \in \mathbf{I}, k \neq i \qquad (8)$$ where, t_{ij}^m : transport mark up rate, τ^m : parameter, ε_{ij}^m : error term. Suppose ε_{ij}^m are independently and identically Gumbel distributed, We obtain a simple share type trade function as a Logit type choice function: $$s_{ij}^m = \frac{y_i^m \exp\left[-\lambda^m q_i^m\left(1+\tau^m t_{ij}^m\right)\right]}{\sum_{k \in \mathbf{I}} y_k^m \exp\left[-\lambda^m q_k^m\left(1+\tau^m t_{kj}^m\right)\right]} \quad , \qquad (9)$$ where s_{ij}^m is interregional trade choice probability, y_i^m is production, q_i^m is f.o.b. price, t_{ij}^m is transport mark up rate, and τ^m and λ^m are parameters. The c.i.f. prices satisfy the following condition: $$p_j^m = \sum_{i \in \mathbf{I}} s_{ij}^m q_i^m\left(1+\tau^m t_{ij}^m\right) \qquad (10)$$
Market equilibrium	The market clearing conditions are as follows. The remarkable point of this paper is considering the Leontief inverse matrix on the equation (13)

condition	deriving from Input-Output table to consider the intermediate inputs. Therefore, we can get the benefit information include the intermediate inputs. Labor market: $\sum_{m\in\mathbf{M}} L_i^m = \overline{L_i}$ (11) Capital market: $\sum_{i\in\mathbf{I}}\sum_{m\in\mathbf{M}} K_i^m = \overline{K}$ (12) Goods market (demand): $\begin{bmatrix} 1-a_i^{11} & \cdots & 0-a_i^{1N} \\ \vdots & \ddots & \vdots \\ 0-a_i^{m1} & \cdots & 1-a_i^{MN} \end{bmatrix}^{-1} \begin{bmatrix} N_i d_i^1 \\ \vdots \\ N_i d_i^m \\ \vdots \\ N_i d_i^M \end{bmatrix} = \begin{bmatrix} X_i^1 \\ \vdots \\ X_i^m \\ \vdots \\ X_i^M \end{bmatrix}$ (13) $z_{ij}^m = X_j^m s_{ij}^m$, (14) where z_{ij}^m is interregional trade volume and X_j^m is final demand. Goods market (supply): $y_i^m = \sum_{j\in J}\left(1+\tau^m t_{ij}^m\right) z_{ij}^m$ (15) F.o.b price: $q_j^n = a_{0i}^n cv_j^n + \sum_{m\in M} a_j^{mn} \sum_{i\in I} s_{ij}^m q_i^m \left(1+\tau^m t_{ij}^m\right)$ (16)

The analytical steps are diagrammed in Fig. 2. A change in the road network results in changes in travel times among each region, which in turn changes interregional trade by altering distribution cost. This will increase or decrease production, depending on the demand for goods, and will cause changes in employment income and consumption. Finally, the information about the benefit incidence on each region is measured. An increase in consumption indicates a positive benefit incidence and a decrease indicates a negative incidence.

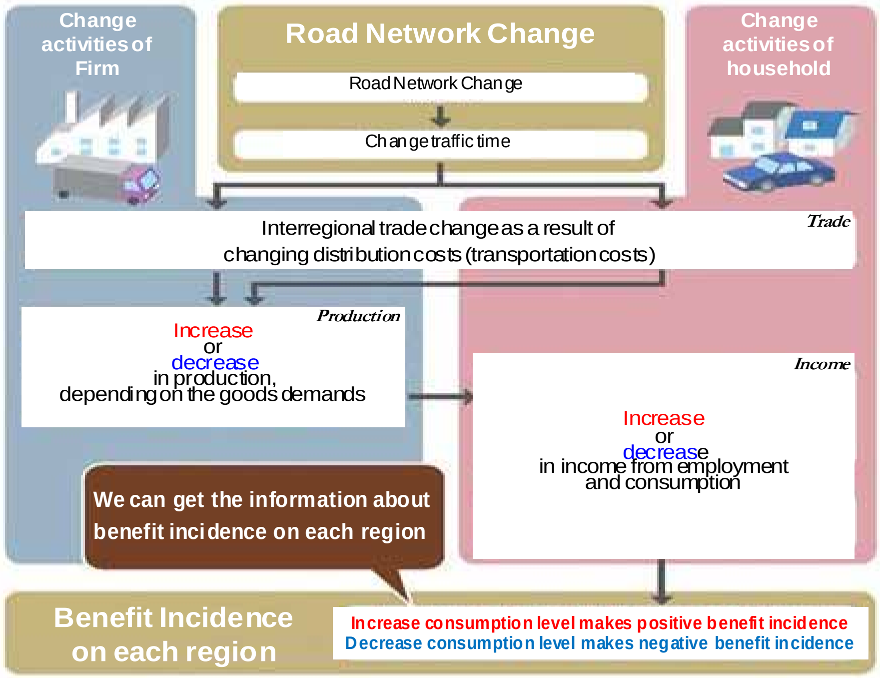

Figure 2 - Analytical Steps in the RAEM-Light model

2.2 Data Requirement and Data Sources

The RAEM-Light model does not require extensive data inputs. The basic economic data come from the national accounts statistics of the Statistics Bureau in Japan. In addition to the transportation data, transportation time and volume are required. Transportation time is calculated by a network route choice model based on the Dijkstra algorithm using a Digital Road Map from the Japan Digital Road Map Association (Speed data in Traffic census 2005 is included on the each link). Transportation volume is calculated from an OD survey (Traffic census 2005).

2.3 Model Calibration

Most parameters in SCGE models are estimated by calibration; this is also true for the RAEM-Light model. The share parameter a_i^m and efficiency parameter A_i^m in the production function are estimated by the calibration method, as is the share parameter β^m in the utility function. An upper bar (—) indicates data from statistical information, as previously described. The input output coefficient a_i^{Mm} follows from Eq.17. Here, $\bar{x}_i^{Mm}$ is intermediate input for industry m in region i and $\bar{Y}_i^m$ is a product for industry m in region i. These values come from each prefectural Input-Output Data and are expressed in monetary terms:

$$a_i^{Mm} = \frac{\bar{x}_i^{Mm}}{\bar{Y}_i^{0m}} \qquad (17)$$

The value added ratio a_i^{0m} follows from Eq.18. Here, $\bar{v}_i^m$ is value added for industry m in region i and $\bar{Y}_i^m$ is products for industry m in region i. These values come from each prefectural Input-Output Data and are expressed in monetary terms:

$$a_i^{0m} = \frac{\bar{v}_i^m}{\bar{Y}_i^m} \tag{18}$$

The share parameter a_i^m follows from Eq.19. Here, $\bar{L}_i^m$ is labor input for industry m in region i, and $\bar{K}_i^m$ is capital input for industry m in region i. These values come from prefectural I/O data and are expressed in monetary terms:

$$a_i^m = \frac{\bar{L}_i^m}{\bar{L}_i^m + \bar{K}_i^m} \tag{19}$$

The efficiency parameter A_i^m follows from Eq.20. Here, $\bar{v}_i^m$ are production of industry m in region i. These values come from prefectural I/O data and are expressed in monetary terms:

$$A_i^m = \frac{\bar{v}_i^m}{\left(\bar{L}_i^m\right)^{a_i^m}\left(\bar{K}_i^m\right)^{1-a_i^m}} \tag{20}$$

The share parameter β^m is calculated from Eq.21 as follows. Here, $\bar{X}^m$ is the total expense of commodity m. These values are expressed in monetary terms from economic statistics. This parameter is assumed to be the same in each region:

$$\beta^m = \frac{\bar{X}^m}{\sum_{m'} \bar{X}^{m'}} \tag{21}$$

2.4 Statistical Analysis

The parameters for interregional trade can be estimated, as shown in Eq.22.

$$s_{ij}^m = \frac{y_i^m \exp\left[-\lambda^m q_i^m\left(1+\tau^m t_{ij}\right)\right]}{\sum_{i'} y_{i'}^m \exp\left[-\lambda^m q_{i'}^m\left(1+\tau^m t_{i'j}\right)\right]}. \tag{22}$$

This is non-linear relationship, and a grid search method (Christian et al., 1995) is applied to estimate the parameters λ^m and τ^m. s_{ij}^m is the trade share between regions in each sector, calculated from the transport volume data. t_{ij} is the transportation time between region i and region j. q_i^m is the f.o.b. price, calculated by the following equation derived from the formulation of firm behavior.

$$q_i^m\left(w_i, r\right) = C_i^m\left(w_i, r\right) = \frac{w_i^{\alpha_i^m} r^{1-\alpha_i^m}}{A_i^m {\alpha_i^m}^{\alpha_i^m}\left(1-\alpha_i^m\right)^{1-\alpha_i^m}} \tag{23}$$

where w is wage rate, r is capital rate

The results of the grid search are shown in Table 3. Traffic census OD data (share data) are used to estimate the parameters of interregional monetary trade, because interregional monetary data are not available in Japan.

Table 3 - Parameter Values for λ^m and τ^m Derived from the Grid Search Method

	λ			τ		
	Agriculture	Manufacturing	Services	Agriculture	Manufacturing	Services
Northern Chugoku Area	2.69	2.32	1	0.126	0.149	0
Southern Chugoku Area	2.81	2	1	0.104	0.151	0
Kinki Area	3.16	2.5	1	0.108	0.095	0
Shikoku Area	2.63	4.58	1	0.113	0.122	0
Kyusyu Area	1.62	2.68	1	0.127	0.092	0

* Services are not traded interregionally.

2.5 Model Verification

The results of the verification of the model are shown in Fig. 3 and Table 4. Although each of the three aggregated sectors has some bias, this bias probably does not have much influence on the evaluation results, because the results represent the change in production volume that is derived from a comparison of the model results conducted with and without an additional road network. The RAEM-Light model therefore appears to reflect actual economic conditions well.

Table 4 - Comparison of Simulated and Actual Values

Sector	Correlation Coefficient	%RMS
Agriculture	0.99	0.69
Manufacturing	0.98	0.69
Services	1.00	0.23
Aggregation of all sectors (GRP)	1.00	0.04

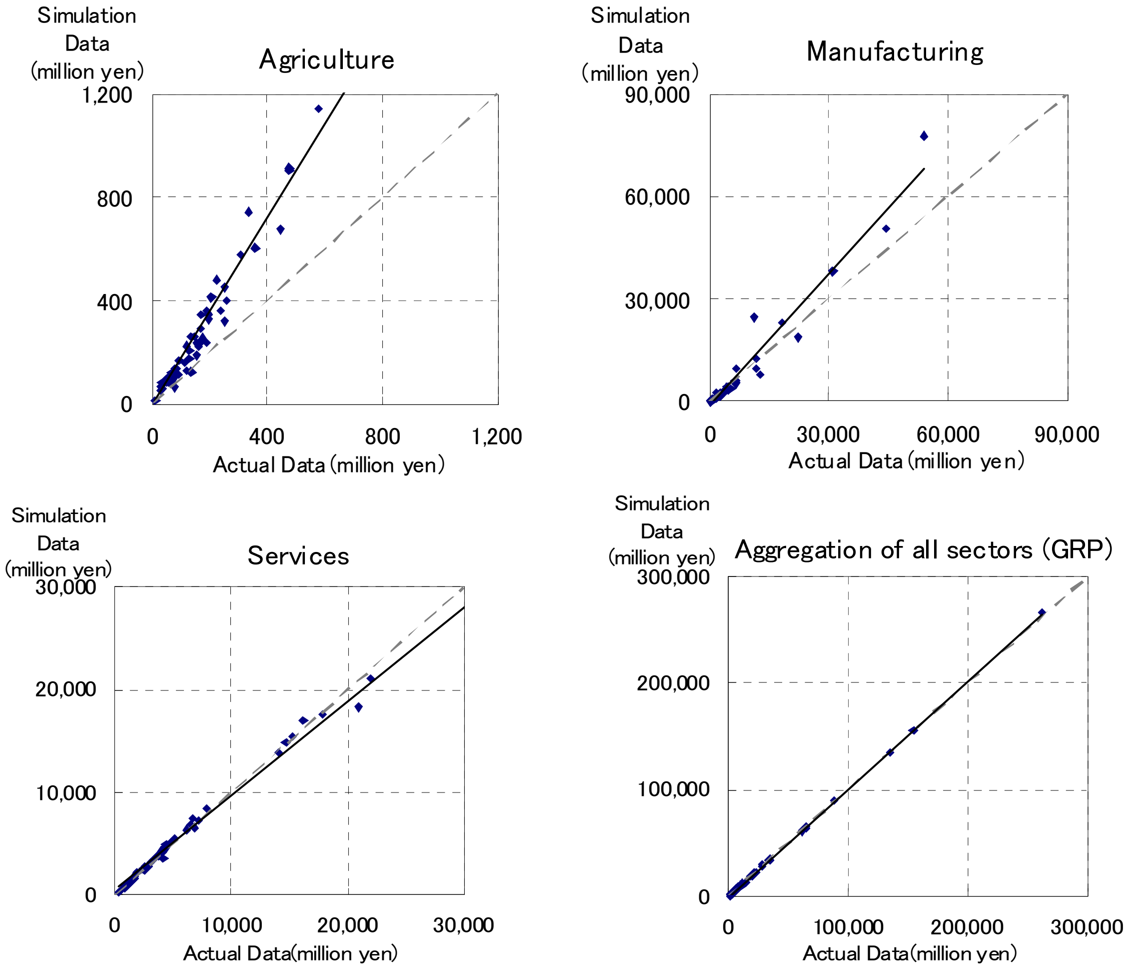

Figure 3 - Comparison of Simulation and Actual Data for Agriculture, Manufacturing, Services, and the Aggregation of All Three (GRP)

3. CASE STUDY

3.1 Study Area and Road Network

This study area consists of 11 prefectures and 172 zones aggregated municipalities (Fig. 4). As Japan becomes more decentralized, these municipalities will have an increasingly important decision-making role in local government. The population distribution of the area is shown in Fig. 5. The Chugoku area is located between the Osaka and Fukuoka metropolitan areas and is subdivided into a southern and a northern area. The population of the southern area is much larger than that of the northern area. The road network for this area is shown in Figure 6. We focused on Route 9, which is a national road network that currently connects the cities of Tottori and Yamaguchi, and the Sanin Line, which is a planned expressway network that will connect the same cities as an additional network in the future. Both networks traverse the Northern Chugoku area.

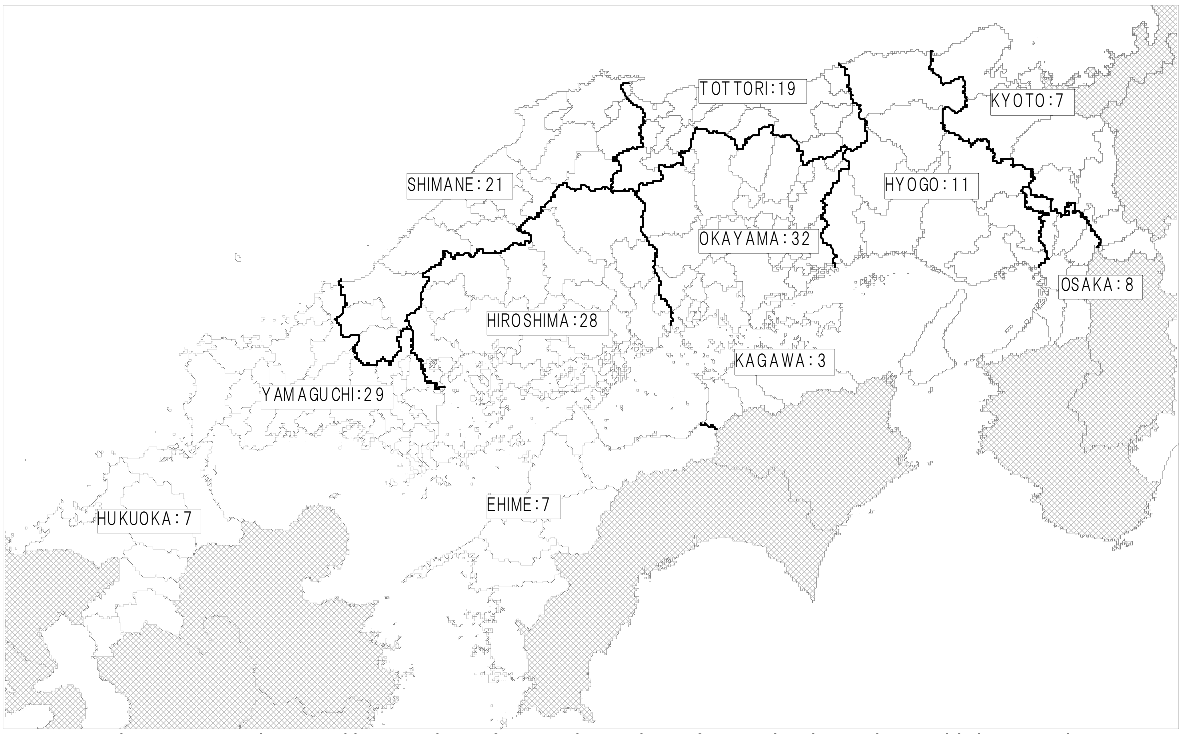

Figure 4 - Study Area (the number of zones in each prefecture is given along with its name)

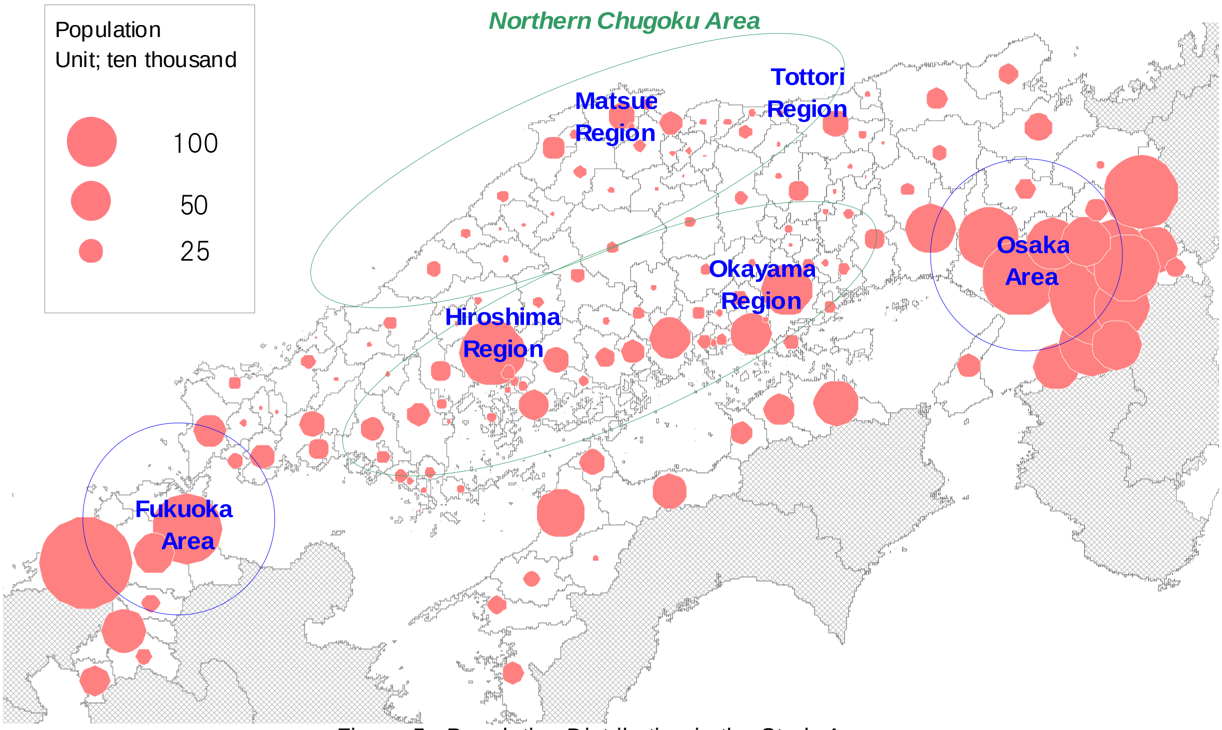

Figure 5 - Population Distribution in the Study Area

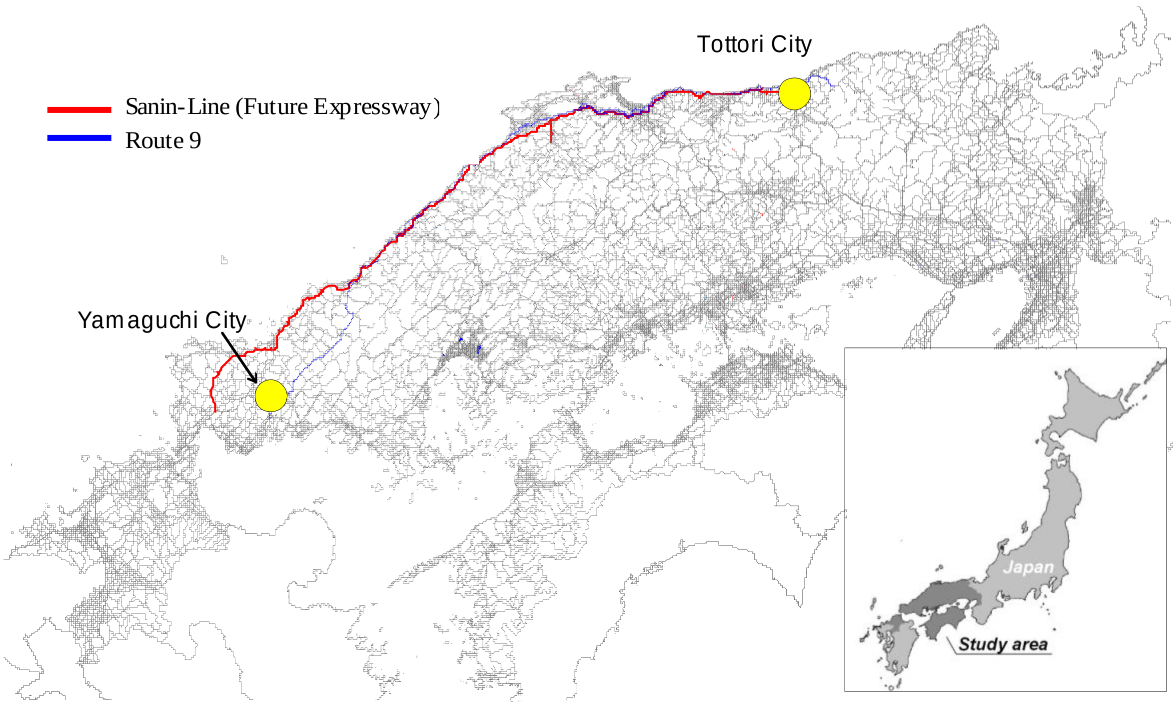

Figure 6 - Road Network in the Study Area (Digital Road Map from the Japan Digital Road Map Association)

3.3 Usual and Disaster Scenarios

We analyzed two stages (development and maintenance) for two cases (usual and disaster), as shown in Table 5. The objective in each scenario was to measure the spatial incidences of economic effects.

Table 5 - Usual and Disaster Scenarios for the Development and Maintenance Stages

Stage	Case	Effect
Development	Usual (Case 1)	*Effect Measured* Effect of saving OD travel time by developing an additional road network. *Without* Present road network *With* Road network is extended with the Sanin-Line *Time-saving Effect = With – Without*
	Disaster (Case 2)	*Effect Measured* If several road networks were developed on the same OD sector, when a road disaster happened, the redundancy effect would reduce the disaster damage. *Without* Present road network *With1* Route 9 can no longer be used and there is no Sanin-Line. *With2* Route 9 can no longer be used but there is a Sanin-Line *Redundancy Effect = With2 – With1*
Maintenance	Usual (Case 3)	*Effect Measured* Maintenance investment, such as improving the pavement, makes it possible to maintain normal expressway service by reducing normal-use damage. *Without* Present road network *With1* Road network is extended with the Sanin-Line (Link speed on the Sanin-Line is normal (70 km/h)) *With2* Road network is extended with the Sanin-Line (Normal link speed on the Sanin-Line is decreased by 10%) *Daily Maintenance Effect = With1 – With2*

	Disaster (Case 4)	*Effect Measured* Maintenance investment, such as earthquake-resistant measures, makes road use more sustainable and secure by reducing disaster damage. *Without* Present road network *With1* Road network is extended with the Sanin-Line *With2* Road network is the same as with Case 1 but the Sanin-Line is closed because of damage (= Present network) *Disaster-resistant Maintenance Effect = With1 – With2*

3.4 Output of the Case Study

3.4.1 Case 1: The Time-Saving Effect

As stated previously, travel time changes affect interregional trade, interregional trade changes cause increases or decreases in the demand for goods in each region, and each firm in each region changes its production of goods in response to regional demand. An increase in consumption in a region is considered to be an incidence of positive benefit. The time-saving effect (benefit incidence) of the development of the Sanin-Line is shown in Fig. 7. The effect spreads not only through the Northern Chugoku area, but also in the Fukuoka area. The positive spill-over effect is especially high in the Fukuoka area, because interregional trade has shifted from the Southern Chugoku area to the Northern Chugoku area, reducing distribution costs and lowering the price of goods.

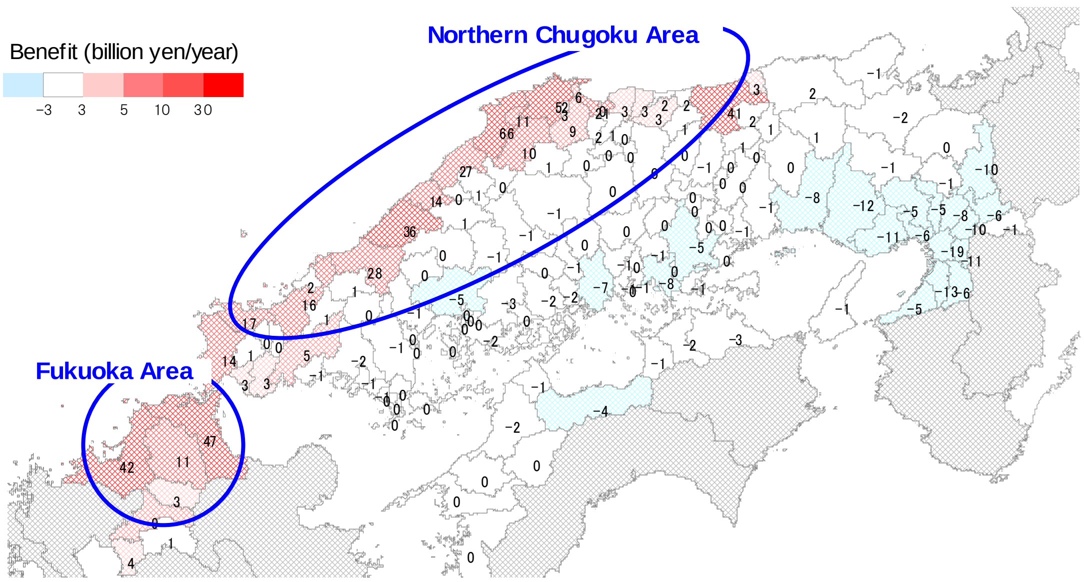

Figure 7 – Case 1—Time-saving Effect of the Development of the Sanin-Line

3.4.2 Case 2: The Redundancy Effect

This case describes the redundancy effect by comparing the results with and without the Sanin-Line if Route 9 were to be closed by some sort of disaster (Fig. 8). The benefit incidence area is similar to that in Case 1, but the balance (degree of positive benefit for each region) is slightly different. We calculated a ratio of change for Case 1 and Case 2 [(Case 2 – Case 1) / Case 1]. We found that the positive benefit incidence from the Tottori region to the Yonago region and around the Yamaguchi region were very high (Fig. 9). This indicates that these regions do not currently have an effective redundancy network and that they could gain additional benefits from the redundancy effect by the development of the Sanin-Line. They therefore have greater incentive to bear some of the investment costs.

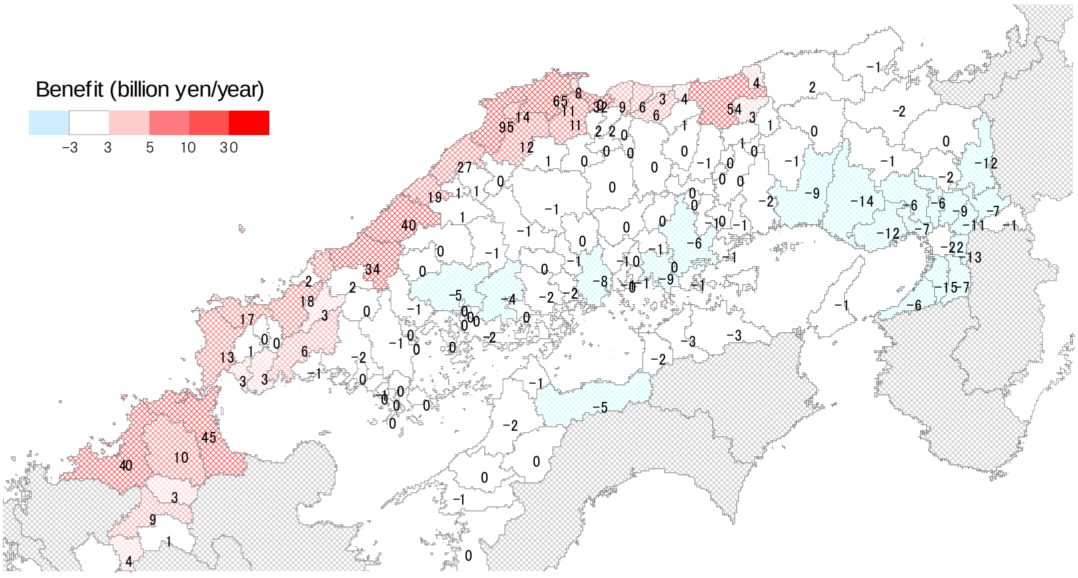

Figure 8 – Case 2—Redundancy Effect of Development of the Sanin-Line

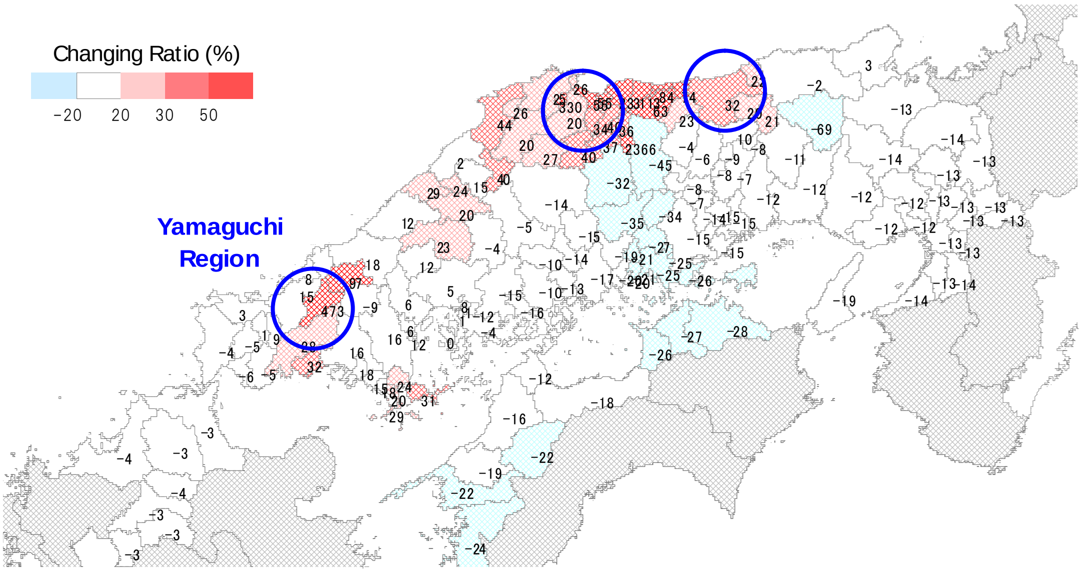

Figure 9 – The ratio (%) of change between Case 1 and Case 2 [(Case 2-Case 1) / Case 1]

3.4.3 Case 3: The Daily Maintenance Effect

A lack of daily maintenance causes a decrease in travel speed (and an increase travel time) because of pavement deterioration in the absence of normal maintenance. The daily maintenance effect of the Sanin Line is shown in Fig. 10, where it is clear that the daily maintenance effect spreads not only to the Northern Chugoku area but also to the Fukuoka region.

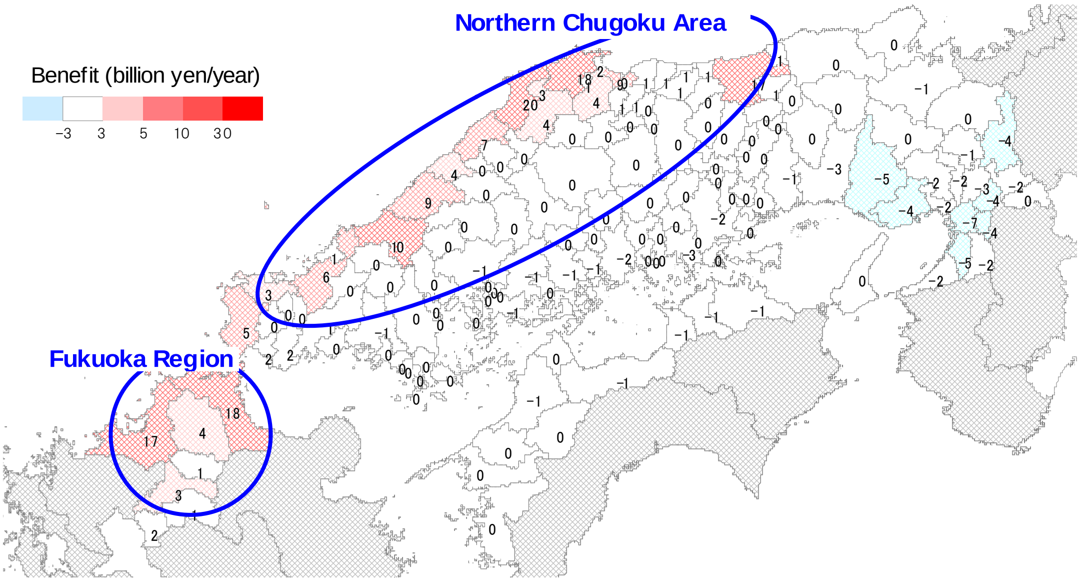

Figure 10 – Case 3—Daily Maintenance Effect of the Sanin Line

3.4.4 Case 4: Disaster-Resistant Maintenance Effect

The disaster-resistant maintenance effect occurs when a road network can maintain normal traffic functions under a disaster scenario; Fig. 11 shows the disaster-resistant maintenance effect of the Sanin Line. The spatial incidence of effect is similar to that of Case 1 (Fig. 7). The ratio of change [(Case 4 – Case 3) / Case 3] is relatively high in some regions (Fig. 12), indicating that these regions are sensitive to decreases in travel time on the Sanin Line and therefore should have incentive to invest in daily maintenance.

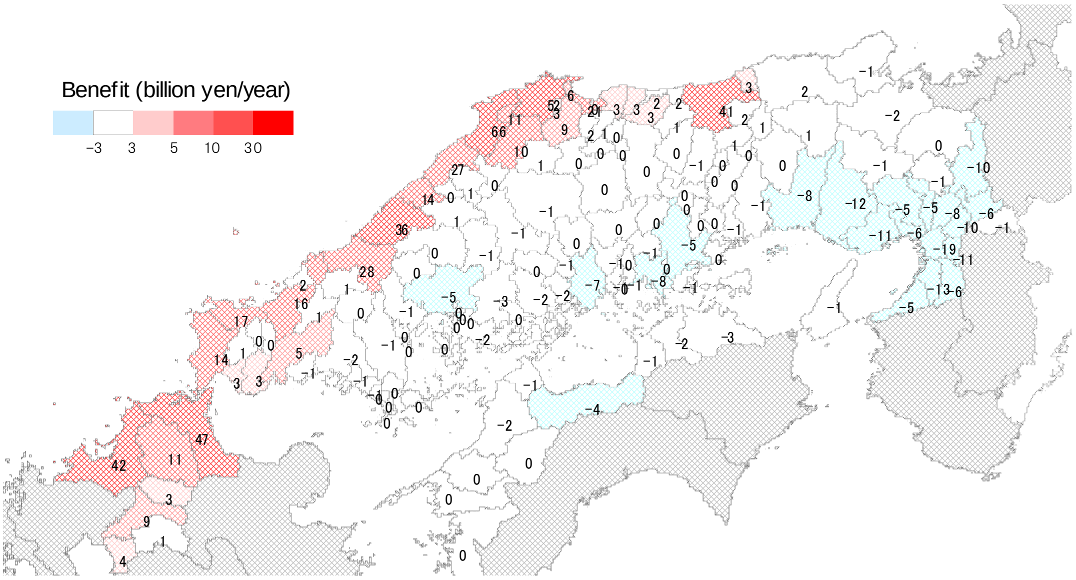

Figure 11 – Case 4—Disaster-Resistant Maintenance Effect on the Sanin Line

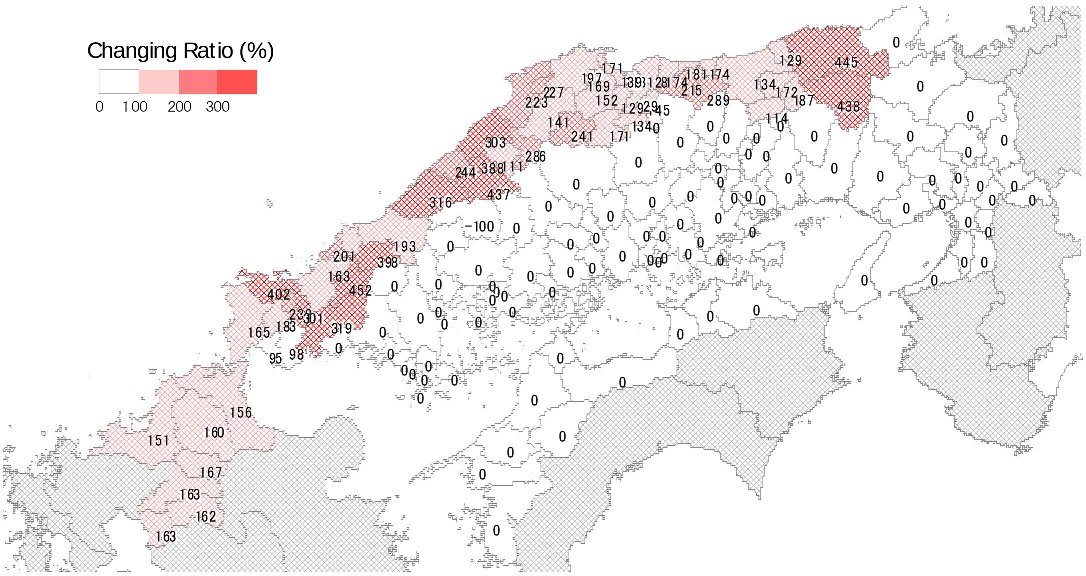

Figure 12 – The ratio (%) of Change [(Case 4 – Case 3) / Case3]

4.5 Limitations of this Study and Future Research Possibilities

The limitations of this study and future extensions of the study include the following.

- Transportation time is calculated by a network route choice model based on the Dijkstra algorithm. Tolls and network congestion are not taken into consideration. Although this study simplified the traffic conditions, these conditions could be included in the output if traffic flow information is applied.

- This study considers the interregional trade of goods within the study area but ignore the trade with the rest of country as well as international trade. This study focus on Chugoku area with Sanin-Line and Route 9 in study area. Analyzing the traffic census OD data in

Chugoku area, the most traffic trade used by the road network is within the study area. Hence we considered that a road investment in Chugoku area does not much affect to a rest of country.

- As mentioned in subsection 3.3, the objective of each scenario is to gather basic information about the road investment cost burden by measuring the spatial incidence of the economic effect. However, this study is not sufficient to discuss the total amount of disaster cost because the disaster conditions are not well described. In future studies, these probabilities should be accounted for.

- Although we assumed that all Route 9 or Sanin-Line sections would be closed in the disaster scenario, the spatial incidence of economic effect depends on the scale of the road network section. For practical application, the scale of maintenance would have to be clarified.

4. CONCLUSIONS

- The spatial incidence of the economic effect of road investment differs between the usual and the disaster scenarios for both the development and maintenance stages. As Japan becomes more decentralized, it will become more important to consider optimum allocation of the road network cost burden among local governments. Each road network section should be recognized as local public goods, and the spatial effect differences should be analyzed.

- In the development stage, the time-saving effect under the usual scenario spread over a large area as a result of the spill-over effect. The redundancy effect under the disaster scenario was more limited to regions that currently do not have sufficient redundancy. Therefore, the cost burden of road development should be decided on by considering not only the time-saving effect but also the redundancy effect.

- In the maintenance stage, the spatial incidences of the daily maintenance effect and disaster-resistant maintenance effect are different. When considering the maintenance cost burden, the objective of maintenance should be clarified because the spatial incidences of the effect differ.

- Measuring spatial economic incidence supplies us with effective information to help decision-makers make better choices in the future. Future research should consider traffic congestion and detours as well as the probabilities of disaster occurrence.

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