Estimation of the Impact of the New High-Speed Rail in Japan from a Spatial Economic Perspective

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Abstract

The development of intercity transportation systems can significantly impact regional economies and national land structures. This study offers a model to evaluate the effects of new high speed rail systems on economic and population structures based on spatial economics (also called new economic geography), which has rapidly developed in terms of theory and computational methods in recent years. We apply the current model to the new Japanese high-speed rail project, SCMAGLEV, and estimate the short and long run economic effects on population distribution. The results of the short run analysis are generally consistent with the intuitive expectation that large effects will be generated mainly in the areas around Tokyo and Osaka, which are the terminals of SCMAGLEV. In contrast to the trend in the spatial distribution of benefits in the short run equilibrium, the population is expected to decline in many regions in the long run. The long run results suggest that population agglomeration can develop in limited areas of the country.

JEL classification: C68, D58, H54, R12, R13, R23, R41, O18
Keywords: Spatial economics; High-speed rail; Demography; Economic impact

1 Introduction

The development of high-speed rail systems (HSRs) should contribute to the transportation accessibility of multi-regional economic systems, thus reducing travel and transportation time between regions. The Central Linear Shinkansen (SCMAGLEV), which is currently under construction, is a new HSR transportation system that will dramatically shorten the travel time between three major cities in Japan: Tokyo, Nagoya, and Osaka. The advanced engineering technology 'SuperConducting MAGnetic LEVitation' railway system has achieved significant speed-ups, and the project title SCMAGLEV was derived from the abbreviation of its name. The travel times for the Tokyo-Nagoya route (scheduled to open in 2027) and the Tokyo-Osaka route (scheduled to open in 2045) will be approximately 40 min and 67 min, respectively, which is approximately the same as the time required for intracity transportation, despite route distances of over 250 km and 400 km, respectively.

High-speed rail systems have a dominant modal share of intercity passenger transit over a wide range of travel lengths in Japan, and the modal share of rail is expected to increase significantly after the launch of the SCMAGLEV (Yamaguchi and Yamasaki (2010)). Furthermore, Transportation policy council, Chuo Shinkansen subcommittee (2011) stated some additional goals of the SCMAGLEV project, as well as the improvement of the intercity passenger transport system. Enhancing the global competitiveness of the three metropolitan areas where SCMAGLEV's nodes are located is given high priority. In addition, economic growth in other cities along the route was explicitly stated as a project goal.

On the one hand, the government expects a blueprint for the formation of a Super Mega Region linking the three metropolitan areas of Tokyo, Nagoya, and Osaka due to the national-level spatial impact of SCMAGLEV (Ministry of Land, Infrastructure, Transport and Tourism (2019)). On the other hand, there is concern that the expansion of the catchment area of megacities may swallow up the markets of local regions and lead to a decline in industrial activities in such regions.

The economic impacts of infrastructure projects were evaluated using cost-benefit analysis (CBA) from the perspective of transportation project efficiency. Practical guidelines on CBA for evaluating transportation investment projects have been established in various countries. Typical CBA, based on the partial equilibrium

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approach, evaluates only one-dimensional efficiency and does not measure the indirect effects on other markets. Benefits are measured by focusing on the primary market, which is directly affected by policy implementation.

However, a change in transportation accessibility implies a shift in the generalized cost of transportation in the inter-regional trade of goods and services, which affects the supply and demand relationship of goods and services through the market. The impact of transportation market spillovers to various markets through the interdependence among industrial sectors and regions eventually causes changes in the regional welfare level. Another economic impact evaluation concept, the general equilibrium approach, is required from the perspective of regional distribution and incidence benefits. The general equilibrium model analysis, which describes simultaneous equilibrium in multiple markets, focuses on spillovers from markets affected by policy intervention into other markets. For example, economic development caused by the improvement of transport systems, namely the transportation market, is of typical interest in general equilibrium analyses.

However, from a long-term perspective, regions with a higher level of welfare are more attractive in terms of residential location choice, which may change the pattern of the regional distribution of households, that is, the structure of the population distribution in the country. Changes in population distribution are not of central interest in welfare evaluation analyses such as traditional CBA and even multi-regional general equilibrium analysis. These benefit evaluation approaches usually assume that households' residential locations do not change.

This study offers a quantitative multiregional economic model to assess the effects of intercity transportation systems, especially HSR systems, on the national population distribution based on spatial economics (also called new economic geography), which emphasizes the agglomeration of economic activities and the resulting population distribution. Furthermore, we apply the model to the SCMAGLEV project and consider its short and long run impacts on population distribution.

2 Literature review

Since the launch of Shinkansen in Japan, HSR systems have been introduced in Europe, including TGV in France, AVE in Spain, and ICE in Germany, and are now spreading worldwide. Givoni (2006) reviewed the technical characteristics and development history of HSR and showed that the typical aspects of HSR, high-speed and large capacity, facilitated the demand shift from other modes of transportation, such as air and conventional rail.

The standard method for economic evaluation of HSR projects is CBA, which has been widely applied in Europe (de Rus (2008), Campos and de Rus (2009)). The CBA concept is used to evaluate the efficiency of an investment project and is measured using a one-dimensional index. The traditional CBA methodology has limitations in properly assessing wider economic impacts (Graham (2007), Vickerman (2018)) such as economies of agglomeration (Venables (2016)). Furthermore, CBA does not explicitly evaluate interdependencies among regions or industries. Therefore, spatial and inter-industry spillover effects cannot be measured.

Existing empirical analyses support the idea that HSR development causes spatially uneven economic effects and economic spillovers from the invested regions to other regions. Vickerman (1997) reviewed the development of HSR in Europe and pointed out that HSR developments tend to accelerate the concentration of economic activity in large cities that serve as access points. Puga (2002) explored that HSR in Europe has promoted development in major transportation node cities, but has not contributed to the development of minor nodes. Vickerman (2015) noted that transportation accessibility improvements by European HSR and economic development were less pronounced in intermediate regions between major cities. Li and Xu (2018) examined the impact of the introduction of HSR in Japan in the 20th century from the perspective of economic geography. They showed that service industries were concentrated in the Tokyo metropolitan area, whereas manufacturing industries were dispersed in peripheral regions. Sasaki et al. (1997) used a supply-oriented econometric model to investigate the effects of the Japanese HSR, Shinkansen. They showed that the Shinkansen stimulated economic activity in developed cities but did not necessarily contribute to mitigating regional disparities. A panel regression analysis of several accessibility and economic indicators by Chen and Haynes (2017) showed that the Chinese HSR contributed to the convergence of regional income inequality. Empirical studies support the spatio-economic impact of HSR. However, it is not clear whether HSR promote a reduction in economic disparity, lead to economic decentralization, or accelerate the concentration of economic activity in urbanized metropolitan areas.

The multi-regional economic modeling of a transport system is an appropriate approach to estimate the ex-ante evaluation of spatial economic impacts in the manner of the general equilibrium concept (Lakshmanan (2011), Vickerman (2017), Yu (2018)). Multiregional Input–Output (MRIO) and spatial computable general equilibrium (SCGE) models are popular "operational" multi-regional economic models for transportation project appraisal (Wegener (2011)). Because the MRIO and SCGE models use MRIO tables or a social accounting matrix as benchmark equilibrium data, they are adequate for exploring the effects of transportation investment on inter-regional and inter-sectoral economic impacts.

Traditional MRIO-based models are demand-driven and usually assume a fixed technical structure (Yu (2018)). The random utility based MRIO (RUBMRIO) models that introduce elastic trade coefficients with random utility maximization-based models into MRIO systems (de la Barra (1989), Kockelman et al. (2005), Bachmann et al. (2014)) can relax the limitations of the fixed trade share. However, estimating the influence on regional productivity and subsequent economic impacts needs to focus more on supply side economic activities, because transportation investment will directly influence changes in the cost structure of production by reducing the generalized cost for tradable intermediate demand. As such, SCGE models, which highlight the Walrasian general equilibrium mechanism, are more desirable options for capturing the spillover effects of economic impacts.

In Europe, SCGE models with dozens and hundreds of regional classifications have been applied to appraise rail investment projects, such as Knaap and Oosterhaven (2011) for rail-link development in the Netherlands and Bröcker et al. (2010) for the TEN-T project, which encompasses many HSR projects. Koike et al. (2015) applied SCGE analysis to HSR development in Japan, Korea, and Taiwan to estimate the economic benefits and impact on CO2 emissions. The model endogenously reflects passenger travel as a household consumption demand for travel and intermediate input demand for business trips in production activities. Moreover, their model considered the impact of travel time reduction owing to HSR on the modal split share. The results suggest that welfare gains in mega HSR terminal cities (Tokyo, Osaka, Seoul, Busan, Taipei, and Kaohsiung) and intermediate cities (Nagoya, Daejeon, and Taichung) are significant in Japan, Korea, and Taiwan. Hiramatsu (2018) examined the economic and employment impact of the Kyushu Shinkansen using a multiregional economic model incorporating residential location choice. While positive effects on national economic development and job creation were estimated, the analysis implied that the regional differences in these effects within the Kyushu region were large. Kim et al. (2019) applied an SCGE model considering production factor mobility to an HSR investment project in a less developed region of Korea and showed that it leads to population concentration in metropolitan areas but decreases economic interregional disparity. Chen (2019) investigated an ex-post evaluation of the regional economic effects of HSR in China using a dynamic SCGE model. These results suggest that HSR development has positive regional economic effects, particularly in terms of facilitating economic growth in underdeveloped areas.

The standard computable general equilibrium (CGE) and SCGE models highlight the evaluation of the economic impact, whereas the demographic impact is essentially a secondary target. Although several SCGE models (e.g., Kim et al. (2019)) that consider the interregional mobility of factors of production estimate labor migration by HSR, they do not explicitly identify the dynamics of population movement.

The impact of transport investment on population distribution is the principal focus of urban land use transport models. Many operational urban land use transport integrated (LUTI) models initiated by Lowry (1964) have been developed and implemented for practical applications (European Conference of Ministers of Transport (1975), Wegener (2004)). In particular, LUTI models have an advantage in analyzing the impact on transportation and location changes in urban areas, as they are based on sophisticated formulations of the location choice behavior of residences and production activities. However, some functions for production and demand in the model are derived independently of the microeconomic foundation. Hence, LUTI models are not fully consistent with the general equilibrium concept.

By extending the monopolistic competition trade model to include labor mobility, Krugman (1991) established a theoretical framework to explain endogenous population agglomeration. Fujita et al. (2001) systematized spatial economics, integrating the theoretical modeling of spatial interdependence in international trade, urban economics, and regional economics to treat spatial population concentration and dispersion. Since then, many theoretical studies have been conducted on spatial economics (Baldwin et al. (2005), Combes et al. (2008)). Spatial economics is a general equilibrium model that explicitly addresses increasing returns and imperfect competition. It describes the stable long run equilibrium of population distribution as the remaining point of population dynamics. This concept, especially the stability of equilibrium, has not been addressed in the existing SCGE models.

However, the application of spatial economics to the impact analysis of actual infrastructure policies has not been popular, owing to computational difficulties in the long run equilibrium of the real-world model. Deriving the analytical solution of the equilibrium is essentially impossible, except for an unrealistically simplified spatial economic model.

Quantitative spatial economics (QSE) is an emerging methodology in quantitative economic geography that highlights the spatial aspects of economic activities and their interrelationships (Eaton and Kortum (2002), Redding and Sturm (2008), Redding and Rossi-Hansberg (2017)). Allen and Arkolakis (2014) is a seminal study of the application of QSE to transportation infrastructure development. This study investigates the contribution of U.S. interstate highways to the geographical formation of population distribution by conducting a counterfactual simulation using the QSE model.

Takayama et al. (2018) was the first study to apply the QSE approach to road transportation policy in Japan, simulating uniform nationwide transportation cost reductions and total population decline. This study uses an algorithm developed by Takayama et al. (2014, 2016) and Ishikura et al. (2018), which iteratively derives a stable long run equilibrium.

In the above QSE analysis, industrial sectors were not classified, unlike most SCGE model analyses. Regional differences in the input-output structure and interregional trade patterns by the goods sector should not be discarded in the spatial impact analysis of the transportation policy. This is because Tokyo, Japan's largest consumption center, is the eastern terminal of SCMAGLEV, whereas the Chukyo region, Japan's largest manufacturing center, is the intermediate point. This study offers a QSE-type spatial economics model that considers explicit inter-industrial interaction and analyzes the short and long run economic impacts of the SCMAGLEV project on the Japanese spatial economy.

3 Model

3.1 Overview and Assumptions

Our model is based on Ishikura and Yokoyama (2022) for short run modeling and Takayama et al. (2014) and Ishikura et al. (2018) for long run modeling. The economic system covered by the model consists of $\mathcal{R}$ regions and the goods sector is classified into $\mathcal{I}$ sectors. In region r, industrial sector i produces its own sectoral goods or services (henceforth simply denoted as goods).

The model assumes a so-called Dixit-Stiglitz type monopolistic competition market. Thus, producers face a monopolistically competitive market, with free entry and exit. Production technology is subject to economies of scale at the producer level. Households with homogeneous preferences exist in each region, and their behavior is portrayed as the behavior of aggregated representative households. Households have a certain labor endowment as a single production factor and gain factor income by inelastically supplying labor.

Households cannot change their places of residence in the short term. This means that the goods and factor markets are cleared in the equilibrium price systems when the factors are immobile. In the long run, households choose their residential locations to maximize their utility.

3.2 production

Firms labeled by industrial sector in each region exclusively produce horizontally differentiated goods under increasing returns to scale technology. As a production technology, we assume a nested constant elasticity of substitution (CES) technology in which the upper level is a Cobb-Douglas type and the lower level is a CES type. In other words, the price index h_s^j for all inputs to the production of goods in region s of sector j and the price index g_s^i for the intermediate inputs of sector i goods are formulated as follows:

$$h_s^j = \eta_s^j \left(w_s\right)^{1-\sum\limits_{i\in\mathcal{I}} \alpha_s^{ij}} \prod_{i\in\mathcal{I}} \left\{ \left(g_s^i\right)^{\alpha_s^{ij}} \right\}, \tag{1}$$

$$g_s^i = \left\{ \sum_{r\in\mathcal{R}} \int_0^{n_r^i} \left(p_{rs}^i\left(k\right)\right)^{1-\sigma^i} dk \right\}^{\frac{1}{1-\sigma^i}}, \tag{2}$$

where w_s is the factor price in region s, p_{rs}^i is the price of good i produced in region r in the region of demand s, and n_r^i is the number of varieties, equivalent to the number of firms in sector i produced in r. α_s^{ij} is the monetary input coefficient. σ^i is the elasticity of substitution across differentiated goods in sector i. η_s^j denotes a parameter related to the inverse of productivity.

The assumption of the iceberg transportation cost concept yields the following relationship between the price in the demand region p_{rs}^i and that in the production region p_r^i:

$$p_{rs}^i\left(k\right) = p_r^i\left(k\right)\tau_{rs}, \tag{3}$$

where τ_{rs}^i is the number of shipments from region r required to satisfy one unit demand for good i in region s.

Let C_s^j denote the cost function for producing variety i in region s: As we assume increasing returns to scale at the firm level, production must include a fixed amount of composite input γ_j^F, which is independent of the level of production, as well as the variable input $\gamma_V^j x_s^j$ which depends on the production level. The fixed component is assumed to be common across production regions.

$$C_s^j\left(x_s^j(k)\right) = \left(\gamma_F^j + \gamma_V^j x_s^j(k)\right) h_s^j \tag{4}$$

Because monopolistic competition and free entry/exit are assumed in the Dixit-Stiglitz type model, the price is equal to the marginal cost multiplied by the markup:

$$p_s^j(k) = \frac{\sigma^j}{\sigma^j - 1}\gamma_V^j h_s^j. \tag{5}$$

Under the zero-profit condition, the average production cost is equal to the price in the production region.

Summarizing the above equations, the production volume is determined independently of the price of goods, as follows:

$$x_s^j(k) = \frac{\gamma_F^j}{\gamma_V^j}\left(\sigma^j - 1\right) = \zeta^j. \tag{6}$$

Because the prices and output of individual goods varieties do not depend on variety type k, we omit the k notation in the following.

Let S_s^j be the aggregate output of j in the region s. As the production value is equal to the product of the production cost of variety and the number of varieties, the following relationship holds:

$$S_s^j = n_s^j C_s^j = n_s^j p_s^j \zeta^j. \tag{7}$$

Applying Shepard's lemma to (1) and (2), the real intermediate inputs of i produced in region r to the production of sector j in region s, m_{rs}^{ij} is derived as follows:

$$m_{rs}^{ij} = \left(\frac{p_r^i \tau_{rs}^i}{g_s^i}\right)^{-\sigma^i} \alpha_s^{ij}\frac{S_s^j}{g_s^i}. \tag{8}$$

Similarly, the input demand for the production factor l_s^j is represented by

$$l_s^j = \left(1 - \sum_{i\in\mathcal{I}}\alpha_s^{ij}\right)\frac{S_s^j}{w_s}. \tag{9}$$

3.3 Households

The consumption of goods in each region is determined by the utility-maximizing behavior of the regional households. For consumer preferences, we assume a nested CES function similar to that of production technology. Assuming that the diversity index of goods is the same for intermediate input demand and consumption, the price index of good i in demand region s is expressed by Equation (2). Therefore, the indirect utility function is defined as:

$$V_s = E_s \prod_{i\in\mathcal{I}}\left(g_s^i\right)^{-\beta^i}, \tag{10}$$

where E_s is the disposable income of individual households in s and β^i is the preference share parameter (common across regions). Applying Shepard's lemma to equation (2), we obtain the real consumption demand of individual households, $\hat{c}_{rs}^i$ for good i produced in region r:

$$\hat{c}_{rs}^i = \left(\frac{p_r^i \tau_{rs}^i}{g_s^i}\right)^{-\sigma^i}\beta^i\frac{E_s}{g_s^i} \tag{11}$$

Let N_s denote the number of households in the region s. The assumption that household preferences in the region are homogeneous yields the aggregate consumption demand of households in region s for good i produced in region r:

$$c_{rs}^i = N_s \hat{c}_{rs}^i. \tag{12}$$

3.4 market equilibrium

The aggregate demand for good i produced in region s, D^i_s, is the sum of consumption demand and intermediate input demand in the value terms:

$$D^i_s = \beta^i N_s E_s + \sum_{j\in\mathcal{I}} \left(\alpha^{ij}_s S^j_s\right). \tag{13}$$

Let q^i_{rs} be the quantity of variety i produced in region r shipped to region s; that is,

$$q^i_{rs} = \tau^i_{rs}\left(c^i_{rs} + \sum_{j\in\mathcal{I}} m^{ij}_{rs}\right) = \left(p^i_r\right)^{-\sigma^i}\left(\frac{\tau^i_{rs}}{g^i_s}\right)^{1-\sigma^i} D^i_s. \tag{14}$$

This includes demand for transportation services.

The total trade value of good i produced in region r and demanded in region s in value terms, including transportation consumption, Q^i_{rs}, is given by

$$Q^i_{rs} = n^i_r p^i_r q^i_{rs} = n^i_r \left(\frac{p^i_r \tau^i_{rs}}{g^i_s}\right)^{1-\sigma^i} D^i_s. \tag{15}$$

Summing Q^i_{rs} for the region of production r yields the trade demand for goods i demanded in regions s and D^i_s. The relationship between and (7) yields

$$Q^i_{rs} = \frac{n^i_r \left(p^i_r \tau^i_{rs}\right)^{1-\sigma^i}}{\sum_{r\in\mathcal{R}} n^i_r \left(p^i_r \tau^i_{rs}\right)^{1-\sigma^i}} D^i_s = \frac{S^i_r \left(p^i_r\right)^{-\sigma^i} \left(\tau^i_{rs}\right)^{1-\sigma^i}}{\sum_{r\in\mathcal{R}} S^i_r \left(p^i_r\right)^{-\sigma^i} \left(\tau^i_{rs}\right)^{1-\sigma^i}} D^i_s. \tag{16}$$

Because the sum of Q^i_{rs} for the region of demand s and adding net exports to the Rest of the World (ROW) Z^i_r equals the total output of good i produced in region r,

$$S^i_r = \sum_{s\in\mathcal{R}} Q^i_{rs} + Z^i_r \tag{17}$$

holds.

Let $\overline{z^i_r}$ denote the real net exports of i in region r, measured by the price in the production region. The goods market equilibrium is expressed as follows:

$$S^i_r = \sum_{s\in\mathcal{R}} \left[\frac{n^i_r \left(p^i_r \tau^i_{rs}\right)^{1-\sigma^i}}{\sum_{r\in\mathcal{R}} n^i_r \left(p^i_r \tau^i_{rs}\right)^{1-\sigma^i}} D^i_s\right] + p^i_r \overline{z^i_r}. \tag{18}$$

The aggregate factor income in region s, Y_s is equivalent to the sum of the factor input costs for the industrial sector:

$$Y_s = \sum_{j\in\mathcal{I}} \left(w^j_s l^j_s\right). \tag{19}$$

Because the production factor is assumed to be immobile in the short run, the factor market-clearing condition is as follows:

$$w_s N_s = Y_s = \sum_{j\in\mathcal{I}} \left(1 - \sum_{i\in\mathcal{I}} \alpha^{ij}_s\right) S^j_s. \tag{20}$$

3.5 Relationships with extraterritorial economies

The model explicitly considers the balance of payments with economies outside the target region, and the disposable income that households can spend on consumption demand is the amount that includes not only factor income but also net income transfer due to the current surplus or deficit with outside economies. Current transfer is inextricably linked to the capital account balance, which is determined by the relationship between savings and investment and is essentially determined by dynamic decision-making. However, our model, which does not consider capital accumulation, does not consider dynamic investment behavior. The current account balance of each region within the study area is assumed to be fixed so that it is consistent with the domestic trade balance at the benchmark equilibrium. Regarding the balance of payments relationship with the ROW, we assume that the real net exports of each industrial sector in each region $\overline{z_s^i}$ is fixed at the benchmark equilibrium. Income transfers are determined such that the regional balance of payments remains consistent in the equilibrium price system.

That is, the regional external surplus over the ROW X_s^{ROW} is represented by

$$X_s^{ROW} = \sum_{i\in\mathcal{I}} Z_s^i = \sum_{i\in\mathcal{I}} p_s^i \overline{z_s^i}. \tag{21}$$

The regional aggregate of household disposable income is equal to factor income minus net income transfer payments:

$$N_s E_s = f\left(Y_s\right) - X_s^{ROW}, \tag{22}$$

where $f\left(Y_s\right)$ is the sum of the factor income in the region minus the income transfers related to the interregional income transfer payments, excluding the ROW, and is considered a function of factor income. Although the consistent closure of regional accounts is essential for an accurate general equilibrium analysis of multiregional economic systems, various methodologies and interpretations have been proposed. A uniformly agreed upon method has yet to be established (Hosoe et al. (2010)). For details on the methods employed in this study, see the Appendix.

3.6 Short run equilibrium

In the short run, households are immobile across regions and the endowment of production factors in each region is fixed. In equilibrium, price formation must be consistent with the optimal behavior of each economic agent.

The following equations define the price index of regional aggregated goods and the price of a variety.

$$g_s^i = \left\{ \sum_{r\in\mathcal{R}} n_r^i \left(p_r^i \tau_{rs}^i\right)^{1-\sigma^i} \right\}^{\frac{1}{1-\sigma^i}}, \tag{23}$$

$$p_s^j = \psi_s^j \left(w_s\right)^{1-\sum\limits_{i\in\mathcal{I}} \alpha_s^{ij}} \prod_{i\in\mathcal{I}} \left(g_s^i\right)^{\alpha_s^{ij}}. \tag{24}$$

Combining (7) and (20) yields the factor market-clearing condition

$$w_s N_s = \sum_{j\in\mathcal{I}} \left(1 - \sum_{i\in\mathcal{I}} \alpha_s^{ij}\right) n_s^j p_s^j \zeta^j. \tag{25}$$

Similarly, combining (7), (13), (18), and (22) yields the market-clearing conditions for the goods market.

$$n_r^i p_r^i \zeta^i = \sum_{s\in\mathcal{R}} \left[\frac{n_r^i \zeta^i \left(p_r^i \tau_{rs}^i\right)^{1-\sigma^i}}{\sum\limits_{r\in\mathcal{R}} n_r^i \zeta^i \left(p_r^i \tau_{rs}^i\right)^{1-\sigma^i}} \left\{ \beta^i \left(f\left(w_s N_s\right) - X_s^{ROW}\right) + \sum_{j\in\mathcal{I}} \alpha_s^{ij} \zeta^j n_s^j p_s^j \right\} \right] + p_r^i \overline{z_r^i}. \tag{26}$$

The notation for the exogenous parameters is rearranged as follows:

$$\psi_s^j = \frac{\sigma^j \gamma_V^j \eta_s^j}{\sigma^j - 1}. \tag{27}$$

The endogenous variables of the short run equilibrium are the factor prices, price index of regional aggregated goods, price of the variety in the region of production, and the number of varieties, namely, w_r^i, g_r^i, p_r^i, and n_r^i.

3.7 long run equilibrium

In the long run, we assume that households can freely choose a residential region in which they can obtain higher utility. When the preferences of all households are homogeneous, and they can move freely between regions, as assumed in typical new economic geography models, a completely concentrated equilibrium may occur. This means that all households choose one specific region, and the populations of the other regions are zero. This approach appears unrealistic.

To avoid this phenomenon, we adopt a long run equilibrium framework that allows for heterogeneous preferences among households, as in Akamatsu et al. (2012). Specifically, we assume the following utility function:

$$\tilde{V}_r(\kappa) = V_r + \nu_r + \varepsilon_r(\kappa). \tag{28}$$

$\varepsilon_r(\kappa)$ denotes the utility representing the idiosyncratic taste of the residential location choice of individual household κ. ν_r represents the characteristics (fixed effects) of region r. A similar approach was adopted by Takayama et al. (2016), Ishikura et al. (2018), and Takayama et al. (2018).

Assuming that the distributions of $\{\varepsilon_r(\kappa), \forall\kappa\}$ are Gumbel distributions, we obtain the logit type location choice probability function:

$$P_r = \frac{\exp\{\theta(V_r + \nu_r)\}}{\sum\limits_{r\in\mathcal{R}} \exp\{\theta(V_r + \nu_r)\}}, \tag{29}$$

where θ is the heterogeneity of preferences, that is, the inverse of the variance parameter ε_r.

Our model imposes constraints on the residential choices of households. We assume that not all households can freely choose (migrate) their residences, and only a certain rate λ of regional households can migrate. The long run equilibrium condition is

$$N_r = \hat{N}_r + \tilde{N}_r, \tag{30}$$

$$\hat{N}_r = P_r \lambda N \tag{31}$$

and

$$(1-\lambda)N = \sum_{r\in\mathcal{R}} \tilde{N}_r, \tag{32}$$

where $\hat{N}_r$ denotes the number of households in region r that can migrate and $\tilde{N}_r$ denotes the number of households in region r that cannot. The total number of households in all regions N is exogenously given.

3.8 Derivation of stable equilibrium states

In the framework of the spatial economics model, it is known that there can be multiple long run equilibria and that there can be stable and unstable equilibria. Our model describes the transition of the economy from a benchmark equilibrium to a new stable long run equilibrium due to HSR. We adopt an iterative solution algorithm based on the logit-type perturbed best-response dynamics offered by Akamatsu et al. (2012), which is the only solution trajectory that converges from an arbitrary state to a stable equilibrium state. The law of motion for the volume of regional households in region r is:

$$\dot{N}_r = \frac{\exp\{\theta(V_r + \nu_r)\}}{\sum\limits_{r\in\mathcal{R}} \exp\{\theta(V_r + \nu_r)\}} N - N_r. \tag{33}$$

A stable long run equilibrium state is obtained by iteratively calculating the equilibrium state until a steady state is reached (Akamatsu et al. (2012)).

4 Estimation of impacts of SCMAGLEV

4.1 Scenario and data

This study considers the change in interregional travel time for passenger trips due to the opening of the new HSR, SCMAGLEV, as an exogenous change in transportation conditions. In Japan, HSR is used only to carry passengers and does not entail the transportation of freight. The modal share of vehicle transit is dominant in Japanese domestic freight transportation at more than 80% in terms of tonnage[1]. Therefore, we assume that the transportation margin in trade between the primary and manufacturing sectors depends only on the transportation time of the road network. HSR transport contributes only to trade in the tertiary industrial sector, which does not include commodity transport in our model.

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[1] source: Net Freight Flow Census 2015

Table 1: Elasticity parameter σ^i

sector(i)	1	2	3
σ^i	-2.6196	4.7643	2.3996
t-value	85.83***	35.59***	71.02***
N	1081	1081	1081
deviance	12.440	0.761	39.880

(*:$p < 0.05$, **:$p < 0.01$, ***:$p < 0.001$)

The model assumes that the supply and demand locations of the production factors are identical. This assumption holds for most Japanese prefectures. However, in some megacities, this assumption might not be satisfied due to the large number of commuters crossing prefectural borders. This can lead to an underestimation of the size of a city. Therefore, our regional classification introduces the urban employment area concept (Kanemoto and Tokuoka (2002)), in which municipalities linked by commuting are considered to fall under the same area. More than 80% of the municipalities in the three prefectures adjacent to Tokyo (Chiba, Kanagawa, and Saitama) and one prefecture adjacent to Osaka (Nara) belong to the Tokyo and Osaka UEAs, respectively. Therefore, we integrate these prefectures into the Tokyo Metropolitan Employment Area (Tokyo MEA) and the Osaka Metropolitan Employment Area (Osaka MEA). Eventually, the Japanese national economy is classified into 43 regions.

The industrial sectors were classified into three categories: primary (agriculture, forestry, and fisheries), manufacturing, and tertiary sectors. We use the inter-prefectural input-output table for 2005 produced by Ishikawa and Miyagi (2003) as the benchmark equilibrium data for calibrating the model parameters[2].

From the benchmark equilibrium data, we obtain the actual value of interregional trade in the goods sector. This study assumes that the shortest transport/travel time is an index of inter-regional trade barriers. Following the above assumption, we adopt freight transport time for goods trade (primary and manufacturing) and passenger travel time for service trade. The shortest paths between prefectures in terms of transport/travel time were extracted from the National Integrated Traffic Analysis System (NITAS) provided by the Ministry of Land, Infrastructure, Transport, and Tourism. Specifically, the representative point of the region was set as the prefectural capital, and the transportation modes used were freight transport, rail, and air for passenger travel. NITAS can extract the shortest transport/travel time and route between regions under the transportation network conditions as of October 2015.

We import the parameters with respect to the elasticity of substitution between the varieties of goods, σ^i from Ishikura et al. (2018) (Table 1). The transportation margin τ^i_{rs} in this model can be defined as a function of the trade barrier, namely, the shortest transport/travel time (min) t_{rs}:

$$\left(\tau^i_{rs}\right) = \left\{\exp\left(a^i \ln t_{rs}\right)\right\}^{\frac{1}{1-\sigma^i}} . \tag{34}$$

Sectoral interregional trade in the benchmark year Q^i_{rs} is given by the above inter-prefectural input-output table. The parameter a^i of (34) is estimated by converting (16) into the fixed-effects gravity form:

$$Q^i_{rs} = A_r B_s \left(\exp\left(a^i \ln t_{rs}\right)\right) \tag{35}$$

using the Poisson pseudo-maximum likelihood method. Table 2 presents the estimation results.

We follow the calibration process described in Ishikura and Yokoyama (2022). The benchmark data provide direct information for calibrating the parameters for the aggregated sectoral commodities. First, α^{ij}_s and β^i are calculated using the value shares of intermediate and consumption demand by sector. Subsequently, we obtain the regional production outputs S^i_r, factor income $w_s N_s$, and regional net exports $\overline{p^i_r z^i_r}$. The benchmark price system can be set arbitrarily owing to the Walrasian general equilibrium system. Solving (18) for n^i_r yields the benchmark equilibrium number of varieties. The final parameters ζ^i_r and Ψ^i_r are derived using (7) and (24), respectively.

The benchmark equilibrium state describes the situation before opening the SCMAGLEV. The transportation conditions after opening the SCMAGLEV were set according to the following procedure.

- Extract origin-destination pairs where the shortest route includes the section of Tokyo-Nagoya, Tokyo-Shin Osaka, and Shin Osaka-Nagoya, using the existing HSR, Shinkansen-Nozomi.

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[2] The newest available inter-prefectural input-output table, although the year of the data is not consistent with the transportation data.

Table 2: Transportation margin

sector(i)	1	2	3
a^i	-1.1848	-1.1697	-2.2063
t-value	-3.56	-14.30^{***}	-9.18^{***}
N	2209	2209	2209
deviance	6.45e+07	5.46e+08	1.27e+09

(*:$p < 0.05$, **:$p < 0.01$, ***:$p < 0.001$)

- The travel time for Tokyo-Nagoya, Tokyo-Shin Osaka, and Shin Osaka-Nagoya sections using SCMAGLEV are assumed to be 40 minutes, 67 minutes, and 27 minutes, respectively. [3].
- Replace the travel time of the above HSR sections with the travel time of SCMAGLEV and recalculate the shortest travel time and routes for the extracted origin-destination pairs.

By assumption, passenger travel time directly affects only the transportation margin for the service sector. Thus, the margin remained unchanged in the primary and manufacturing sectors.

Both θ, logit variance parameter, and λ, the fraction of households that can freely choose their residence, are not determined by the benchmark data, and therefore need to be given exogenously. In this study, we set $\theta = 1$ and $\lambda = 0.5$, although this is ad hoc.

4.2 Results and discussion

Table 3 summarizes the short run welfare impacts and changes in sectoral production, as well as long run population changes. The short run equilibrium of the model is equivalent to that of the static SCGE model with no interregional labor migration. EV is the equivalent valuation, which is an index of the aggregate regional benefit measured by the price system in the benchmark states (before policy implementation). The REV in Table 3 is called the relative equivalent valuation index (Bröcker (1998)) and is unaffected by the size of the economy. The REV is the rate of change in income (measured at pre-policy prices) required to achieve the post-policy utility level relative to pre-policy income, defined as $REV = \frac{V_{post} - V_{ante}}{V_{ante}}$. Note that V_{ante} and V_{post} are the utility levels before and after policy implementation, respectively.

Although we observe a rise and fall in sectoral production outputs, all regions experience positive benefits. In other words, because of changes in the competitive relationship between regions and industries, welfare improves in all regions in the new equilibrium state. There is no clear correlation between the changes in sectoral production and the magnitude of the benefits. Industrial specialization will progress in each region.

Geographically, the three regions where the SCMAGLEV nodes are located are Tokyo MEA, Aichi and Osaka MEA (Fig. 1) gain a significant benefit. In addition, relatively large benefits arise with SCMAGLEV and in areas where conventional HSR runs. This result supports the idea that nationwide economic development, which is a goal of SCMAGLEV development, should be discussed. While EV is a regional aggregate measure of benefits, REV is a proxy for welfare changes per regional household. Regional characteristics of the REV (Fig. 2) are slightly different from those of EV. Areas with large REV are more concentrated around Tokyo MEA, Aichi and Osaka MEA.

The long run equilibrium analysis, which focused on demographic change, showed more contrasting spatial characteristics (Fig. 3). Contrary to the trend in the spatial distribution of benefits in the short run equilibrium, the population is expected to decline in many regions of Japan. More specifically, almost every region north of the Tokyo MEA and west of the Osaka MEA will experience a population decline. The fairly large population growth results are almost consistent with regions with large REV in the short run equilibrium (Table 3), such as Gifu, Mie, Fukui, Wakayama, and the nodes of the SCMAGLEV (Tokyo MEA, Aichi and Osaka MEA).

The finding that a region with positive benefits in the short run equilibrium has a declining population in the long run may seem contradictory. The underlying mechanisms require further investigation. Because the benefits (and REV) that serve as welfare measures in the short run equilibrium are comparisons before and after policy implementation, they are positive if the level of utility in the region improves. By contrast, in the long run equilibrium, the choice probability of residence is defined by the relative relationship between utility levels, as in equation (29), and population movement is caused by the dynamics in equation (33). This implies that the positivity or negativity of the benefits in the short run equilibrium is not directly related to population

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[3] The operator, Central Japan Railway Company, announced the fare of SCMAGLEV would be almost similar to the conventional HSR.

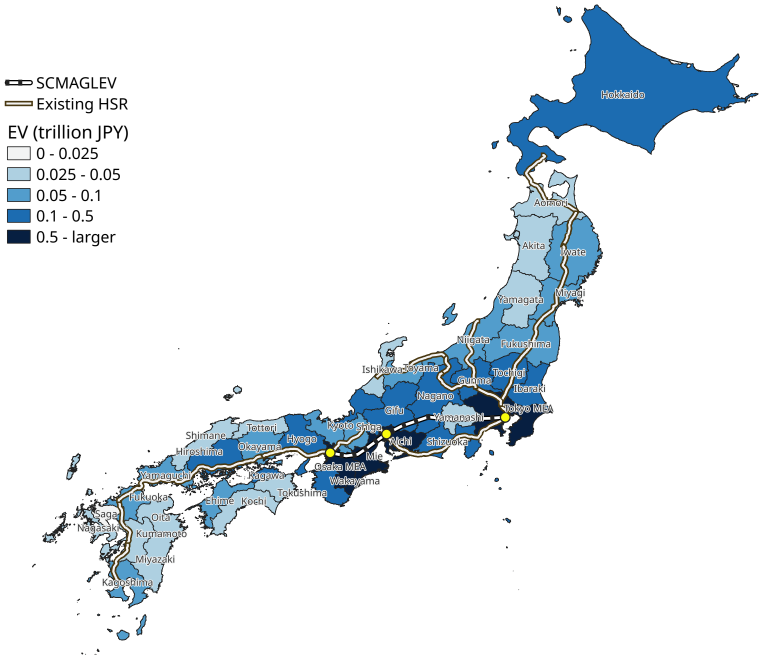

Figure 1: Regional benefit distribution (EV index)

increases or decreases. If the implementation of a policy leads to positive benefits in the short run, households in all regions may shift their residences from regions with relatively low levels of utility to those with high levels of utility, resulting in population decline, even in regions where welfare improves.

One of the main goals of the SCMAGLEV project is economic development in three metropolitan areas (Tokyo, Nagoya (Aichi), and Osaka) as well as other places along the HSR by improving fast and stable accessibility to metropolitan regions (Transportation policy council, Chuo Shinkansen subcommittee (2011)). Our analysis supports this purpose in terms of regional welfare improvement because of the positive benefits in every region. However, the results for the long run equilibrium imply that regional differences in benefits promote population concentration in the three metropolitan areas.

Japan's national population began to decline before 2010, and the population of municipalities outside Tokyo and a few other large metropolitan zones has been declining since then. Thus, even before the launch of SCMAGLEV, the Japanese population distribution continued to be concentrated in metropolitan areas. Our analysis suggests that the project will accelerate the centralization of population distribution and increase inter-regional disparities in population size.

Despite the aforementioned regional characteristics of demographic change, the magnitude of the population change is small, and the rate of change is less than 1 percent, as shown in 3. Therefore, under the assumptions and parameters of this analysis, population movement is almost negligible in terms of changes in national population distribution.

4.3 Sensitivity analysis with respect to λ

The parameters regarding the share of the immobile factor λ, set ad hoc in this study, may have contributed to the characteristics of these results. If the characteristics vary sensitively depending on λ, the findings of the model analysis are not robust. Therefore, the sensitivity of the long run equilibrium results was analyzed in relation to changes in λ.

The results of the sensitivity analysis show that there was no dramatic change in the population distribution property in response to changes in λ. For example, the results for the population-increasing and population-decreasing groups are presented in Fig.4 and Fig.5, respectively. Both figures indicate that the percentage change in the population reacts smoothly depending on the change in λ. There was no effect on the positive or negative direction of change, indicating that the population change pattern was robust to the proportion of immobile factors.

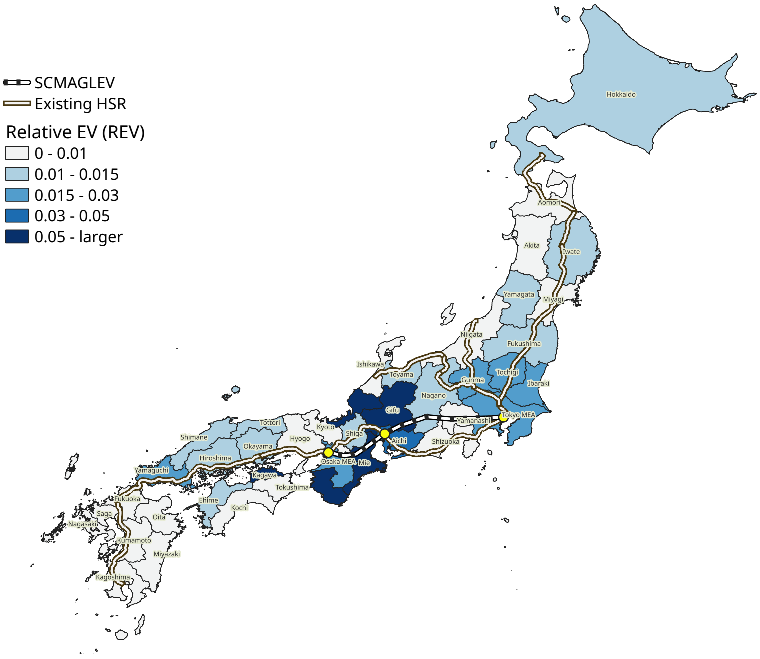

Figure 2: Short run welfare impacts (Relative EV (REV) index)

5 Concluding remarks

This study developed a quantitative model to estimate the economic and demographic impacts of developing an HSR system based on the theoretical framework of spatial economics. We conducted a simulation analysis of the impact of SCMAGLEV on the spatial economic system in Japan from the perspective of short and long run equilibrium concepts.

The estimated short run economic impacts are generally consistent with the intuitive expectation that large effects will be generated primarily in areas around Tokyo, Aichi and Osaka, which are the nodes of the SCMAGLEV. Furthermore, the results suggest a positive welfare effect for the entire region. Thus, our analysis supports the idea that the goals of the project will be achieved in terms of economic development.

In contrast to the trend in the spatial distribution of benefits in the short run equilibrium, the population is expected to decline in many regions in the long run. The long run results suggest that population agglomeration can develop only in areas near the SCMAGLEV nodes.

However, the population concentration in metropolitan regions due to migration implies depopulation in other regions. Although our analysis assumes that Japan's total population has remained unchanged, it is declining. Independent of the SCMAGLEV project, Japan's rural areas are losing their populations faster. The Japanese government is concerned about a declining labor force and falling national income due to population decline and aging. In particular, there are concerns regarding the rapid shrinkage of local economic societies in rural areas (Ministry of Health, Labour and Welfare (2015)).

This study suggests that the SCMAGLEV project will accelerate the population concentration in metropolitan areas. Population decline in rural areas may not have been the desired outcome of the project. However, as the welfare impacts in the short run analysis suggest, accessibility development of the trunk transportation system leads to productivity improvement in the national economy. Thus, the demographic change brought about by this transportation policy was efficient population relocation and not problematic migration.

Acknowledgements

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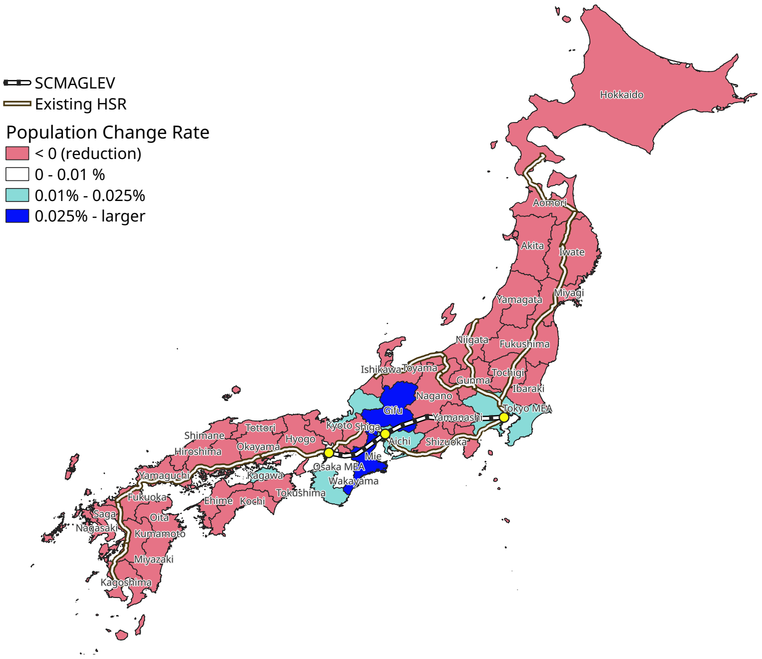

Figure 3: Long run results (rate of change in population)

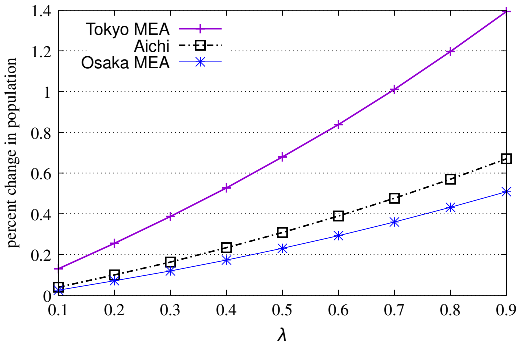

Figure 4: Sensitivity analysis (selected increasing group)

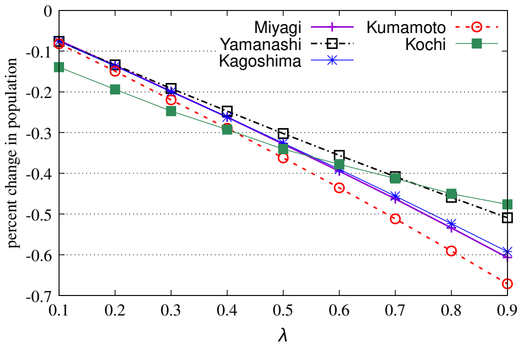

Figure 5: Sensitivity analysis (selected decreasing group)

A Closure rules of regional accounts

Let ρ_s be the ratio of the sum of the aggregate disposable income of regional households $N_s^0 E_s^0$ and the external surplus over the ROW X_r^{ROW0} to the factor income Y_s^0 in the benchmark equilibrium.

$$\rho_s = \frac{N_s^0 E_s^0 + X_r^{ROW0}}{Y_s^0} \tag{36}$$

This study assumes ρ_s is a fixed coefficient even in the new equilibrium state. In other words, we assume that the impact of transportation policy on macroeconomic borrowing and lending relationships between regions is negligible. Introduce a new parameter

$$\rho = \frac{\sum_{r\in\mathcal{R}} \rho_s Y_s}{\sum_{r\in\mathcal{R}} Y_s}. \tag{37}$$

Assuming regional accounts,

$$N_s E_s = \frac{\rho_s Y_s}{\rho} - X_s^{ROW}, \tag{38}$$

the regional balance of payments can be closed in the new equilibrium without contradicting either the balance of payments relationship with the ROW or the other regional economies in the study area. Note that ρ is a variable that depends on the change in Y_s associated with a change in the equilibrium state. Thus, we can rewrite Equation (22) as

$$f\left(Y_s\right) = \frac{\rho_s Y_s}{\rho}. \tag{39}$$

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Table 3: Summary of results

	EV∗	REV	change in sectoral outputs∗			change in population (%)
			Sector1	Sector2	Sector3	
Hokkaido	0.2293	0.0103	-0.01	-0.10	0.05	-0.29
Aomori	0.0452	0.0089	0.00	-0.02	0.00	-0.30
Iwate	0.0680	0.0139	0.01	-0.02	-0.01	-0.25
Miyagi	0.0532	0.0059	-0.02	-0.11	0.02	-0.32
Akita	0.0409	0.0097	0.00	-0.02	0.00	-0.29
Yamagata	0.0455	0.0102	0.07	-0.10	-0.01	-0.28
Fukushima	0.0772	0.0102	-0.14	-0.01	0.06	-0.27
Ibaraki	0.2732	0.0240	-0.09	0.49	-0.18	-0.15
Tochigi	0.1767	0.0246	-0.07	0.18	-0.06	-0.08
Gunma	0.1719	0.0239	-0.04	0.20	-0.08	-0.11
Tokyo MEA	2.7299	0.0182	0.21	-7.85	7.59	0.22
Niigata	0.0932	0.0097	0.04	-0.14	0.01	-0.29
Toyama	0.0553	0.0130	0.06	-0.12	0.01	-0.30
Ishikawa	0.0417	0.0086	-0.05	-0.05	0.02	-0.30
Fukui	0.2004	0.0657	-0.07	0.18	-0.06	0.24
Yamanashi	0.0256	0.0076	0.01	-0.03	-0.01	-0.29
Nagano	0.1091	0.0137	0.08	-0.10	-0.02	-0.25
Gifu	0.4993	0.0710	-0.05	1.17	-0.51	0.67
Shizuoka	0.1135	0.0081	-0.13	-0.31	0.20	-0.31
Aichi	0.9840	0.0314	-0.10	10.97	-4.22	0.24
Mie	0.5015	0.0643	-0.08	1.01	-0.40	0.81
Shiga	0.0707	0.0128	-0.01	-0.39	0.15	-0.15
Kyoto	0.0899	0.0100	-0.02	-0.99	0.26	-0.18
Osaka MEA	0.8229	0.0213	-0.01	1.07	0.26	0.11
Hyogo	0.1761	0.0091	-0.02	-1.42	0.58	-0.20
Wakayama	0.2204	0.0617	-0.08	0.27	-0.13	0.32
Tottori	0.0269	0.0117	0.00	-0.02	0.00	-0.26
Shimane	0.0379	0.0128	0.00	-0.02	0.00	-0.24
Okayama	0.0839	0.0115	0.03	-0.15	0.02	-0.25
Hiroshima	0.1328	0.0117	0.11	-0.26	0.01	-0.25
Yamaguchi	0.0928	0.0169	0.09	-0.08	-0.01	-0.25
Tokushima	0.0260	0.0083	-0.09	0.04	0.01	-0.33
Kagawa	0.1833	0.0516	0.57	-0.36	-0.11	0.23
Ehime	0.0589	0.0105	-0.02	-0.05	0.01	-0.27
Kochi	0.0251	0.0087	-0.01	-0.01	0.00	-0.28
Fukuoka	0.0917	0.0051	0.06	-0.41	0.07	-0.33
Saga	0.0161	0.0057	-0.03	-0.03	0.01	-0.35
Nagasaki	0.0331	0.0069	-0.02	-0.04	0.00	-0.33
Kumamoto	0.0333	0.0056	-0.09	-0.07	0.04	-0.35
Oita	0.0388	0.0083	-0.02	-0.07	0.01	-0.33
Miyazaki	0.0301	0.0071	-0.01	-0.03	0.00	-0.32
Kagoshima	0.0547	0.0090	-0.01	-0.06	0.01	-0.32
Okinawa	0.0416	0.0101	0.00	-0.01	-0.01	-0.29

∗ unit: trillion JPY