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Abstract

This study aims to clarify the existence of regional differences and the impact of the 2008 Lehman (Brothers) shock, the collapse of a major U.S. securities firm that triggered the global financial crisis, on these differences based on the regional cost-of-living index (RCLI) in Japan. We apply a methodology developed by Kakwani and Hill (2002), which is an axiomatic approach for constructing the multilateral spatial cost-of-living indices, to compare the price levels of households between regions of Japan. The results show that, overall, a shrinkage of regional differences after the Lehman shock. However, the impact of the Lehman shock on the cost of living varies from region to region. In Japan, the Lehman shock lowered the RCLI in urban areas rather than rural areas. This finding implies that urban areas in Japan are more susceptible to macro shocks, which reduce regional differences with rural areas. Furthermore, based on the results of the cost-of-living index by group commodity, we offer a policy implication for the fundamental elimination of regional differences between Japan's urban and rural areas. This would encourage, for example, an increase in the cost of living in rural areas through increased public transport investment and costs, an accompanying increase in rent of housing in surrounding areas, and an increase in communication costs owing to the spread of high-speed Internet services, such as 5G.

Keywords: Regional cost-of-living index; group commodity; Fisher index; multi-regional comparison; the Lehman shock

JEL classification codes: D12, R22

Ⅰ. INTRODUCTION

Recently, in Japan, a policy of "regional revitalisation" (*Chihou Sousei* in Japanese)[1] has attracted attention. This policy aims to revitalise Japan's entire economy by reducing overconcentration in Tokyo. For the purpose of revitalising the regional economy from the perspective of households, it would be effective to increase the cost of living in regions other than Tokyo to eliminate the difference in the cost of living between regions, particularly between urban and other areas. Meanwhile, in the Japanese economy, exogenous macro shocks have occurred and affected households, such as the Lehman shock in 2008. This event had the greatest impact on Japanese households through falling income and prices. It reduced the real GDP growth rate for 2008 to -3.4%, the biggest decline the Japanese economy has faced since World War II. In addition, in the consumer price index (CPI), the growth rate in the following year, 2009, was -1.4%, which was expected to be detrimental for households. Under these circumstances, an impact on the cost of living at the regional level could be expected. In addition, Japanese households at the regional level might have been feeling the effects of the Lehman shock for some time.

Japan has 47 prefectural government cities organised in nine regions. Regional variations in average annual temperatures, food cultures, and traffic conditions, among other factors, generate differences in weight at the item level for group commodities in the CPI and also affect group commodity prices.

In a demand analysis based on panel data at the regional level, the importance of commodities may differ across regions. In other words, it is not usually realistic to assume that the commodity price level is identical throughout a region. For example, the price level of housing in Sapporo, north of the Japanese archipelago, is not identical to that of Naha, in the south. Similarly, the cost of living by group commodity is not identical throughout a region.

The purpose of this study is to verify the regional differences in the cost-of-living index and to clarify the differences in the effects of the Lehman shock on the cost of living by region. We discuss the realisation of regional revitalisation from the perspective of households. Furthermore, to clarify these differences, we apply a methodology developed by Kakwani and Hill (2002), which is an axiomatic approach for constructing the multilateral spatial cost-of-living indexes, to compare the price levels of households in different regions of a country. In Japan, from the perspective of welfare cost, Miyakoshi (2010) measures the cost disparity during the 'lost decade' of the Japanese economy from 1990 to 2002 using consumer groups incorporating income quintiles and nine regions. The author shows the costs in the low- and middle-income quintiles and in urban areas are much higher. On the other hand, this is the first study to measure the effects of a macro shock such as the Lehman shock from the perspective of the regional cost of living in Japan. Furthermore, the present study is useful for measuring the impact of future macro shocks, such as the coronavirus pandemic, on households' cost of living.

Ravallion and Walle (1991) show that, in a developing country, the cost-of-living index in the urban areas is substantially higher than in rural areas. The authors adopt housing and rice as commodities with spatial disparities in prices and show that housing prices significantly differ between urban and rural areas. On the other hand, Araya and Rivera (2013) develop a spatial housing price index in Chile by comparing several estimation methods and show that the axiomatic approach, such as the demand system, generally understate the spatial index compared with the hedonic approach. However, in the axiomatic approach as well, regional disparities are naturally measured, similar to those in other literature. Kurre (2003) investigates these regional disparities in developed countries such as the United States.

The structure of the rest of this paper is as follows. In section Ⅱ, we introduce the almost ideal demand system (AIDS) model advocated by Deaton and Muellbauer (1980) as an estimation model. Section Ⅲ discusses the data sources. Section Ⅳ provides estimates of the cost-of-living index for 47 cities, which are then compared with different regions. Finally, section Ⅴ concludes.

Ⅱ. MODEL SPECIFICATION

a) Estimation model

To measure the regional differences in the cost-of-living index, the exact functional form of a Japanese representative household's expenditure needs to be specified. The previous studies often define the appropriate demand function using the AIDS model proposed by Deaton and Muellbauer (1980). In this study, we extend this model to the regional dimension. First, we define the price independence generalized logarithmic (PIGLOG) cost function for a regional dimension *k*:

$$\ln e(\mathrm{u_k}, \mathbf{p}_\mathrm{k}) = a(\mathbf{p}_\mathrm{k}) + \mathrm{u_k}\, b(\mathbf{p}_\mathrm{k}), \tag{1}$$

where $a(\mathbf{p}_\mathrm{k})$ and $b(\mathbf{p}_\mathrm{k})$ are homogeneous functions of degree one and zero in $\mathbf{p}_\mathrm{k}$, respectively; $\ln e(\mathrm{u_k}, \mathbf{p}_\mathrm{k})$ is the minimal cost for achieving utility $\mathrm{u_k}$ while facing price vector $\mathbf{p}_\mathrm{k}$ in region *k*. This study is interested in measuring the RCLI when different regions are allowed to experience different prices $\mathbf{p}_\mathrm{k}$. Therefore, we express $a(\mathbf{p}_\mathrm{k})$ and $b(\mathbf{p}_\mathrm{k})$ as functions of the prices in region k, as follows:

$$a(\mathbf{p}_\mathrm{k}) = \alpha_0 + \alpha'\ln\mathbf{p}_\mathrm{k} + \frac{1}{2}(\ln\mathbf{p}_\mathrm{k})'A(\ln\mathbf{p}_\mathrm{k}), \qquad (2)$$

$$b(\mathbf{p}_\mathrm{k}) = \beta_0 + \beta'\ln\mathbf{p}_\mathrm{k}, \qquad (3)$$

where α and β are $n \times 1$ vectors and A is an $n \times n$ matrix. Second, applying Shephard's lemma to the cost function (1), we obtain the budget shares in region k as follows:

$$\mathbf{w}_\mathrm{k} = \alpha + A(\ln\mathbf{p}_\mathrm{k}) + \beta\ln\left(\frac{x_k}{P_k}\right) + \delta\ln\mathbf{z}_k + \boldsymbol{\varepsilon}_k \qquad (4)$$

$$\text{for} \quad k = 1, \ldots, K,$$

where $\mathbf{w}_\mathrm{k}$ denotes the budget share in the region k, $\ln\left(\frac{x_k}{P_k}\right)$ is the logarithm of the real expenditure, $\ln\mathbf{z}_k$ is the logarithm of demographic variables, and $\ln P_k$ is the aggregate price index in region k. $\ln P_k$ is given by

$$\ln P_k = \alpha_0 + \alpha'\ln\mathbf{p}_\mathrm{k} + \frac{1}{2}(\ln\mathbf{p}_\mathrm{k})'A(\ln\mathbf{p}_\mathrm{k}) \qquad (5)$$

The price index of (5) is non-linear. In our estimation, a linearly approximated price index is typically used to avoid the complications induced by estimation of a non-linear price index. Originally, in the AIDS model, when a non-linear price index is used for estimation, it is difficult for the parameters to converge, especially the constant term α_0. In addition, it is uncertain how to transform the panel estimation to obtain consistent and unbiased estimators in a non-linear fixed effects model.[2] Therefore, we use $\ln P_k^s$, the linear approximation proposed by Stone (1954), in substitution for (5):

$$\ln P_k^s = \mathbf{w}_\mathrm{k}\ln\mathbf{p}_\mathbf{k}. \qquad (6)$$

In addition, in the AIDS model, the conditions of adding-up, homogeneity, and symmetry in the parameters must be satisfied. The adding-up condition, which is automatically satisfied using the $n-1$ equations in the estimation, implies $\alpha' I = 1$ and $\beta' I = AI = 0$, where I is the $n \times 1$ vector whose elements all equal 1. The homogeneity restriction implies $\beta' I = 0$, and the symmetry restriction implies $A = A'$. These two restrictions are imposed on the parameters in the estimation of (4).

In the proposed model, the error term $\boldsymbol{\varepsilon}_k$ in (4) can be written as:

$$\boldsymbol{\varepsilon}_k = \boldsymbol{\mu}_k + \mathbf{v}_{kt}, \qquad (7)$$

where $\boldsymbol{\mu}_k$ denotes the individual fixed effect in region k. In addition, $\mathbf{v}_{kt}$ is usually assumed to be strictly exogenous, with $E(\boldsymbol{v} \mid \boldsymbol{\mu}, \ln\mathbf{p}, \ln(\mathbf{x}/\mathbf{P})) = 0$.

b) Regional cost-of-living index with multi-regional comparison

The cost-of-living index is expressed as the ratio of the minimal cost required to achieve a certain utility level and the price change of a commodity. Many previous studies, such as Deaton and Muellbauer (1980), Fry and Parshardes (1989), Lewbel (1989), Pollak (1989), Diewert (2001), and Kakwani and Hill (2002), have focused on the cost-of-living index of demand systems. Among them, Kakwani and Hill (2002) develop an axiomatic approach to construct bilateral and multilateral spatial cost-of-living indexes. They compare the cost-of-living indexes in Thailand using the Paasche, Laspeyres, Fisher, and Tornqvist indexes and show that the Fisher and Tornqvist indexes outperform the Paasche and Laspeyres indexes.

In this study, we use the Fisher cost-of-living index, which is the geometric mean of the Laspeyres and Paasche indexes. The Laspeyres index reflects the cost of maintaining the utility level of a reference region when faced with the prices of a comparison region. Meanwhile, the Paasche index states the cost of maintaining the utility level when faced with the prices of a comparison region. In general, the Laspeyres index tends to overestimate increases in price, while the Paasche index tends to underestimate them. Furthermore, since these indexes ignore the substitution possibility to use a fixed basket, they may produce biased estimates. Conversely, the Fisher index should avoid this problem because it takes into account the consumption basket of both regions.

The regional cost function of (1) is estimated using the parameters in (4). Since $a(\mathbf{p}_k)$ in (2) can be approximated identically the aggregate price index of (5), the initial value of α_0 is set so that the value of $a(\mathbf{p}_k)$ does not deviate from the value of the aggregate price index in the estimation of the cost function.[3] Furthermore, we assume that there is a regional price differences between the reference and comparison regions. The Fisher cost-of-living index is given by

$$RCLI(\mathbf{p}_\mathrm{k}, \mathbf{p}_\mathrm{s}, \mathrm{u}_\mathrm{k}, \mathrm{u}_\mathrm{s}) = \frac{1}{2}\left[\frac{\ln e(\mathrm{u}_\mathrm{k}, \mathbf{p}_\mathrm{s})}{\ln e(\mathrm{u}_\mathrm{k}, \mathbf{p}_\mathrm{k})} + \frac{\ln e(\mathrm{u}_\mathrm{s}, \mathbf{p}_\mathrm{s})}{\ln e(\mathrm{u}_\mathrm{s}, \mathbf{p}_\mathrm{k})}\right], \tag{8}$$

where $\mathbf{p}_\mathrm{k}$ and $\mathbf{p}_\mathrm{s}$ represent the price vectors of the reference region *k* and the comparison region *s*, respectively. The first term in square brackets of (8) represents the Laspeyres cost-of-living index, which is determined by a ratio of the minimal cost function given the utility level u_k incurred by the reference region when faced with the comparison prices $\mathbf{p}_s$ relative to the cost incurred by a reference region when faced with the reference prices $\mathbf{p}_\mathrm{k}$. Similarly, the second term in square brackets represents the Paasche cost-of-living index, which is determined by a ratio of the minimal cost function given the utility level u_s occurred by the comparison region when faced with the comparison prices $\mathbf{p}_\mathrm{s}$ relative to the cost occurred by a comparison region when faced with the reference prices $\mathbf{p}_\mathrm{k}$. The Fisher cost-of-living index is calculated by using both the price changes and utility levels of both the reference and comparison regions.

Following Kakwani and Hill (2002), we extend (8) to comparisons across multiple regions:

$$RCLI_{ks} = \frac{1}{R}\sum_{r-1}^{R}(RCLI_{kr} - RCLI_{sr}), \tag{9}$$

where $R \geqq 3$. However, it is assumed that the ratio of the cost of living in regions *k* and *s* does not depend on region *R*, which is the base region. The extension to multi-regional comparisons allows the measurement of not only the ratio of minimal costs between two regions but also the average of the ratios between higher regions.

c) Regional cost-of-living index for each group commodity

In this subsection, we define the cost-of-living index by group to examine the cost of each group. First, we assume that there are 10 groups of commodities, such as food, housing, fuel, light and water charges, furniture and household utensils, clothing and footwear, medical care, transportation and communication, education, culture and recreation, and other consumption expenditures; the indexes that correspond to these groups are calculated as group cost-of-living indexes. Second, we assume that if the utility function is weakly separable in the partition $[x^1, x^2, \dots, x^N]$ of N groups, where x^m is the *m*-th group expenditure, then any group is separable from the remaining groups.[4] The cost-of-living index for the *m*-th group of commodity is given by the geomean of the ratio of group cost functions:

$$RCLI^m\left(\mathbf{p}_k^m,\mathbf{p}_s^m,\mathbf{p}_k^l,\mathbf{p}_s^l,\mathrm{u}_k^m,\mathrm{u}_s^m\right)=\frac{1}{2}\left[\frac{\ln e\left(\mathrm{u}_k^m,\mathbf{p}_s^m,\mathbf{p}_s^l\right)}{\ln e\left(\mathrm{u}_k^m,\mathbf{p}_k^m,\mathbf{p}_k^l\right)}+\frac{\ln e\left(\mathrm{u}_s^m,\mathbf{p}_k^m,\mathbf{p}_k^l\right)}{\ln e\left(\mathrm{u}_s^m,\mathbf{p}_k^m,\mathbf{p}_k^l\right)}\right], \tag{10}$$

where $\mathbf{p}_k^m$ and $\mathbf{p}_s^m$ represent the own-price vector for the *m*-th group of commodities in reference region *k* and comparison region *s*. Furthermore, $\mathbf{p}_k^l$ and $\mathbf{p}_s^l$ represent the cross-price vector for the *l*-th group in reference region *k* and comparison region *s*, respectively. In other words, the cost of the *m*-th group of commodities is influenced by the cross-price term. The group cost-of-living index is expressed by the group cost function. The group index of the cost of living of (10) differs in concept from the complete index. Moreover, it is not possible to combine group indexes to obtain the aggregate cost-of-living index. Furthermore, similar to (9), the group cost-of-living index of (10) is extended to a multi-regional comparison.

Ⅲ. DATA

The household survey data used in this study comprise monthly data for workers' households in 47 prefectural capital cities. We obtain data on expenditures for each group commodity and household demographics from the *Family Income and Expenditure Survey* (*Kakei Chosa* in Japanese) conducted by the Japanese Statistics Bureau from January 2000 and December 2016. We classify expenditure data into 10 major categories: food; housing (without accounting for imputed rent); fuel, light, and water charges; furniture and household utensils; clothing and footwear; medical care; transportation and communication; education; culture and recreation; and other consumption expenditures. The demographic data used include the number of household members, age of the household head, and home ownership rate. However, expenditure data for Sendai and Fukushima are not available from April to May 2011, as they were severely damaged by the Great East Japan Earthquake. For this problem, based on listwise deletion to deal with missing values, we use a total of 9585 observations in the analysis. In addition, we conduct t-tests to determine whether the distributions of the two samples are statistically equal in the balanced on listwise deletion and unbalanced samples. Table A.I shows that no significant differences are statistically found for all variables. In other words, there is no distribution effect of deleting the missing values.

We also obtain price data from the CPI as the 2015 standard. In Japan, the regional CPI for housing prices without accounting for imputed rent is not published. Therefore, we omit imputed rent when calculating the series for housing by removing imputed rent from existing housing prices. However, we face a statistical constraint: imputed rent exists only in Tokyo and is not disclosed for each city. To address this data constraint, we create imputed rent data for each city based on the CPI weights as the 2015 standard.

Imputed rent is usually included in statistical data, but it has been pointed out that the imputed rent itself is underestimated as a statistical problem in Japan (Arai 2005). In other words, by including imputed rent, the CPI and the cost-of-living index itself may be underestimated. This problem is serious when calculating regional differences. Therefore, in this study, the imputed rent is removed from expenditure and housing prices.

Table I shows the regional average prices of the 10 group commodities used in this study. The housing price series does not account for imputed rent. For the housing price, the difference between the maximum and minimum values is large, and the standard deviation is also large. Since housing prices that do not consider imputed rent depend on such items as net rent and housing equipment and repair, the price difference is large across regions.[5] Furthermore, the furniture and household utensils price series has a high average and is also large across regions. In the demand system, the logarithm of real expenditure is generally perceived as the logarithm of real income. The average difference across regions in the logarithm of real expenditure in Japan is smaller than that in other countries.

The map of Japan in Figure 1 shows the 47 cities analysed in our study in nine regions (Hokkaido, Tohoku, Kanto, Chubu, Kinki, Chugoku, Shikoku, Kyushu, and Okinawa). Since Tokyo is the capital and the economic center of Japan, we set Tokyo, which belongs to the Kanto region, as the reference region in this study. In addition, Tokyo has a large economic scale (e.g., in terms of GDP), and a significant difference in the cost-of-living index exists between Tokyo and other cities. The surrounding area of Tokyo is called the *Greater Tokyo area*, and it includes Tokyo, Chiba, Saitama, and Yokohama. This area has a higher GDP[6] and population concentration than the rest of Japan. After Tokyo, Osaka is Japan's second largest city. The surrounding area of Osaka is called the *Greater Osaka area*, and it includes Osaka, Kyoto, Kobe, and Nara. In general, the nine cities of Sapporo, Tokyo, Yokohama, Nagoya, Kyoto, Osaka, Kobe, Hiroshima, and Fukuoka are positioned as major cities based on their population and economic scale.

Table I Descriptive statistics of log prices and log real expenditure

variables	Average	S.D.	Min	Max
$\ln p_1$	4.540	0.037	4.443	4.659
$\ln p_2$	4.566	0.154	3.786	5.011
$\ln p_3$	4.485	0.076	4.308	4.702
$\ln p_4$	4.717	0.134	4.480	5.226
$\ln p_5$	4.574	0.055	4.367	4.791
$\ln p_6$	4.606	0.023	4.474	4.697
$\ln p_7$	4.589	0.020	4.524	4.735
$\ln p_8$	4.633	0.070	4.457	4.865
$\ln p_9$	4.654	0.073	4.502	4.935
$\ln p_{10}$	4.524	0.049	4.419	4.635
$\ln \frac{x}{P}$	12.627	0.149	11.579	13.394

Notes: Descriptive statistics for 9585 observations. S.D denotes the standard deviation. Subscript numbers represent the following commodities as 1. food, 2. housing, 3. fuel, light and water charges, 4. furniture and household utensils, 5. clothing and footwear, 6. medical care, 7. transportation and communication, 8. education, 9. culture and recreation, and 10. other consumption expenditures.

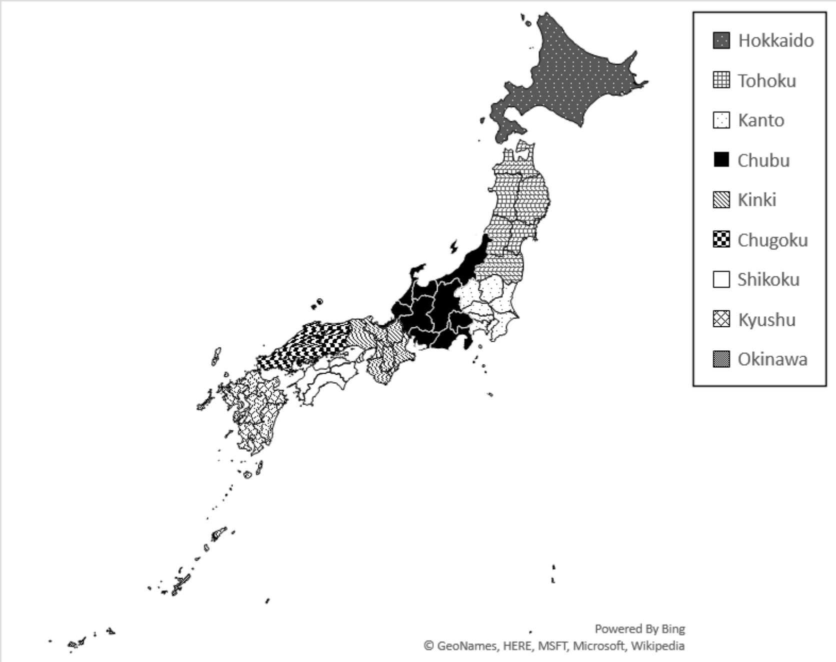

Figure 1. Map of Japan

Ⅳ. MEASURING JAPAN'S REGIONAL COST-OF-LIVING INDEXES

a) Estimation results

Table II shows the estimation results of (4). All own-price parameters are statistically significant at the 5% level. However, the coefficient on the cross-price term of clothing and recreation is mostly not significant, but the cross-price parameters of housing, fuel, and transportation and communication are all significant. Furthermore, an increase in the number of household members increases the budget shares for food; fuel, light, and water charges; and education. Meanwhile, the older the household head increases the budget shares for food; fuel, light, and water charges; and furniture. In Japan, household heads are ageing, and these budget shares tend to increase. Furthermore, the home ownership rate is significant only for housing shares. In other words, the increase in the home ownership rate effectively decreases the housing share without accounting for imputed rent.

As described in Section III, the results of this study are based on listwise deletion to deal with missing values. As a result, 3 out of 9588 observations were removed from the estimation, but these account for only 0.04% of the total. This method generates estimator bias when there are many missing values, and the standard error becomes large. However, in this study, the estimation results have sufficiently small standard error, and the impact of listwise deletion is considered small, as shown in Table A.I. However, to ascertain that the estimation results are not misleading, we added the quasi-Hausman tests by Verbeek and Nijman (1992) to confirm the robustness of the results. Essentially, this is a test for attrition bias, but it implicitly analyses whether deleting missing values has any effect on the estimators. In addition, it the assumption that the attrition is random, which is not the case in this study, and therefore, we allowed this assumption to be relaxed. The lower part of Table II shows the quasi-Hausman test results. First, we tested against the null hypothesis that there is no difference in the estimator and variance-covariance matrix based on the balanced and unbalanced samples. As a result, the null hypothesis was not rejected at 5% level of significance, and the presence of estimator bias by deleting the missing values was not confirmed. Second, we incorporated a method of supplementing

Table II Estimated results

	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9
$\ln p_1$	0.3115	—	—	—	—	—	—	—	—
	(0.007)								
$\ln p_2$	-0.0089	0.0185	—	—	—	—	—	—	—
	(0.002)	(0.002)							
$\ln p_3$	-0.0168	-0.0026	0.1090	—	—	—	—	—	—
	(0.003)	(0.001)	(0.002)						
$\ln p_4$	-0.0054	-0.0038	-0.0019	0.0501	—	—	—	—	—
	(0.003)	(0.001)	(0.002)	(0.003)					
$\ln p_5$	-0.0426	-0.0013	-0.0034	0.0030	0.0556	—	—	—	—
	(0.004)	(0.001)	(0.002)	(0.002)	(0.005)				
$\ln p_6$	-0.0446	-0.0026	-0.0104	-0.0079	0.0040	0.0399	—	—	—
	(0.005)	(0.001)	(0.003)	(0.003)	(0.004)	(0.006)			
$\ln p_7$	-0.1148	0.0069	0.0119	-0.0316	-0.0197	-0.0208	0.2054	—	—
	(0.008)	(0.004)	(0.004)	(0.005)	(0.005)	(0.007)	(0.025)		
$\ln p_8$	-0.0160	-0.0071	-0.0081	-0.0207	-0.0022	0.0098	-0.0421	0.0738	—
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.008)	(0.005)	
$\ln p_9$	-0.0075	-0.0012	-0.0160	-0.0060	0.0117	0.0003	-0.0523	0.0036	0.1017
	(0.005)	(0.002)	(0.003)	(0.004)	(0.004)	(0.004)	(0.009)	(0.004)	(0.007)
$\ln \frac{x}{P}$	-0.1030	-0.0102	-0.0525	-0.0019	0.0066	-0.0100	-0.0399	0.0112	0.0188
	(0.004)	(0.003)	(0.002)	(0.004)	(0.003)	(0.003)	(0.013)	(0.007)	(0.006)
$\ln z_1$	0.0726	-0.0142	0.0276	-0.0041	-0.0039	-0.0008	-0.0270	0.0940	-0.0028
	(0.004)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.012)	(0.006)	(0.005)
$\ln z_2$	0.0744	-0.0198	0.0319	0.0024	-0.0171	-0.0021	-0.0306	-0.0389	-0.0382
	(0.005)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)	(0.017)	(0.009)	(0.007)
$\ln z_3$	0.00001	-0.0003	0.00001	0.00003	0.00002	-0.00001	0.0001	0.00006	0.00002
	(2E-05)	(1E-05)	(1E-05)	(2E-05)	(1E-05)	(2E-05)	(6E-05)	(4E-05)	(3E-05)

quasi-Hausman test

Case:	Chi-square statistic	p-value
a) balanced sample vs. unbalanced sample	165.971	1.000
b) balanced sample vs. complemented sample by the average	-28.468	1.000
c) balanced sample vs. complemented sample by the PLS	-1.704	1.000

Notes: The value in parentheses represents the standard error. $\ln z_1$ denotes the number of households, $\ln z_2$ denotes the age of household head, and $\ln z_3$ denotes the home ownership rate. The homogeneity and symmetry restrictions are imposed on parameters. A quasi-Hausman tests were performed on differences between the balanced and unbalanced samples, between the balanced and complemented samples by the average, and between the balanced and complemented samples by the panel least squares, based on both estimators and the variance-covariance matrix. The quasi-Hausman statistic can be negative in a finite sample. The estimation results for the unbalanced and two complemented samples were omitted to reduce the space. The results of these estimations can be requested.

missing values with averages and estimates. One was to supplement the missing values with the average of the 3 months before and after the Great East Japan Earthquake, including March 2011. The other was to supplement the missing values with estimates using the panel least squares method. Based on these estimation results, we performed quasi-Hausman tests and confirmed there was no statistically significant difference for both balanced samples with listwise deleted values and with complementary values. Based on these results, the misleading estimation results due to the removal of missing values is almost negligible in this study.

In addition, we measured the goodness of fit of the model to ensure that the estimation results were robust out-of-sample. Table III shows the average of the out-of-sample observed values and the predicted values based on the estimated results. The estimated budget shares were measured without significant deviation from the observed values. In addition, we calculated the root mean square error (RMSE) and mean absolute error (MAE) to measure the goodness of fit of the estimated model. Both results show that there is good fit of the model to the real data scenarios even out of the sample period.

Furthermore, the results of this study were estimated under the assumption of separability for group commodities. However, it should be confirmed beforehand that not making this assumption does not affect the estimation results. For the case without a weak separability assumption, we applied the generalised composite commodity theorem (GCCT) proposed by Lewbel (1996). However, it is necessary to assume that the relative price vectors of the *i*-th commodity price and the group price are independent of the aggregate expenditure and the price index. The estimation results without weak separability are presented in Table A.II. Some of the estimates are somewhat different from Table II, but not so different as to override the direction of the estimation results. Overall, similar results were derived and found to be robust to this analysis. In addition, the lower part of Table A.II shows that the likelihood ratio test comparing the log likelihoods of the two models had no statistically significant differences between the cases with and without the assumption of weak separability, indicating robustness to the original results. In other words, it would be possible to derive similar results even if weak separability were not assumed.

Table III Goodness of fit in out-of-sample period, from January 2000 to April 2020

Variables	Average		RMSE	MAE
	Observed	Estimated		
w_1	0.263 (0.034)	0.252 (0.022)	0.023	0.018
w_2	0.019 (0.015)	0.018 (0.009)	0.014	0.008
w_3	0.073 (0.018)	0.075 (0.014)	0.009	0.007
w_4	0.038 (0.014)	0.036 (0.058)	0.015	0.010
w_5	0.041 (0.011)	0.044 (0.007)	0.014	0.012
w_6	0.041 (0.014)	0.037 (0.036)	0.014	0.010
w_7	0.163 (0.058)	0.153 (0.014)	0.060	0.039
w_8	0.056 (0.037)	0.056 (0.019)	0.031	0.022
w_9	0.098 (0.022)	0.104 (0.012)	0.022	0.017
w_{10}	0.206 (0.045)	0.226 (0.031)	0.049	0.038

Notes: The value in parentheses represents the standard deviation. The RMSE is calculated by $\sqrt{1/T\sum_{t=1}^{T}(w_i - \widehat{w}_i)^2}$ where $\widehat{w}_i$ denotes the estimated budget share. In addition, the MAE is calculated by $1/T\sum_{t=1}^{T}|w_i - \widehat{w}_i|$.

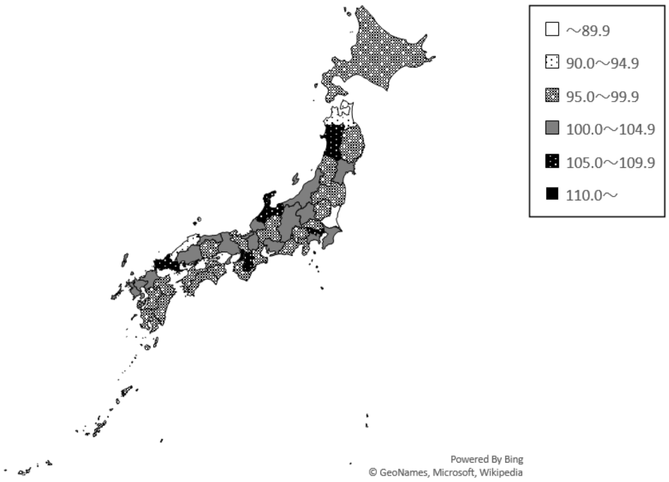

Figure 2a. The average RCLI in 47 cities from January 2000 to October 2008

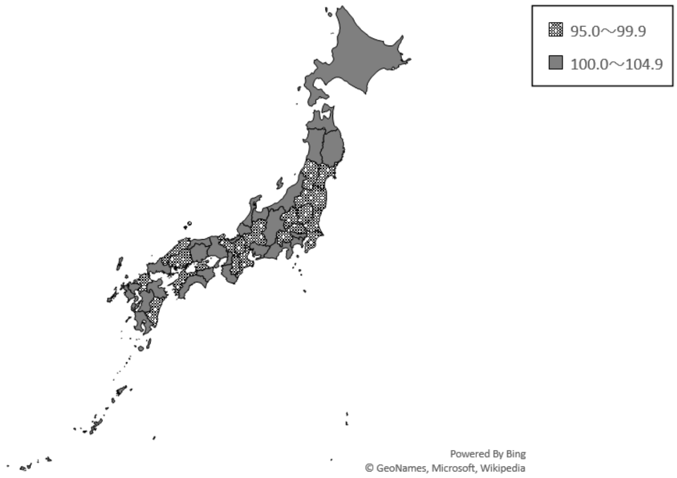

Figure 2b. The average RCLI in 47 cities from November 2008 to December 2016

b) Comparison of the regional cost-of-living indexes for 47 cities

Table IV presents the average RCLI and its standard error for the 47 cities. The standard errors represent the values calculated from the jackknife variance estimator and the bootstrap method. In (9), we set the regional average as reference region *k* and address the deviation of the ratio measured from comparison regions *s*. In other words, we compare how many times the RCLI in the comparison regions differs from that of the regional average.[7]

Table IV shows that 23 out of 47 cities report an average value higher than 100. In particular, urban cities around Sendai (including Akita), around Tokyo (including Chiba and Yokohama), around Kanazawa (including Niigata, Toyama, and Fukui), and around Osaka (including Kobe and Nara) show concentrations higher than 100. Conversely, outside these urban cities, many cities report values lower than 100, including Aomori, Yamagata, and Fukushima in the Tohoku region, Mito and Utsunomiya in the Kanto region, and all cities in the Shikoku region. There is no tendency for high RCLIs to characterise any particular region, but are concentrated around major cities, such as Tokyo, TableⅣ The average regional cost of living indices

Region	City	RCLI	Std.error		Region	City	RCLI	Std.error	
			jackknife	bootstrap				jackknife	bootstrap
Hokkaido	Sapporo	100	0.144	0.143	Kinki	Tsu	98.2	0.146	0.145
Tohoku	Aomori	96.5	0.721	0.712		Otsu	99.7	0.233	0.232
	Morioka	99.7	0.189	0.187		Kyoto	99	0.159	0.157
	Sendai	102	0.515	0.402		Osaka	105.9	0.398	0.392
	Akita	106.2	0.268	0.266		Kobe	102.2	0.277	0.275
	Yamagata	97.9	0.15	0.149		Nara	103	0.262	0.256
	Fukushima	97.3	0.697	0.623		Wakayama	98.4	0.164	0.165
Kanto	Mito	92.3	0.321	0.320	Chugoku	Tottori	100.1	0.105	0.106
	Utsunomiya	97.9	0.115	0.115		Matsue	95.8	0.229	0.226
	Maebashi	100.1	0.129	0.130		Okayama	99.3	0.145	0.144
	Saitama	97	0.155	0.154		Hiroshima	100.2	0.092	0.091
	Chiba	101.6	0.18	0.177		Yamaguchi	103.9	0.175	0.175
	Tokyo	103.8	0.234	0.231	Shikoku	Tokushima	99.1	0.154	0.152
	Yokohama	100.7	0.091	0.090		Takamatsu	99.3	0.099	0.099
Chubu	Niigata	101.2	0.097	0.097		Matsuyama	97.4	0.161	0.158
	Toyama	103.6	0.225	0.224		Kochi	99.5	0.099	0.098
	Kanazawa	104.9	0.233	0.230	Kyushu	Fukuoka	100.2	0.204	0.203
	Fukui	101.6	0.163	0.164		Saga	101	0.109	0.108
	Kofu	97.7	0.174	0.173		Nagasaki	100.4	0.132	0.132
	Nagano	100.3	0.122	0.124		Kumamoto	99.2	0.116	0.115
	Gifu	98.2	0.121	0.120		Oita	98.8	0.132	0.132
	Shizuoka	98.6	0.162	0.163		Miyazaki	99.3	0.113	0.112
	Nagoya	101.1	0.101	0.099		Kagoshima	99.6	0.096	0.094
					Okinawa	Naha	100.5	0.147	0.147

Note: The standard errors represent the values calculated from the jackknife variance estimator. Similar results can also be observed in the standard errors calculated by the bootstrap method. Bootstrap standard errors were calculated from samples generated by 100 iterations of resampling.

Osaka, and Kanazawa. In other words, the tendency of RCLI differs at the city level rather than at the regional level. Even if a city belongs to the same region as the major cities, the cost of living for that city tends to be low when it is geographically separate from a metropolis. This affects the value of the RCLI. For example, this tendency is remarkable in the Kanto region.

Meanwhile, the difference in the RCLI at the city level changes after the Lehman shock. Figures 2 a and b show the distribution of the average RCLI when the period is divided into before and after the Lehman shock, from January 2000 to October 2008 and from November 2008 to December 2016, respectively. In the period before the Lehman shock, the RCLI range is wide, showing values from less than 89.9 in Mito to more than 110.0 in Osaka. As shown in Table IV, cities with high RCLIs are concentrated around Tokyo, Osaka, and Kanazawa. This trend changes in the period after the Lehman shock. The RCLI range shrinks from 95.0 to 104.9. Cities with low RCLI before the Lehman shock tend to show rising RCLI after the shock, but cities with high RCLI originally tend to show falling RCLI. In other words, the differences between the regions shrink after the Lehman shock and the RCLIs are concentrated around the average.

From Figure 2, which compares average RCLIs, there appears to be no significant difference between cities in Japan. Therefore, we examine the RCLI differences between cities using statistical tests. The left side of Table V reports the t-test results for the difference from the regional average (=100). From January 2000 to October 2008, the null hypothesis is rejected at the 5% level for all cities except Sapporo, Nagano, Otsu, Kyoto, Tottori, and Nagasaki. Most cities differ significantly from the regional average. From November 2008 to December 2016, the null hypothesis is rejected for all except 10 cities, such as Sapporo, Sendai, and Shizuoka. The difference between these results indicates that the level of RCLI approaches the average after the Lehman shock. The right side of Table V reports the t-test results for the average difference in the RCLI between Tokyo and other cities. We assume that Tokyo is a reference city in Japan. From January 2000 to October 2008, the null hypothesis of no average difference is rejected for all cities except Toyama, Kanazawa, and Nara at the 5% level. However, from November 2008 to December 2016, the null hypothesis is rejected at the 5% level, except for 7 cities, such as Aomori, Sendai, Morioka, Fukui, Osaka, Okayama, and Saga. These results confirm that statistically significant differences exist in the RCLI between Tokyo and other cities before the Lehman shock and show decreasing differences between Tokyo and other cities after the Lehman shock. In particular, this tendency is observed to be concentrated in the Tohoku and Chubu regions.

Similarly, in Table VI, we perform the χ^2 test for the average difference within a region. The city with the largest economy in each region is selected as reference city *s*. From January 2000 to October 2008, the null hypothesis of no difference is rejected in all regions at the 5% level. However, at the city level, the null hypothesis is not rejected at the 5% level, for example, between Nagoya and Niigata, between Nagoya and Fukui in the Chubu region, between Hiroshima and Tottori in the Chugoku region, and between Fukuoka and Saga in the Kyushu region.

Meanwhile, from November 2008 to December 2016, the null hypothesis of no average difference is also rejected in all regions at the 5% level. However, at the city level, results do not significantly reject the null hypothesis compared to test results from January 2000 to October 2008. Consistent with the results in Table V, this tendency is observed intensively in the Tohoku and Chubu regions. These results show reduced differences between the reference city and other cities within a region after the Lehman shock.

Table V The t tests for regional difference

City s	Null hypothesis $H_0: \overline{RCLI}_s = 100$				Null hypothesis $H_0: \overline{RCLI}_{\text{Tokyo}} = \overline{RCLI}_s$			
	2000/1-2008/10		2008/11-2016/12		2000/1-2008/10		2008/11-2016/12	
	Test stat	P-value	Test stat	P-value	Test stat	P-value	Test stat	P-value
Sapporo	-0.139	0.395	0.223	0.389	-18.756	0.000	-4.366	0.000
Aomori	-5.665	0.000	3.460	0.001	-10.326	0.000	-1.757	0.085
Morioka	-4.705	0.000	4.930	0.000	-19.821	0.000	-1.455	0.138
Sendai	28.052	0.000	-0.496	0.352	-10.782	0.000	-1.634	0.105
Akita	42.279	0.000	12.949	0.000	9.097	0.000	5.239	0.000
Yamagata	-14.730	0.000	-6.413	0.000	-29.080	0.000	-8.673	0.000
Fukushima	-14.902	0.000	-2.212	0.035	-28.293	0.000	-3.027	0.004
Mito	-88.096	0.000	-9.813	0.000	-63.582	0.000	-11.449	0.000
Utsunomiya	-14.168	0.000	-11.365	0.000	-29.169	0.000	-11.635	0.000
Maebashi	5.067	0.000	-6.464	0.000	-17.215	0.000	-8.445	0.000
Saitama	-18.837	0.000	-10.546	0.000	-31.724	0.000	-11.440	0.000
Chiba	14.688	0.000	-2.264	0.031	-8.680	0.000	-6.259	0.000
Tokyo	25.619	0.000	5.914	0.000	-	-	-	-
Yokohama	8.482	0.000	2.563	0.016	-20.103	0.000	-3.282	0.002
Niigata	15.794	0.000	4.258	0.000	-16.623	0.000	-2.499	0.018
Toyama	48.958	0.000	4.017	0.000	0.850	0.277	-2.406	0.023
Kanazawa	33.263	0.000	8.704	0.000	0.611	0.330	4.900	0.000
Fukui	7.322	0.000	6.921	0.000	-11.902	0.000	0.171	0.393
Kofu	-22.999	0.000	-2.583	0.015	-34.320	0.000	-6.337	0.000
Nagano	1.273	0.177	2.313	0.028	-18.699	0.000	-3.807	0.000
Gifu	-9.651	0.000	-12.160	0.000	-26.329	0.000	-12.176	0.000
Shizuoka	-14.910	0.000	0.955	0.252	-29.309	0.000	-4.305	0.000
Nagoya	14.361	0.000	3.208	0.003	-16.531	0.000	-3.110	0.003
Tsu	-34.628	0.000	-0.739	0.303	-36.857	0.000	-5.161	0.000
Otsu	1.706	0.093	-3.564	0.001	-14.261	0.000	-6.156	0.000
Kyoto	-1.939	0.061	-8.414	0.000	-19.736	0.000	-10.114	0.000
Osaka	27.476	0.000	4.365	0.000	9.472	0.000	-0.584	0.336
Kobe	8.096	0.000	3.688	0.001	-4.433	0.000	-3.162	0.003
Nara	20.927	0.000	-0.132	0.395	-1.039	0.232	-4.551	0.000
Wakayama	-21.133	0.000	2.152	0.040	-33.056	0.000	-3.771	0.000
Tottori	0.799	0.289	0.159	0.393	-20.065	0.000	-5.214	0.000
Matsue	-31.065	0.000	-8.764	0.000	-39.861	0.000	-10.227	0.000
Okayama	-10.923	0.000	6.564	0.000	-27.057	0.000	-1.866	0.070
Hiroshima	3.161	0.003	-0.291	0.382	-21.019	0.000	-5.179	0.000
Yamaguchi	34.026	0.000	10.862	0.000	-1.937	0.062	3.305	0.002
Tokushima	-11.566	0.000	2.085	0.046	-27.378	0.000	-3.157	0.003
Takamatsu	-2.725	0.010	-8.594	0.000	-23.110	0.000	-9.449	0.000
Matsuyama	-28.881	0.000	-5.114	0.000	-36.475	0.000	-7.755	0.000
Kochi	-9.447	0.000	0.369	0.372	-27.233	0.000	-4.628	0.000
Fukuoka	7.039	0.000	-7.931	0.000	-12.103	0.000	-9.774	0.000
Saga	6.419	0.000	6.149	0.000	-16.991	0.000	-1.777	0.082
Nagasaki	1.415	0.146	4.086	0.000	-18.182	0.000	-2.438	0.021
Kumamoto	-13.998	0.000	1.080	0.222	-29.199	0.000	-3.996	0.000
Oita	-22.229	0.000	2.048	0.049	-32.845	0.000	-3.999	0.000

Miyazaki	-7.589	0.000	-2.886	0.007	-26.408	0.000	-6.262	0.000
Kagoshima	-7.459	0.000	1.551	0.120	-26.107	0.000	-4.376	0.000
Naha	-4.496	0.000	12.072	0.000	-23.765	0.000	2.824	0.008

TableⅥ The χ^2 test for regional difference within a region

Null hypothesis $H_0: \overline{RCLI}_s = \overline{RCLI}_v$		df	2000/1-2008/10 Test stat	P-value	2008/11-2016/12 Test stat	P-value
(i) Within Tohoku region		5	1237.405	0.000	10.489	0.033
	v = Aomori	1	57.047	0.000	0.967	0.326
	v = Morioka	1	128.476	0.000	1.242	0.265
s = Sendai	v = Akita	1	307.524	0.000	6.871	0.009
	v = Yamagata	1	384.481	0.000	0.253	0.615
	v = Fukushima	1	359.877	0.000	1.157	0.282
(ii) Within Kanto region		5	3588.844	0.000	270.191	0.000
	v = Mito	1	2221.484	0.000	71.559	0.000
	v = Utsunomiya	1	439.977	0.000	68.843	0.000
	v = Maebashi	1	150.673	0.000	37.652	0.000
s = Tokyo	v = Saitama	1	505.701	0.000	65.668	0.000
	v = Chiba	1	37.717	0.000	20.948	0.000
	v = Yokohama	1	233.293	0.000	5.520	0.019
(iii) Within Chubu region		8	1326.061	0.000	112.426	0.000
	v = Niigata	1	0.026	0.872	0.291	0.590
	v = Toyama	1	349.282	0.000	0.302	0.583
	v = Kanazawa	1	222.206	0.000	30.855	0.000
	v = Fukui	1	0.276	0.600	6.493	0.011
s = Nagoya	v = Kofu	1	383.190	0.000	8.396	0.004
	v = Nagano	1	20.371	0.000	0.317	0.573
	v = Gifu	1	133.708	0.000	64.578	0.000
	v = Shizuoka	1	217.003	0.000	1.193	0.275
(iv) Within Kinki region		5	2125.494	0.000	75.510	0.000
	v = Tsu	1	840.116	0.000	8.558	0.003
	v = Otsu	1	203.829	0.000	15.218	0.000
	v = Kyoto	1	314.661	0.000	38.700	0.000
s = Osaka	v = Kobe	1	60.167	0.000	2.551	0.110
	v = Nara	1	49.964	0.000	6.473	0.011
	v = Wakayama	1	656.758	0.000	4.010	0.045
(v) Within Chugoku region		4	793.079	0.000	81.126	0.000
	v =Tottori	1	0.759	0.384	0.054	0.816
s = Hiroshima	v = Matsue	1	423.847	0.000	24.894	0.000
	v = Okayama	1	59.090	0.000	10.926	0.001
	v = Yamaguchi	1	309.383	0.000	45.252	0.000
(vi) Within Shikoku region		3	301.698	0.000	25.708	0.000
	v = Tokushima	1	29.080	0.000	14.598	0.000
s = Matsuyama	v = Takamatsu	1	145.295	0.000	0.220	0.639
	v = Kochi	1	127.323	0.000	10.890	0.001
(ⅶ) Within Kyushu region		6	340.141	0.000	185.407	0.000
	v = Saga	1	2.805	0.094	52.515	0.000
	v = Nagasaki	1	10.504	0.001	39.745	0.000
	v = Kumamoto	1	84.517	0.000	23.688	0.000
s = Fukuoka	v = Oita	1	138.543	0.000	32.138	0.000
	v = Miyazaki	1	52.103	0.000	6.288	0.012
	v = Kagoshima	1	51.670	0.000	31.033	0.000

In summary, the difference between the regional average and each city, the difference between Tokyo and each city, and the difference between a reference city and other cities within a region tend to shrink after the Lehman shock. These findings indicate that the Lehman macro shock had the effect of reducing regional differences based on the cost-of-living index. In addition, the RCLI range in urban areas shifts downward rather than the RCLI range in rural areas shifting upward. In other words, the Lehman shock had the effect of reducing the RCLI in urban areas. However, for the purpose of regional revitalisation, the opposite effect is desirable; that is, raising the range of the RCLI in rural areas would improve the overall cost of living.

c) Comparison of the regional cost-of-living indexes by group commodity

Table VII presents the average group index for the 47 cities in this study by commodity from January 2000 to December 2016. There are large differences between cities in housing in particular. For example, the minimum value is 86.6 for Mito and the maximum value is 109.1 for Osaka. As mentioned in section II, housing does not include imputed rent. As a result, the group index naturally increases in cities where the weight of equipment repair costs and rent is high. In general, the group index values in Osaka are high. This result may reflect regional characteristics, such as the high weight of other rents in Osaka. On the contrary, in rural cities, such as Mito and Matsue, the values of the group indices are low, because the weight of imputed rent in housing is relatively high.

In *b)* of section IV, we compare the aggregate RCLIs for the 47 cities and show the change in their distributions in the period before and after the Lehman shock. In this subsection, we clarify whether similar movements are observed in the index by group. First, Figures 3 and 4 show the commodities that changed significantly during the period before and after the Lehman shock. Figure 3a shows that, before the Lehman shock, the range of the average index of housing is widespread: Aomori, Mito, Wakayama, and Matsue have the lowest range values while Kanazawa, Toyama, Osaka, and Tottori have the highest range values. The values are not concentrated in a specific area and are distributed in various ranges. On the other hand, in Figure 3b, after the Lehman shock, this trend changes and is narrowed down to two ranges: the values are concentrated around the average, and the distribution of values is unbiased in each region. Originally, the cities with a range around the average do not change over time. Similarly, Figures 4a and b show the change of the group indexes for transportation and communication during the period before and after the Lehman shock. In Figure 4a, during the period before the Lehman shock, the ranges of the average index of transportation and communication are wide: Aomori, Fukushima, Fukui, Nagano, Gifu, Tottori, and Kumamoto have the lowest range values while Tokyo, Kanagawa, Osaka, and Kobe have the highest range values. It shows a high index in cities where public transportation is relatively developed, and a low index in cities where it is not. However, in Figure 4b, there is a tendency for the group index to concentrate around the average during the period after the Lehman shock, and the distribution is narrowed down to two ranges around the average. In particular, in a specific area such as cities belonging to the Kinki, Shikoku, Kyushu regions, this tendency becomes stronger.

Second, Figures 5a and b show a group commodity that does not have a remarkable change of distribution during the period before and after the Lehman shock. In Figures 5a and b for education, cities that range from 95.0 to 99.9 before the Lehman shock change to 100.0 to 104.9 after the shock. This is observed particularly in the Chubu, Chugoku, and Shikoku regions. An increase in the index for education is observed in rural areas. On the contrary, in the Kanto and Kinki regions, the group

TableⅦ The average regional cost of living indices by commodity

City	Food	Housing	Fuel	Furniture	Clothing	Medi.	Trans.	Edu.	Rec.	Other
Sapporo	97.0	103.8	98.4	99.3	100.1	99.8	102.4	99.0	99.8	100.1
Aomori	102.1	93.2	100.5	100.7	102.9	100.1	97.1	102.5	100.9	100.5
Morioka	102.8	99.5	98.5	98.5	95.8	99.5	100.8	101.2	99.5	100.3
Sendai	102.0	97.7	102.0	101.1	100.4	98.5	98.2	98.8	98.7	99.3
Akita	105.3	105.3	101.9	99.9	100.2	99.6	101.1	98.6	99.5	100.8
Yamagata	89.9	99.8	100.1	102.1	104.3	100.7	101.6	100.3	97.5	99.8
Fukushima	101.3	93.9	97.1	97.6	99.0	99.7	96.4	100.2	99.4	98.8
Mito	96.3	86.6	91.4	98.9	101.1	100.2	101.2	101.2	101.0	99.9
Utsunomiya	91.4	104.1	100.3	98.6	102.1	101.0	98.5	100.3	101.3	99.9
Maebashi	102.9	96.8	99.7	101.2	103.1	99.4	98.8	99.4	100.2	100.4
Saitama	101.4	96.0	94.1	101.5	98.2	99.9	99.8	99.6	99.4	99.9
Chiba	105.9	101.7	97.4	102.2	99.6	98.7	99.7	98.2	99.0	99.5
Tokyo	107.3	103.5	98.8	101.9	100.6	98.8	101.1	97.9	99.4	99.7
Yokohama	101.8	102.2	98.3	100.8	97.2	99.0	103.0	98.7	98.0	100.4
Niigata	96.5	103.3	99.1	99.6	98.6	101.7	101.4	100.1	101.7	100.0
Toyama	94.7	104.1	105.7	100.2	100.7	101.4	102.8	98.9	99.4	100.8
Kanazawa	96.9	110.4	106.6	98.2	98.9	100.0	101.1	100.1	99.4	99.8
Fukui	96.6	104.1	104.6	98.1	99.2	99.3	99.8	100.0	103.5	100.1
Kofu	97.5	97.1	99.7	96.1	98.5	101.3	101.0	102.4	100.2	100.5
Nagano	104.9	98.7	96.6	99.5	99.1	100.3	100.0	100.7	99.8	99.9
Gifu	95.7	102.3	97.6	103.5	99.7	99.6	97.8	98.8	99.8	100.7
Shizuoka	92.5	102.5	102.4	97.7	99.9	99.5	102.2	100.5	101.1	99.5
Nagoya	100.6	99.8	101.7	100.3	100.8	100.3	100.2	99.3	100.2	100.2
Tsu	99.6	100.3	98.0	97.5	97.2	100.8	100.5	101.2	98.6	100.2
Otsu	106.9	101.4	95.9	99.3	98.0	100.3	96.9	99.0	100.8	99.1
Kyoto	103.7	98.2	97.7	101.8	98.4	99.1	100.1	98.8	99.1	100.2
Osaka	104.6	109.1	97.5	102.1	100.5	98.4	103.1	97.4	99.6	99.9
Kobe	106.6	97.4	98.7	98.7	100.9	99.8	103.9	99.1	98.7	100.0
Nara	109.8	103.5	95.9	102.2	96.9	99.1	98.6	98.1	100.9	99.8
Wakayama	110.3	94.6	95.9	98.8	95.9	99.9	100.2	99.9	98.3	98.9
Tottori	95.8	106.5	99.2	97.2	99.6	101.4	98.7	102.9	100.2	100.0
Matsue	95.0	87.6	101.3	98.0	100.3	102.0	100.7	102.7	100.9	100.1
Okayama	99.3	96.7	101.3	98.6	99.7	100.7	100.7	101.2	99.8	100.4
Hiroshima	93.6	100.3	103.2	102.2	98.7	99.9	102.2	99.2	99.7	100.3
Yamaguchi	104.6	103.4	104.8	101.7	98.3	99.4	97.7	98.8	100.5	100.1
Tokushima	95.4	102.6	97.5	98.1	101.7	99.8	102.4	99.6	100.7	100.1
Takamatsu	99.9	100.0	101.9	98.6	99.7	100.4	100.3	100.6	99.0	99.5
Matsuyama	97.8	96.1	97.7	98.7	103.0	100.9	99.6	101.6	99.8	100.0

Kochi	95.7	100.4	100.7	99.7	102.0	100.5	99.8	100.1	100.6	100.1
Fukuoka	97.3	101.8	104.1	102.3	100.4	100.1	97.6	99.5	100.0	100.1
Saga	101.6	101.6	99.7	100.4	98.8	100.7	96.9	101.5	100.3	100.1
Nagasaki	102.3	94.0	104.8	99.6	99.6	101.0	98.5	100.7	101.1	99.5
Kumamoto	97.5	100.0	101.6	104.2	102.7	98.4	96.7	99.0	101.6	99.3
Oita	100.4	97.3	99.7	100.0	101.5	99.4	100.1	100.0	99.3	99.8
Miyazaki	103.5	99.3	98.4	100.6	102.0	96.8	98.4	100.3	100.0	100.3
Kagoshima	97.9	99.6	102.7	101.1	101.0	100.3	98.3	99.4	100.7	99.8
Naha	95.5	100.5	107.3	99.2	101.4	100.4	100.3	100.7	99.4	99.7

index for education is below the regional average from the period before the Lehman shock, and the difference within each region is small. In other words, the cost of education is higher in rural regions than in urban regions. This is a matter of allocation in the cost of living. In rural areas, housing and transportation costs are kept lower than in urban areas; therefore, it is possible to spend more on education.

In this way, the degree of influence of the Lehman shock differs depending on the property of the group commodity. Since housing and transportation are group commodities with a higher budget share than others, a change in these indexes has a larger impact on the aggregate RCLI. However, education is susceptible to regional influences, and thus, the impact of a macro shock or a change over time is small.

In Table VIII, we perform the χ^2 test by group commodity for the average difference within a region. As for Table VI, for the reference city *s* in each region, the city with the largest economy in that region is selected. From January 2000 to October 2008, the null hypothesis of no difference is rejected in almost all regions and group commodities at the 5% level. However, for other consumption in the Chugoku region only, the null hypothesis is not rejected at the 5% level.

Meanwhile, from November 2008 to December 2016, in some regions and group commodities, the null hypothesis of no difference is not rejected at the 5% level. In Tohoku region especially, the null hypothesis is not rejected for seven groups, excluding food, fuel, and transportation. In other words, within the Tohoku region, a reduction in regional differences in the RCLI of these commodities is observed during the period after the Lehman shock. This is consistent with the results in Tables IV and VII. In addition, in the Chugoku and Shikoku regions, the null hypothesis is not rejected for some commodities, such as fuel, furniture, and other consumption.

These results show declining differences in the indexes of particular regions in a group commodity after the Lehman shock. In addition, most group commodities show declining chi-squared statistics after the Lehman shock. The decrease in the cost of living for these commodities reduces the differences in the index within a region. This decline may be caused by a downward shift in urban areas rather than an upward shift in rural areas.

V. CONCLUDING REMARKS

This study focuses on the existence of regional differences in Japan and the variations in the effects of the Lehman shock between regions based on the RCLI. After the Lehman shock, a decline in the cost of living is observed in most cities, and the impact of the macro shock has continued for some time. The findings suggest as follows. First, there are regional differences in the RCLI, particularly in

Table Ⅷ The χ^2 test for regional difference within a region by commodity

	Food	Housing	Fuel	Furniture	Clothing	Medicine	Trans.	Education
2000/1-2008/10:								
(i) s = regional	29224.116	12731.241	22495.875	48896.859	11202.756	38615.441	15661.109	97445.813
average, v = all cities	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(ii) s = Tokyo,	37795.130	5792.723	2377.083	35535.040	4883.519	33127.775	3416.543	98628.757
v = other cities	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(iii) Within Tohoku	1095.541	323.135	500.192	4238.677	664.766	1160.758	181.532	4444.023
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(iv) Within Kanto	4618.745	1776.472	648.404	2149.292	893.578	2165.790	342.721	9149.155
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(v) Within Chubu	1792.209	1127.572	683.831	2526.393	444.402	1828.481	425.567	5246.744
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(vi) Within Kinki	604.582	2634.532	90.915	4685.641	628.682	5309.046	686.359	7870.282
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(ⅶ) Within Chugoku	1686.570	813.601	630.366	3554.584	59.593	1781.844	1244.921	12244.310
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(ⅷ) Within Shikoku	31.640	247.399	546.195	167.645	84.187	503.288	321.541	1352.443
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(ⅸ) Within Kyushu	192.177	349.861	985.886	934.760	323.082	2161.447	503.434	2169.988
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
2008/11-2016/12:								
(i) s = regional	3647.640	3326.899	3050.673	2484.617	1768.673	2774.122	1699.842	2141.360
average, v = all cities	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(ii) s = Tokyo,	2963.717	1918.148	1302.517	2316.622	876.882	1850.454	342.293	1145.078
v = other cities	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(iii) Within Tohoku	11.467	9.536	18.082	6.620	9.536	8.275	12.699	4.725
region	(0.022)	(0.089)	(0.001)	(0.157)	(0.089)	(0.142)	(0.026)	(0.317)
(iv) Within Kanto	429.772	387.997	21.490	208.014	129.681	262.211	16.417	160.267
region	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.012)	(0.000)
(v) Within Chubu	262.874	234.620	230.513	215.568	60.286	166.097	256.604	73.911
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(vi) Within Kinki	116.548	62.784	37.068	201.378	361.121	153.695	31.076	70.333
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(ⅶ) Within Chugoku	209.989	104.131	1.336	92.298	78.160	179.730	36.311	71.208
region	(0.000)	(0.000)	(0.721)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(ⅷ) Within Shikoku	37.680	131.095	11.072	5.008	115.243	21.054	65.380	201.549
region	(0.000)	(0.000)	(0.004)	(0.082)	(0.000)	(0.001)	(0.000)	(0.000)
(ⅸ) Within Kyushu	663.444	281.810	45.871	94.614	107.267	451.963	40.052	115.971
region	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Note: The value in parentheses represents p-value.

the period before the Lehman shock from January 2000 to October 2008. A high RCLI tends to be more concentrated around major cities, such as Tokyo, Osaka, and Kanazawa. If other cities are geographically separated from these metropolitan areas, their RCLIs tend to be lower. This is also shown by the chi-squared test results for differences between the 47 cities. Furthermore, the t-test results show a significant difference between Tokyo and other cities. However, this result does not indirectly indicate a high level of cost of living only in Tokyo. Similar results would be obtained if the statistical test were performed by setting Osaka or Kanazawa as the reference city instead of Tokyo. Second, in the period after the Lehman shock from November 2008 to December 2016, with the decline in the RCLI of urban areas, regional differences shrink. In other words, the impact of the

Lehman shock is greater in urban areas than in rural areas, which lowers the RCLI. Previous studies from the perspective of measuring welfare costs suggest the existence of the business slump related to urban areas with high costs such as the Kanto and Kinki regions in the 'lost decade' for the Japanese economy (Miyakoshi, 2010). In other words, at economic turning points such as macro shocks, the impact on the regional economy of urban areas is greater than that of rural areas. In addition, in the indexes for each group commodity, we find that housing and transportation and communication affect the fluctuation of regional differences before and after the Lehman shocks. After the Lehman shock, the indexes of these group commodities are distributed around the average and shrink the regional differences. However, this result does not suggest that it will essentially eliminate regional differences with urban areas. Meanwhile, these results imply the necessity of a regional inflation policy for specific cities and/or commodities to improve the aggregate RCLI. In particular, such a policy would be concentrated on rural cities other than the Greater Tokyo area, the Greater Osaka area, and Kanazawa and surrounding cities.

Based on these findings, we propose the following the policy implications to improve the RCLI of rural cities. First, to raise the group index for transportation and communication, transport costs would increase by improving the convenience and development of public transportation in rural cities. In rural cities, the utilisation rate of public transportation has been declining due to poor convenience and low level of service, and transport costs have been shrinking. Improving the public transport environment would be expected to increase the utilisation rate and raise transport costs. This could also have the synergistic effect of increasing the convenience of public transportation, which in turn could increase rents in the surrounding areas. In other words, we expect an increase in the group index for housing. Second, an increase in the usage rate of Internet services would raise communication costs. Rural cities have a high aging population and a lower rate of Internet service usage than metropolitan areas.[8] The increase in communication costs due to higher usage rates would raise the group index for transportation and communication. In addition, the spread of high-speed communications such as 5G in rural cities would lead to higher communication costs.

These would be partially in line with the concept of 'smart cities', which are designed to bring about continuous economic development in rural cities through the efficient operation of social and living infrastructure services. Furthermore, the relocation of offices from urban areas to rural areas, which is currently ongoing in Japan, will be effective in raising the regional cost of living because it involves population migration. In addition, increasing the number of younger people migrating to rural cities would lead to a sustained and rising cost of living. For the purpose of regional revitalisation, raising the RCLI in rural cities would eliminate regional differences from urban areas.

As a statistical challenge in Japan, the omission of imputed rent in housing prices affects the RCLI. Due to data limitations, imputed rent is substituted with weighted regional average data in this study. Therefore, it may underestimate imputed rent compared to the original regional differences. In future research, we aim to calculate the imputed rent data for each region by incorporating a hedonic approach and to measure differences in the CPI series. The present study is useful for measuring the impact of future macro shocks, such as the coronavirus pandemic, on households' cost of living.

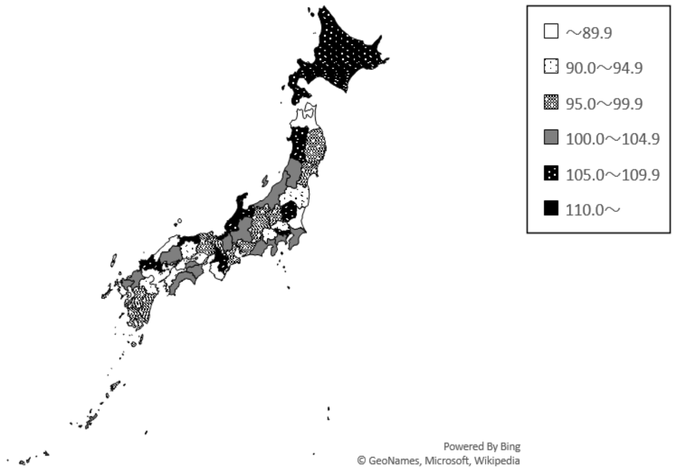

Figure 3a. The average RCLI of housing in January 2000 to October 2008

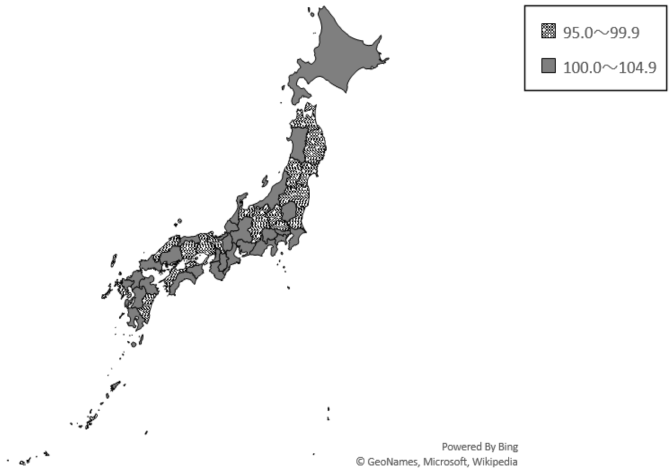

Figure 3b. The average RCLI of housing in November 2008 to December 2016

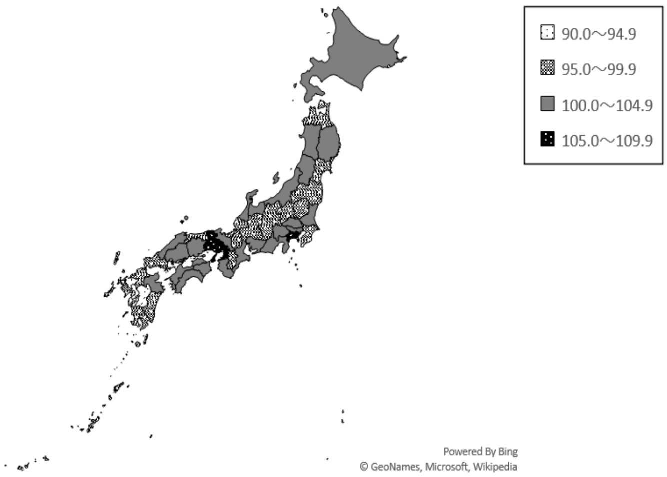

Figure 4a. The average RCLI of transportation and communication in January 2000 to October 2008

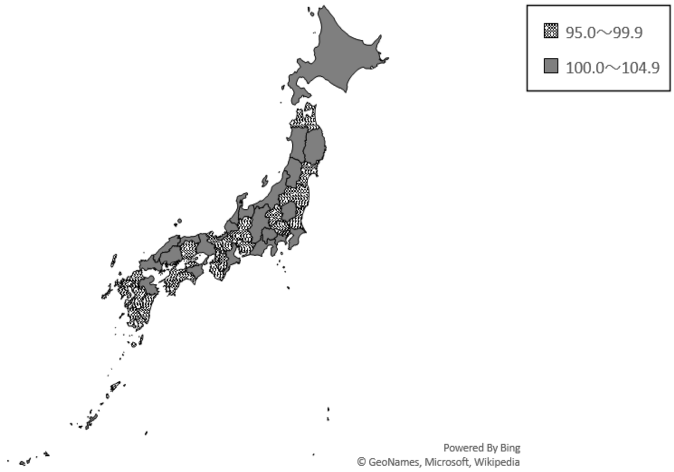

Figure 4b. The average RCLI of transportation and communication in November 2008 to December 2016

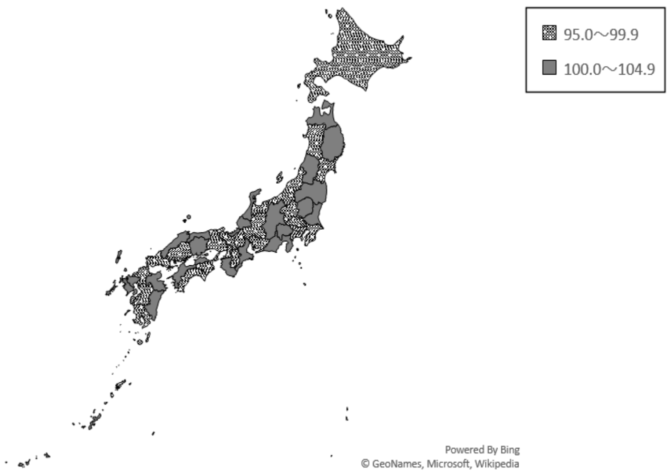

Figure 5a. The average RCLI of education in January 2000 to October 2008

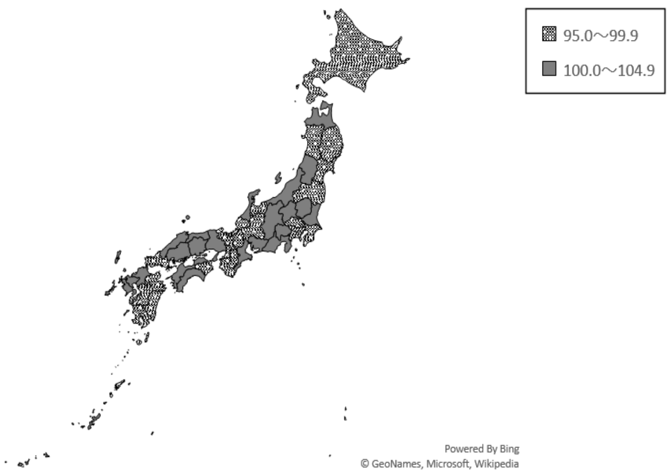

Figure 5b. The average RCLI of education in November 2008 to December 2016

APPENDIX

In Table A.I, we statistically tested whether the two distributions between the unbalanced sample with the original missing values and the balanced sample by listwise deletion were equal.

Table A.I The pre-tests for difference between unbalanced and balanced samples

variables	Average		Test statistics	p-value
	unbalanced	balanced		
w_1	0.225 (0.030)	0.225(0.030)	-0.161	0.872
w_2	0.021 (0.014)	0.021(0.014)	-0.032	0.974
w_3	0.067 (0.018)	0.067 (0.018)	-0.082	0.934
w_4	0.039 (0.015)	0.039 (0.015)	-0.056	0.956
w_5	0.048 (0.014)	0.048 (0.014)	-0.076	0.939
w_6	0.038 (0.012)	0.038 (0.012)	-0.066	0.947
w_7	0.152 (0.052)	0.152 (0.052)	-0.063	0.950
w_8	0.062 (0.033)	0.062 (0.033)	-0.040	0.968
w_9	0.113 (0.026)	0.113 (0.026)	-0.094	0.925
w_{10}	0.236 (0.048)	0.236 (0.048)	-0.106	0.916
$\ln\frac{x}{P}$	12.623 (0.269)	12.627 (0.149)	-1.259	0.208

Note: The value in parentheses represents the standard deviation. The t-test was performed on the average difference between the balanced and unbalanced samples.

Table A.II shows the estimation results without the assumption of weak separability of commodities. In the estimation model, we denoted W_M as the M-th group budget share, ln$X$ as the logarithm of aggregate expenditure, and lnP_M as the M-th group price. Without the assumption of weak separability, the group AIDS model was aggregated across commodities as follows. The AIDS model in the M-th group in region k is $W_{Mk} = a_M + \sum_{M=1}^{N} b_{MJ} \ln P_{Mk} + c_M(\ln X_k - \ln S_k) + D \ln Z_k + e_{Mk}$ for $M = 1, \ldots, N$. The aggregate price index used the Stone index as (6), $\ln S_k = \sum_{J=1}^{M} W_{Jk} \ln P_{Jk}$. The model was estimated using $N - 1$ equations, because $\sum_{J=1}^{N} W_{Jk} = 1$. In addition, the homogeneity and symmetry conditions were imposed on parameters.

The lower part of Table A.II shows the results of the likelihood ratio test. It compares the log likelihoods of the models with and without the assumption of weak separability. The results show that there is no statistically significant difference between the two models. This is the same for the results for each group equation.

Table A.II Estimated results of aggregation across commodities without weak separability

	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9
$\ln P_1$	0.3034	—	—	—	—	—	—	—	—
	(0.007)								
$\ln P_2$	-0.0070	0.0151	—	—	—	—	—	—	—
	(0.002)	(0.003)							
$\ln P_3$	-0.0192	-0.0024	0.1008	—	—	—	—	—	—
	(0.003)	(0.001)	(0.003)						
$\ln P_4$	-0.0135	-0.0036	-0.0017	0.0532	—	—	—	—	—
	(0.003)	(0.002)	(0.002)	(0.004)					
$\ln P_5$	-0.0392	-0.0007	-0.0028	0.0002	0.0543	—	—	—	—
	(0.005)	(0.001)	(0.003)	(0.002)	(0.005)				
$\ln P_6$	-0.0309	-0.0019	-0.0135	-0.0066	0.0082	0.0338	—	—	—
	(0.005)	(0.001)	(0.003)	(0.003)	(0.004)	(0.006)			
$\ln P_7$	-0.1103	0.0099	0.0103	-0.0296	-0.0175	-0.0121	0.1925	—	—
	(0.008)	(0.005)	(0.004)	(0.006)	(0.005)	(0.006)	(0.025)		
$\ln P_8$	-0.0044	-0.0035	-0.0088	-0.0193	0.0039	0.0139	-0.0343	0.0984	—
	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.008)	(0.005)	
$\ln P_9$	-0.0306	-0.0014	-0.0132	0.0009	-0.0003	-0.0014	-0.0675	-0.0536	0.2812
	(0.005)	(0.004)	(0.003)	(0.005)	(0.004)	(0.005)	(0.013)	(0.006)	(0.013)
$\ln \frac{X}{S}$	-0.1052	-0.0129	-0.0547	-0.0031	0.0039	-0.0113	-0.0589	0.0282	0.0560
	(0.004)	(0.006)	(0.002)	(0.005)	(0.003)	(0.003)	(0.012)	(0.007)	(0.010)
Log likelihood ratio test for the models without vs. with the assumption of weak separability									
system	6.873								
	(1.000)								
group	0.118	4.011	0.227	0.759	0.036	0.164	0.027	0.025	2.195
	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)

Notes: In the upper part of the table, the value in parentheses represents the standard error. In the lower part of the table, the value in parentheses represents p-value.

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Footnotes:

[1] The regional revitalisation policy was announced at a press conference by former prime minister Shinzo Abe on September 3, 2014, after the inauguration of his second Cabinet. This government policy concerns major issues facing Japan, such as rapid population decline and super-aging, to

create an autonomous and sustainable society in which each region takes advantage of its unique characteristics.

[2] Recent studies, such as Arellano, Blundell, and Bonhomme (2017), have shown that this problem can be avoided when T is sufficiently large. However, it is not clear whether it can be applied to this study.

[3] Since we assume that the aggregate price index is approximated by the Stone index, $\ln P_k \approx \ln P_k^S$.

[4] If this assumption were not taken into account, the relative prices of all commodities would be included in the demand function for each group, which would lead to problems of degrees of freedom and multicollinearity among prices.

[5] In Japan, equipment cost varies by regional climate. For example, equipment repairs and maintenance cost is high in cold areas, such as Sapporo, Niigata, Toyama, Kanazawa, and Fukui.

[6] Tokyo has the highest GDP and GDP per capita among the 47 prefectures. Next are Aichi (whose prefectural capital is Nagoya) and Osaka. However, because GDP is an indicator of the size of a prefecture's economy, it does not accurately indicate any given city's economy.

[7] In the estimation, we derive the index by multiplying the measured ratio by 100.

[8] In the Ministry of Internal Affairs and Communications on Communications Usage Trend Survey in 2016, the highest rate was for Saitama in the Kanto region (91.2%), and the lowest was for Nagasaki in the Kyushu region (65.4%).