Regional Inflation (Price) Behaviors: Heterogeneity and Convergence

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Abstract

It is generally thought that members in monetary union experience a similar level of inflation. This paper verifies this conventional belief. Using regional data, we present statistical evidence of heterogeneous inflation in Japan. Not only does the average inflation differ significantly across regions, but regional inflation responds differently to common economic and monetary factors. Furthermore, we show no evidence of price convergence in a group of entire regions although there is some evidence of convergence in subgroups. These results suggest that diversified regional inflation can exist within monetary union.

JEL classification: E3, F3

Keywords: Regional inflation, monetary policy, factor models, convergence

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1 Introduction

Having similar levels of inflation has often been argued as an important factor for creating monetary union since only a single monetary policy can be implemented for all regions in the union. Indeed, when forming the euro area in 1999, this was one of the conditions that successful candidate countries had to meet, and the 1992 Maastricht Treaty was one means of safeguarding economic convergence.[1] Although more than a decade has passed since then, the homogeneity of regional inflation is still actively analyzed by many researchers (e.g., Spiru 2007, Horvath and Koprnicka 2008, MacDonald and Wojcik 2008, and Ohnsorge, Choueiri and van Elkan 2008) since there is a queue of countries wishing to join the euro area. The importance of research was also underscored when authorities in Asia discussed the creation of a monetary union in the aftermath of the 1997 Asian crisis as one possible means of promoting regional financial stability, and when the members of the Gulf Cooperation Council agreed in 2001 to form a monetary union sometime in the future.

However, less research has been conducted on those already in the union, possibly reflecting the widely held belief that regions/countries already in the same monetary union experience a similar level of inflation. Using Japanese regional data, this paper examines if this general belief is appropriate. The ideal situation for monetary union may indeed be that not only inflation but everything (e.g., the culture, economic system, laws, etc) is the same within the union.[2] In this regard, Japanese regions may be rather interesting for research since they are very homogenous in terms of culture (language, race, religion, etc) due to geographical and historical reasons.[3]

Thus our general question would be whether Japanese regions meet the conditions for monetary union. More specifically, we focus on inflation/price homogeneity issues, and ask 1) if the level of inflation is the same across regions, and 2) if regional inflation responds to common economic and monetary movements in a similar way. The second question is essentially equivalent to the first but from a different view-point. Furthermore, in the presence of heterogeneous inflation, we ask 3) if regional prices show any sign of convergence. The presence of price convergence will at least give some relief to policymakers even if there is significant heterogeneous inflation as such price discrepancies would be expected to cease in the future.

With respect to price convergence, there have been studies which looked for the causes of discrepancies in Japanese regional prices.[4] Thus their focus was often on relative prices (the ratio of local prices to the benchmark, i.e., $p_{it} - p_{jt}$ where p is log price, and subscript i and t denote region and time and $i \neq j$) rather than regional inflation (i.e., $p_{it} - p_{it-1}$). Using panel unit root test methods, Esaka (2003) studied Japanese relative prices using prefectural data and Tokyo as the benchmark city, and found that local prices particularly in the tradable goods sector tend to move with the benchmark over the long-run. Furthermore, some efforts were made to explain short-term deviations in regional prices. For example, Baba (2008) considered market imperfection by introducing a mark-up in the distribution sector and found that this explains a small fraction of price deviations. Nagayasu and Inakura (2009) showed that differences in price levels can be explained by economic factors such as wages and transaction costs.[5]

In short, we provide evidence of significant discrepancies in regional inflation and no evidence of price convergence in Japan. The first conclusion is supported by a simple statistical test and a factor model in which we identify economic and monetary factors which are common to all regions. The second conclusion of no price convergence in a group consisting of all regions is found using the Phillips-Sul (2007) approach which has some statistical advantages compared with the conventional method such as panel unit root tests. (We shall explain this shortly.) However, there is evidence of convergence in subgroups. Thus our results appear to be in sharp contrast to the conventional belief of policymakers and researchers.

2 Is Regional Inflation the Same within a Monetary Union?

We utilize quarterly data covering 10 regions in Japan; Hokkaido, Tohoku, Kanto, Hokuriku, Tokai, Kinki, Chugoku, Shikoku, Kyushu and Okinawa.[6] Their price data (the Consumer Price Index, CPI (2005=100)) are obtained from the Ministry of Internal Affairs and Communications and are available from 1975Q1 to 2005Q4. Thus our data measure price trends for a comprehensive range of consumer goods and are ones that policymakers closely monitor. Region-specific inflation rates, expressed as annual changes (%), are shown in Figure 1.

<Figure 1>

In addition to price data, there are additional variables used to explain the common factor. They are money (M1 and M2, m), Gross National Income (GNI), and interest rates (the call rate and the return on the Japan Government Bond with 10 year maturity, i). These variables are obtained from the International Financial Statistics of the International Monetary Fund, and they are chosen on the basis of a variant of the standard money demand function.

$$\Delta p_t = \Delta m_t + \gamma \Delta i_t - \beta \Delta gni_t \tag{1}$$

where $t = 1, \ldots, T$ and Δ is a difference operator. Greek letters measure the sensitivity of the interest rate and real income (gni) to inflation (Δp). All variables except the interest rate are in log form, and the interest rate is expressed in terms of annual percentage. Real income is calculated by deflating the GNI by the CPI. Their sign follows economic theory, and thus equation (1) states that inflation is positively associated with monetary variables and negatively with income. Since these explanatory data are not region-specific, we consider them to affect all regions but allow for the possibility of affecting regional inflation with a different magnitude. We focus largely on the common factors because of the availability of the region-specific data, but some regional factors will be considered when attempting to understand regional prices at the end of Section 4.[7]

The basic statistics of regional inflation are shown in Tables 1 and 2. The first table shows that discrepancies may exist among regional inflation within a country. In particular, Okinawa has experienced lower inflation than other regions on average. Many regions experienced inflation of around 2 percent, with the Okinawa region about 1.6 percent. A similar result is also reported in the correlation matrix in Table 2. It shows that Okinawa exhibited a less close relationship with other regions. We believe that this outcome is due partly to the fact that Okinawa is a relatively new region, and thus development of its economic system still lags behind others.[8] This directs us to analyze the response of Japanese regional inflation to the common factor driven by changes in money, interest rates, and income.[9]

<Tables 1 and 2>

We formally examine the homogeneity of regional inflation by statistical tests and report the results in Table 3. This table shows that inflation significantly differs among regions, and also even though we exclude Okinawa which exhibited the lowest inflation, the result remains unchanged. Thus, it seems that there is significant heterogeneity in regional inflation even though Japanese regions have been in the same monetary union for a considerable time. A similar test for Japan, the UK and US using inflation calculated from annual (rather than quarterly) CPI data is carried out in the appendix, and shows that this is a distinctive feature of Japan.[10]

<Table 3>

3 Asymmetric Responses of Regional Inflation

Here, using a factor model, we analyze regional inflation behaviors in response to unobservable economic and monetary movements which are common to all regions.

Previous research often used impulse response functions in order to track the responses to shocks in their time-series analysis. Since we use panel data and attempt to find unobservable common factors in the country, the factor model appears to be an appropriate method. Furthermore, although this paper limits the number of common factors in the system to one, we allow a different composition in the factor.[11]

With N regions and one factor, a static factor model can be expressed in the following observation and transition equations. The observation equation is:

$$\begin{aligned} \Delta p_1 &= a_1 f + v_1 \\ &\vdots \\ \Delta p_N &= a_N f + v_N \end{aligned} \tag{2}$$

Or

$$X = AF + V \tag{3}$$

where $X' = [\Delta p_1, ..., \Delta p_N]$, $F' = [f, ..., f]$, $V' = [v_1, ..., v_N]$, and $A' = diag(a_1, ..., a_N)$. The transition equation is:

$$f = Dz + u \tag{4}$$

Equations (2) to (4) contain the time dimension ($t = 1, \ldots, T$) such that for example regional inflation, Δp, is a $(T \times 1)$ vector, and f is the $(T \times 1)$ vector of an unobservable state variable which is assumed common in all regions and is in turn a function of exogenous variables, z. In order to take account of an endogeneity issue, a common factor is assumed to be associated with the lagged value of economic and monetary variables (z), which are in turn chosen on the basis of the standard money demand function. Each region faces these common economic and monetary shocks captured by f but such shocks may have a different impact on regional inflation, which is reflected in factor loadings, A. One can regard f as an economic factor when real GDP is included and as a monetary factor when f consists of money and/or the interest rate which are instruments for the central bank when conducting monetary policy.

With respect to the residuals, V and u, follow a white noise process, and v represents an idiosyncratic component. For operational purposes, V and f are mutually independent, normal, random variables and are diagonal matrices. For example, $var(v_i) = \Psi_i$ and thus

$$\Psi = \begin{bmatrix} \Psi_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \Psi_N \end{bmatrix}$$

The assumption on V is one popular identification method, and these settings imply that regional-specific events which are not captured by f are not correlated with one another. Finally, the variates f and v are independently distributed. Then, the covariance matrix can be expressed as: $\Sigma = AA' + \Psi$ (see Anderson 1984). Using this covariance matrix, the model can be estimated using the Kalman filter approach which in turn relies on the maximum likelihood method. It is well known that maximum likelihood estimators are consistent and asymptotically normal when data are stationary. Thus, when they are nonstationary, the diffuse Kalman filter approach (De Jong 1988) can be employed.

The results are presented in Tables 4 to 6 where a different specification of the common factor is employed. In Table 4, the common factor is not meaningfully defined, but it is positively and significantly associated with inflation in all regions. The test for parameter equality (Chi^2 test) suggests that regional inflation responded differently to this common factor. These results seems robust to the specification of f, which will be discussed next.

<Table 4>

In Tables 5 and 6, the common factor is specified as a function of particular economic and monetary variables. For instance, the common factor is assumed to be related to money in Table 5. Our results suggest that money is positively associated with inflation which is consistent with economic theory, and furthermore the statistical significance level (in terms of t-values) increases when broad money (M2 ($m2$)) rather than narrow money (M1 ($m1$)) is used in the analysis.[12] This is an expected outcome since M2 captures economic activities more comprehensively and is highly correlated with income at a macro-level. It should be also noted that Okinawa is least responsive to the common factor. With this specification of the common factor, we obtained evidence of the heterogeneous response of regional inflation to monetary variables as the null hypothesis of the equalization of all parameters for f is rejected.

<Tables 5 and 6>

Table 6 specifies the common factor as a function of money, income (gni) growth, and the call or Japanese government bond (jgb) rates. This long-term (10-year maturity) bond rate is used to check the robustness of our previous findings using the call (short) rate which has stayed around 0 percent since the mid 1990s. Our estimates from the call rate may have been biased potentially due to nonlinearity. Since M2 is found to be more significant than M1 in Table 5, this table shows only the results from the former definition of money.[13]

Despite our concern however, the results from the jgb rate are similar to those using the call rate. This table shows that consistent with economic theory (i.e., equation (1)), money and the call/jgb rates are found to be positively correlated with inflation although the latter is statistically insignificant. The former result—that regional inflation increases along with an increase in money—is congruous with our result in Table 5. Furthermore, the common factor is found to be significantly and negatively associated with income growth. Similarly, the common factor (f) enters positively and significantly in each regional inflation equation, and the null hypothesis of the equalization of parameters for the common factor is statistically rejected. Thus as in the case of monetary shocks alone, our data seem to confirm the importance of the common factor in regional inflation and suggest the heterogeneous response of regional inflation to the common factor.

4 Convergence in Regional Prices

The presence of heterogeneous inflation among Japanese regions is a surprising result, at least to us. We thus next investigate whether regional prices are converging during our sample period. While regional inflation may differ in Japan, there may be signs of price convergence. This happens when low (high) price regions experience high (low) inflation. In that case, price convergence occurs and the heterogeneity in inflation becomes a less serious issue. Therefore, it is important to study regional price behaviors as well as inflation.

In this connection, we use the statistical test for convergence (known as the log t test) proposed by Phillips and Sul (2007). Previous literature on price convergence often utilizes the β-convergence criterion originally proposed by Sala-i-Martin (1996). The β-convergence indicates that a region with a low initial price level experiences higher inflation in order to catch up with regions with a high initial price level.[14] Since the panel unit root test was often used in order to test the β-convergence (see Introduction), the use of the Phillips-Sul method departs from most literature on price convergence.

We use the Phillips-Sul method since the unit root in the difference in log price across regions may not necessarily imply price divergence. Phillips and Sul discuss that the unit root test leads to a conclusion of non-convergence among regions when the common factor is non-stationary even if there is a sign of convergence in region-specific factors.[15] Thus in order to circumvent this problem, they provide a general framework which is robust to the characteristics of the common factor.

More specifically, the Phillips-Sul test analyzes the null hypothesis of convergence against the alternative of no convergence and/or partial convergence among subgroups. As will become clear, unlike many studies using relative prices which requires a benchmark price, the Pillips-Sul approach does not need to specify this since the cross-sectional average among a group of regions automatically becomes the benchmark, and this benchmark changes according to the composition of the group.

Suppose that a panel data (X_{it}) can be decomposed into two elements.

$$X_{it} = \delta_{it}\mu_t \tag{5}$$

where μ_t is a common factor and δ_{it} is a transition parameter. Subscripts i and t represent regions ($i = 1, \ldots, N$) and time ($t = 1, \ldots, T$) respectively. Phillips and Sul consider the following slow varying function for δ_{it}.

$$\delta_{it} = \delta_i + \sigma_i \xi_{it} L(t)^{-1} t^{-\alpha} \text{ for } t \geq 1 \tag{6}$$

where δ_i is fixed elements specific to regions, ξ_{it} is $iid(0, 1)$ across i and $\sigma_i > 0$. $L(t)$ is a function of time with $L(t) \to \infty$ as time $\to \infty$, and is assumed to follow $\log t$ following the recommendation of Phillips and Sul (2007). Thus ξ_{it} introduces time-varying and region-specific components to the model. They show that the size of α determines the behavior (i.e., converge or divergence) of δ_{it}. When $\alpha \geq 0$, δ_{it} converges to δ_i and thus this becomes the basis for the statistical hypotheses–H_0: $\delta_i = \delta$ for all i and $\alpha \geq 0$ and H_1: $\delta_i \neq \delta$ for all i and $\alpha < 0$.

They show that these hypotheses can be statistically tested using the following equation.

$$\log\left(\frac{H_1}{H_t}\right) - 2\log L(t) = a + b\log t + u_t \tag{7}$$

where $H_t = \frac{1}{N}\sum_{i=1}^{N}(h_{it} - 1)^2$ and $h_{it} = \frac{X_{it}}{N^{-1}\sum_{i=1}^{N} X_{it}}$. Furthermore, Phillips and Sul showed that b, the key parameter for the convergence test, is related with α and indeed $b = 2\alpha$.

Using these notations, the convergence or divergence of X is consistent with that of $\log(H_1/H_t)$. Under convergence, $\log(H_1/H_t)$ diverges to ∞ since $H_t \to 0$ as $t \to \infty$ for given N. This happens when $\log t$ in equation (7)$\to \infty$ and $\alpha > 0$ in equation (6), or when $2\log L(t) \to \infty$ and $\alpha = 0$. Thus, the concept of price convergence is based on $h_{it} \to 1$ for all i as $t \to \infty$, and so we can study the statistical hypotheses mentioned earlier by examining the size of b: the null of convergence can be tested with $b \geq 0$ and the alternative with $b < 0$. This is known as relative convergence as it measures convergence to some cross-sectional average as can be seen from the definition of H_t and h_{it}, and is in contrast to the concept of level convergence analyzed by Bernard and Durlauf (1996) and Evans and Karras (1996).

When implementing the test, we initially create a subgroup (say, Subgroup A) with $k \geq 2$. In order for this, the panel data are organized by the order of price levels in the final year (i.e., 2005), and Subgroup A is created by including a region with the highest price level. For operational purposes, Phillips and Sul proposed a clustering algorithm for subgroup convergence in the panel data using the t statistics used in the $\log t$ test (i.e., equation (7)). More specifically, the $\log t$ test is carried out for all combinations of subgroups which contain k $(2 \leq k < N)$ regions. Then the optimal number of the subgroup is chosen using the following criterion and the 5 percent critical value for the one side test, i.e., condition (8).

$$k^* = \arg\ \max_k \{t_k\} \text{ subject to } \min\{t_k\} > -1.65 \tag{8}$$

Non-rejection of $\log t$ test for k^* regions indicates price convergence within Subgroup A. But that does not mean that there is no convergence among other regions that do not form this first subgroup unless $k^* = N - 1$.[16] Thus condition (8) is examined in the panel consisting of other regions, and we continue this process until there is evidence of no more convergence.

For the analysis, the CPI (2005=100) used in the previous subsection cannot be used since it does not take account of price discrepancies among regions. Thus, we compiled the price data using the CPI and the index to measure the price differences between regions in 2005 which is also available from the National Statistics Center, the Ministry of Internal Affairs and Communications. Table 7 presents the price level for each region with the country average equal to 100, and shows the highest price in Kanto and the lowest in Okinawa. Furthermore, the compiled data are shown in Figure 2.

<Table 7 and Figure 2>

The results on the convergence tests are shown in Table 8 where both parameter b and its t value are reported in this table.[17] In order to check the robustness of our findings, we also report here results from annual data. Using quarterly data and HAC (Heteroscedasticity and Autocorrelation Consistent) standard errors, we find that our regions can be classified into two groups from the point of view of price convergence. The core group (or Subgroup A) consists of Hokkaido, Tohoku, Kanto, Hokuriku, Tokai, Kinki and Chugoku regions. Their t value is greater than -1.65 and thus there is evidence of convergence among them. Further analysis suggests that there is evidence of no divergence among the rest of the regions (Subgroup B) since the t value is again above the critical value. Interestingly, three regions in Subgroup B are geographically contiguous. Our findings of convergence in sub-groups are also confirmed by the estimated values of H_t (Figure 3) which decrease over time.

<Table 8 and Figure 3>

This result is generally consistent with that from annual data. In this case, the composition of Subgroup A is slightly different from that for quarterly data, and some regions (Tohoku, Tokai, Kinki and Chugoku) now belong to Subgroup B. But there is a tendency for regions in the group to be geographically adjacent, and again Japanese regions can be classified into two groups: the t value for checking convergence in the other regions (Subgroup B) is above the critical value.

These results imply a similarity in price behaviors among geographically close regions, and furthermore suggest that the potential importance of the mark-up in the distribution sector (Baba 2008) and of heterogeneous wages and transaction costs (Nagayasu and Inakura 2009). The heterogeneity in wages among regions can in turn be explained by low labor mobility as Nagayasu and Inakura show that less 2 percent of population move to other prefectures within a one year interval for reasons related to work. Thus despite conventional expectations, the regions cannot be characterized as open economies even within the same country.

We thus extend our analysis to seek reasons for the heterogeneity in price levels. One potential explanation is already hinted at in Table 6 where we find a strong relationship between inflation and income growth. Thus, we utilize income data again, but unlike our study in Table 6, this time they are region-specific and in levels.[18] Furthermore, income ($\widetilde{gni}_{it}$) is expressed per capita using population data. In the panel data context, their relationship can be expressed as equation (9) with fixed (α_i) and time (ϕ_t) effects.

$$p_{it} = \alpha_i + \phi_t + \beta_i(\widetilde{gni}_{it}) + e_{it} \tag{9}$$

Although our data here are region-specific and differ from those used earlier, it may be more appropriate to allow for different income elasticities for regions. Thus we first estimate this equation (without ϕ_t) using the Dynamic Seemingly Unrelated Cointegrating Regression (DSURE) method (Mark, Ogaki and Sul 2005). This method allows us to estimate heterogeneous parameters among regions for simultaneous estimation of multiple cointegrating regressions,[19] and furthermore the DSURE estimators are robust to an endogeneity bias due to the introduction of lagged and lead variables. In order to check the feasibility of the homogeneous parameters, the poolability test is also carried out using the Hauseman type test

(Phillips and Sul 2003) after obtaining heterogeneous parameters.

Table 9 summarizes the results and shows that income is positively and significantly associated with price. This is consistent with Nagayasu and Inakura (2009) who analyzed the relationship between the relative price $(p_{it} - p_t^*)$ and income $(gni_{it} - gni_t^*)$, where the asterisk indicates the variables of a benchmark prefecture. However, no evidence of homogeneity in estimators is obtained by the Hausman type test. Thus, we implement based on equation (9) panel cointegration tests (Pedroni 1999) which allow heterogeneity in adjustment coefficients and parameters. The Pedroni test results are also reported in Table 9 and confirm the presence of cointegration between these data using panel cointegration tests.[20] Thus, while the scope of this exercise is limited due to the availability of region-specific data, regional income goes some way toward explaining the creation of subgroups in Japan. Furthermore, since we utilize a comprehensive data set (i.e., CPI), our result is not inconsistent with Esaka (2003) who shows the tendency of stationarity of relative prices in the tradable goods sector and nonstationarity in the non-tradable sector.

<Table 9>

5 Conclusion and Discussion

Many people believe that regions already in a monetary union experience harmonized inflation. This paper asks if this conventional belief is appropriate using the regional data of a country which has had her own monetary union with her own currency and central bank for a long period of time.

In particular, our main interest is in Japan with its relatively homogenous culture and people. Although national boundaries have modified slightly in the past, it has formed a monetary union with a single central bank of over 100 years standing. Therefore, having a uniform level of regional inflation would be the conventional belief of policymakers and academics.

Our findings are in sharp contrast to this belief and are threefold. First, we provide evidence of regional inflation as statistically different among regions in Japan using the conventional statistical significance level. In contrast, our data do not show significant diversity among regional inflation in the UK and US (see Appendix). Second, using the factor model, this paper identified the common factor driven by monetary and economic activities, and then found that inflation responds to the common shock differently among regions. Finally, no evidence of price convergence is obtained in our group consisting of all regions although there seems to be convergence among subgroups. Discrepancies in regional income seem to go some way toward explaining those in regional inflation.

Please note that this paper is not meant to propose abandoning the inflation/price criterion when considering the formation of monetary union. But our results show that even a country with heterogeneous inflation can maintain monetary union and thus make us rethink the importance of homogeneous prices and/or inflation (or more generally convergence criteria) when forming a monetary union. One potential source of successful monetary union in Japan is intergovernmental fiscal transfers which function as a redistribution of financial wealth. Indeed, Japan has a tightly controlled transfer mechanism from central to local governments although the power of central government has been declining over the past decades. In this regard, Mochida (2001) provides one intriguing example: Tokyo which is a rich prefecture collected Y196,000 per capita worth of prefectural tax revenues in FY1993, while Okinawa managed only Y60,000, the lowest figure among prefectures. However, after taking into account intergovernmental fiscal transfers, the general revenues (per capita) of Okinawa jumped to Y213,000, exceeding that of Tokyo (Y206,000). This level of intergovernmental transfers cannot be observed in other advanced countries. Thus, our findings suggest that countries and regions which lack such an intergovernmental fiscal transfer system may need to consider more seriously inflation/price heterogeneity.

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Notes

[1]With respect to the inflation criterion, it cannot be higher than 1.5% of the average inflation rate of the three countries with the lowest individual rates.

[2]Mundell (1961) is probably the most cited work on the optimum currency area. Generally, there are five principal criteria for a successful currency area: labor mobility across regions, product diversification, openness with capital mobility, price and wage flexibility across the region, and an automatic fiscal transfer mechanism for redistribution of money among regions.

[3]The isolated location of the country was an important factor preventing inward and outward population mobility. But tight immigration laws have been a more relevant explanation in recent years.

[4]There are many similar studies conducted for other countries. See for example Engel and Rogers (1996), Cecchetti, Mark and Sonora (2002), Rogers (2007) and Nath and Sarkar (2009) for the US, Beck, Hubrich and Marcellino (2009), Rogers (2007) and Wolszczak-Derlacz (2008) for European countries, Massidda and Mattana (2008) for Italy, and Das and Bhattacharya (2008) for India.

[5]Apart from these factors, Faber and Stokman (2009) revealed that indirect tax rates and input costs are important economic explanations for heterogeneous price levels in Europe.

[6]Tohoku consists of 6 prefectures (Aomori, Iwate, Miyagi, Akita, Yamagata and Fukushima), Kanto of 9 prefectures (Ibaraki, Tochigi, Gunma, Saitama, Chiba, Tokyo, Kanagawa, Yamanashi and Nagano), Hokuriku of 4 prefectures (Niigata, Toyama, Ishikawa and Fukui), Tokai of 4 prefectures (Gifu, Shizuoka, Aichi and Mie), Kinki of 6 prefectures (Shiga, Kyoto, Osaka, Hyogo, Nara and Wakayama), Chugoku of 5 prefectures (Tottori, Shimane, Okayama, Hiroshima and Yamaguchi),

Shikoku of 4 prefectures (Tokushima, Kanagawa, Ehime and Kochi), and Kyushu of 7 prefectures (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki and Kagoshima). Hokkaido and Okinawa regions contain only Hokkaido and Okinawa prefectures respectively. This classification method is based on that of the Ministry of Internal Affairs and Communications.

[7]Obviously there may be other variables which could be considered to influence inflation, but we use the minimum set of variables for computational ease.

[8]Okinawa was one of the prefectures/regions most severely affected during World War II. It was returned to Japan by the US in 1972, and in order to catch up with other prefectures, the government has set up dedicated offices. In the Cabinet Office, there are sections (e.g., Okinawa Shinkokyoku) in charge of economic development in Okinawa, which exist only for Okinawa. See Takagi, Shintani and Okamoto (2004) for the introduction of the yen in Okinawa in 1972.

[9]Regional inflation is analyzed and some explanations for discrepancies in regional inflation have recently been provided for Europe. For example, Beck, Hubrich and Marcelliono (2009) pointed out, using six euro area countries, that regional inflation differentials are related to non-wage input factors and differences in the economic structure of the regions.

[10]Although our US data show evidence of homogenous inflation, Phillips and Sul (2007) report no evidnece of price convergence in a group consisting of all regions/cities. This seemingly inconsistent result with ours may be attributable to different sample periods used in the analyses. Phillips and Sul used a much longer sample (1918-2001) which contains a period of less integratation among regions/cities.

[11]Our choice of one common factor is consistent with the number predicted by the statistical approach. For example, Bai and Ng (2002) proposed several information

criteria to estimate the true number of common factors in the static factor model. According to their criteria, there seem to be one to three common factors in our panel data. Given that these criteria tend to overestimate the true number in small panel data, our choice of one common factor seems reasonable.

[12]The t-value is 4.10 (=0.041/0.010) for M1 and is 10.47 (=0.178/0.017) for M2.

[13]The results are generally not sensitive to the definition of money.

[14]There is another concept of convergence known as σ-convergence. In this framework, convergence takes places when the price dispersion across regions declines over time. It is known that β-convergence is a necessary but not sufficient condition for σ-convergence.

[15]Using equation (5), the standard convergence model can be written as $X_{it} - X_{jt} = (\delta_{it} - \delta_{jt})\mu_t$ where μ_t is a common factor. The problem with the standard panel unit root test arises when the convergence speed of δ_{it} and δ_{jt} to δ is slower than the divergence speed of μ_t. In this case, $X_{it} - X_{jt}$ may retain nonstationary characteristics even though the convergence condition, δ_{it} and $\delta_{jt} \rightarrow \delta$ as $t \rightarrow \infty$, holds.

[16]The concept of convergence requires at least two regions.

[17]Estimations in this section are based on Sul's computer programs.

[18]Data are also transformed from annual to quarterly data using the cubic-match-last method.

[19]The lag order of three is used for the analysis.

[20]While not shown here, these data are found to be nonstationary using the unit root test.

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Appendix

This appendix shows results from annual data which correspond to Tables 1 and 2, and shows that the heterogeneity in Japanese regional inflation is one unique feature since no evidence of such heterogeneity is observed in the UK and US. Here we use CPI data for the US obtained from the Bureau of Labor Statistics with coverage of 19 regions from 1965 to 2008, but some regions are dropped to create a balanced panel data set. The British authorities do not compile regional price data, and therefore we utilize annual data constructed by Hayes (2005) which covers 11 regions for the period of 1974-1996. As a result, annual data are used for all countries.

Tables A1 and A2 correspond to Tables 1 and 2 based on quarterly data. Table A2 shows that there are significant discrepancies in regional inflation only in Japan.

Table A1. Basic Statistics of Regional Inflation (Annual Data)

Japan	Mean	Std Dev	Min	Max	95% Conf. Interval	
Hokkaido	1.855	2.654	-1.094	8.843	0.912	2.797
Tohoku	2.106	2.769	-0.687	9.464	1.116	3.096
Kanto	2.063	2.619	-0.890	9.003	1.131	2.995
Hokuriku	2.044	2.615	-0.995	8.883	1.114	2.973
Tokai	2.025	2.511	-0.792	9.074	1.150	2.901
Kinki	2.014	2.525	-1.083	9.027	1.108	2.919
Chugoku	2.022	2.697	-0.891	8.910	1.080	2.964
Shikoku	1.928	2.556	-0.792	9.212	1.016	2.839
Kyushu	2.019	2.644	-1.080	8.910	1.058	2.979
Okinawa	1.675	2.308	-0.892	7.792	0.822	2.529
UK						
East Anglia	7.838	5.354	-0.640	20.864	5.593	10.084
East Midlands	7.867	5.261	0.331	21.026	5.680	10.054
North	7.755	5.337	-0.257	21.026	5.658	9.851
North West	7.788	5.110	0.889	19.721	5.536	10.039
South East	7.860	5.220	0.522	20.212	5.899	9.821
South West	7.802	5.410	-0.489	21.026	5.314	10.291
West Midlands	7.793	5.128	-0.298	20.457	6.027	9.559
Yorkshire & Humberside	7.840	5.167	0.611	20.945	5.471	10.208
N Ireland	7.665	5.290	0.261	21.511	5.593	9.738
Scotland	7.785	5.133	0.079	21.188	5.730	9.840
Wales	7.761	5.208	-0.240	21.188	5.826	9.696

Table A1. Continued.

US	Mean	Std Dev	Min	Max	95% Conf. Interval	
Boston-Brockton-Nashua	4.542	2.467	1.300	12.081	3.907	5.178
NY-Northern NJ-Long Island	4.532	2.194	1.546	10.794	3.888	5.176
Phila.-Wilmington-Atlantic City	4.403	2.524	1.016	12.333	3.669	5.136
Pittsburgh	4.369	2.707	0.866	12.896	3.666	5.072
Atlanta	4.324	2.750	1.129	13.016	3.553	5.095
Chicago-Gary-Kenosha	4.353	2.719	1.270	13.527	3.521	5.186
Detroit-Ann Arbor-Flint	4.335	2.795	1.395	14.753	3.492	5.177
Cleveland-Akron	4.415	2.996	0.231	14.135	3.496	5.334
Cincinnati-Hamilton	4.306	2.799	0.658	12.711	3.458	5.155
Milwaukee-Racine	4.316	2.967	0.373	13.952	3.407	5.224
Minneapolis-St. Paul	4.434	2.838	1.300	11.595	3.559	5.309
Dallas-Fort Worth	4.370	3.052	1.341	15.640	3.527	5.214
Houston-Galveston-Brazoria	4.256	3.153	-0.958	12.444	3.312	5.201
LA-Riverside-Orange County	4.454	2.788	1.322	14.641	3.720	5.189
San Francisco-Oakland-San Jose	4.542	2.879	0.816	14.138	3.746	5.337
Seattle-Tacoma-Bremerton	4.531	3.044	1.036	15.254	3.565	5.498
Anchorage	3.839	2.814	0.369	12.879	3.037	4.640
Honolulu	4.354	2.721	-0.233	11.073	3.458	5.249
Portland-Salem	4.369	2.939	0.765	12.724	3.596	5.142

Note: The sample period is 1975-2005 for Japan, 1974-1996 for the UK and 1965-2008 for the US. The Bootstrap method is used to calculate the confidence interval based on 1,000 replications.

Table A2. Basic Statistical Tests for Differences in Regional Inflation (Annual Data)

Country	Mean Test (p-value)
Japan	F[9,20] =2.580(0.0375)
UK	F[10,12] =0.230 (0.9865)
US	F[18,26] =1.740 (0.0970)

Tables

Table 1. Basic Statistics of Regional Inflation (Annual Changes)

	Obs	Mean	Std Dev	Min	Max
Hokkaido	120	1.770	2.839	-1.590	9.919
Tohoku	120	2.014	2.815	-1.079	10.643
Kanto	120	1.962	2.638	-1.378	9.849
Hokuriku	120	1.984	2.621	-1.701	9.385
Tokai	120	1.930	2.553	-1.370	9.768
Kinki	120	1.915	2.547	-1.763	9.736
Chugoku	120	1.922	2.711	-1.367	10.257
Shikoku	120	1.850	2.553	-1.093	9.839
Kyushu	120	1.930	2.673	-1.487	10.414
Okinawa	120	1.594	2.315	-1.186	8.477

Note: The sample period is from 1975Q4-2005Q4.

Table 2. Correlation Matrix of Regional Inflation

	Hokk	Toho	Kant	Hoku	Toka	Kink	Chug	Shik	Kyus	Okin
Hokkaido	1.000									
Tohoku	0.925	1.000								
Kanto	0.902	0.985	1.000							
Hokuriku	0.896	0.980	0.985	1.000						
Tokai	0.909	0.988	0.990	0.981	1.000					
Kinki	0.895	0.980	0.992	0.980	0.989	1.000				
Chugoku	0.898	0.986	0.984	0.979	0.988	0.984	1.000			
Shikoku	0.907	0.987	0.984	0.981	0.987	0.983	0.988	1.000		
Kyushu	0.906	0.984	0.991	0.979	0.982	0.983	0.990	0.991	1.000	
Okinawa	0.851	0.940	0.971	0.952	0.944	0.947	0.948	0.947	0.954	1.000

Note: The sample period is from 1975Q4-2005Q4. Hokkaido (Hokk), Tohoku (Toho), Kanto (Kant), Hokuriku (Hoku), Tokai (Toka), Kinki (Kink), Chugoku (Chug), Shikoku (Shik), Kyushu (Kyus), and Okinawa (Okin)

Table 3. Basic Statistical Tests for Differences in Regional Inflation

Region	Mean Test (p-value)
All 10	F[9,111] = 4.610 (0.000)
Excl. Okinawa	F[8,112] = 2.910 (0.006)

Table 4. Unspecified Common Factors in the Factor Model

Region	Explanatory variable	Coef	Std Err	P-value
Hokkaido	f	3.124	0.228	0.000
Tohoku	f	3.433	0.224	0.000
Kanto	f	3.266	0.213	0.000
Hokuriku	f	3.253	0.213	0.000
Tokai	f	3.179	0.207	0.000
Kinki	f	3.162	0.206	0.000
Chugoku	f	3.299	0.215	0.000
Shikoku	f	3.130	0.204	0.000
Kyushu	f	3.271	0.213	0.000
Okinawa	f	2.717	0.186	0.000
V(Hokkaido)		1.366	0.178	0.000
V(Tohoku)		0.127	0.019	0.000
V(Kanto)		0.086	0.014	0.000
V(Hokuriku)		0.170	0.024	0.000
V(Tokai)		0.078	0.012	0.000
V(Kinki)		0.102	0.015	0.000
V(Chugoku)		0.104	0.016	0.000
V(Shikoku)		0.086	0.013	0.000
V(Kyushu)		0.109	0.016	0.000
V(Okinawa)		0.474	0.062	0.000
Test				
Wald Chi^2(10)=		239.43	–	0.000
Equality of f(Chi^2(9))=		88.06	–	0.000
Log likelihood=		-997.635	–	–

Note: V refers to variance of v in equation (1). The Wald test examines the null hypothesis of all parameters for f being statistically zero, and the Chi^2 test analyzes if they are identical.

Table 5. The Factor Model (Money)

Endogenous variables		Coef	Std Err	P-value	Coef	Std Err	P-value
f	m1	0.041	0.010	0.000			
	m2				0.178	0.017	0.000
Hokkaido (Δp)	f	2.828	0.209	0.000	1.866	0.138	0.000
Tohoku (Δp)	f	3.121	0.205	0.000	2.060	0.135	0.000
Kanto (Δp)	f	2.952	0.193	0.000	1.948	0.128	0.000
Hokuriku (Δp)	f	2.956	0.195	0.000	1.951	0.129	0.000
Tokai (Δp)	f	2.881	0.188	0.000	1.901	0.125	0.000
Kinki (Δp)	f	2.855	0.187	0.000	1.884	0.124	0.000
Chugoku (Δp)	f	3.010	0.197	0.000	1.987	0.130	0.000
Shikoku (Δp)	f	2.824	0.185	0.000	1.864	0.122	0.000
Kyushu (Δp)	f	2.973	0.195	0.000	1.962	0.129	0.000
Okinawa (Δp)	f	2.446	0.169	0.000	1.615	0.112	0.000
V(Hokkaido)		1.379	0.180	0.000	1.380	0.181	0.000
V(Tohoku)		0.126	0.018	0.000	0.127	0.019	0.000
V(Kanto)		0.087	0.014	0.000	0.085	0.013	0.000
V(Hokuriku)		0.171	0.024	0.000	0.170	0.024	0.000
V(Tokai)		0.079	0.012	0.000	0.079	0.012	0.000
V(Kinki)		0.101	0.015	0.000	0.100	0.015	0.000
V(Chugoku)		0.093	0.014	0.000	0.094	0.014	0.000
V(Shikoku)		0.081	0.013	0.000	0.082	0.013	0.000
V(Kyushu)		0.106	0.016	0.000	0.107	0.016	0.000
V(Okinawa)		0.472	0.062	0.000	0.471	0.062	0.000
Test							
Wald Chi^2(13)=		313.970	–	0.000	1026.970	–	0.000
Equality of f (Chi^2(9))=		93.160	–	0.000	92.660	–	0.000
Log likelihood=		-968.775	–	–	-919.450	–	–

Note: V refers to variance of v in equation (1). The Wald test examines the null hypothesis of all parameters for $f$and money (m1 or m2) being statistically zero, and the Chi^2 test analyzes if the parameters for f are identical across regions.

Table 6. The Factor Model
(Money, Income and Call Rate/Japanese Government Bonds Rate)

Endogenous variables		Coef	Std Err	P-value	Coef	Std Err	P-value
f	m2	0.240	0.028	0.000	0.238	0.027	0.000
	gni	-0.140	0.051	0.006	-0.137	0.051	0.008
	call	0.068	0.051	0.182			
	jgb				0.118	0.088	0.180
Hokkaido (Δp)	f	1.797	0.133	0.000	1.797	0.133	0.000
Tohoku (Δp)	f	1.984	0.130	0.000	1.983	0.130	0.000
Kanto (Δp)	f	1.876	0.123	0.000	1.876	0.123	0.000
Hokuriku (Δp)	f	1.879	0.124	0.000	1.879	0.124	0.000
Tokai (Δp)	f	1.831	0.120	0.000	1.831	0.120	0.000
Kinki (Δp)	f	1.815	0.119	0.000	1.814	0.119	0.000
Chugoku (Δp)	f	1.913	0.125	0.000	1.913	0.125	0.000
Shikoku (Δp)	f	1.795	0.118	0.000	1.795	0.118	0.000
Kyushu (Δp)	f	1.890	0.124	0.000	1.889	0.124	0.000
Okinawa (Δp)	f	1.555	0.108	0.000	1.555	0.108	0.000
V(Hokkaido)		1.380	0.180	0.000	1.379	0.180	0.000
V(Tohoku)		0.127	0.019	0.000	0.126	0.019	0.000
V(Kanto)		0.086	0.014	0.000	0.086	0.013	0.000
V(Hokuriku)		0.170	0.024	0.000	0.170	0.024	0.000
V(Tokai)		0.079	0.012	0.000	0.079	0.012	0.000
V(Kinki)		0.101	0.015	0.000	0.101	0.015	0.000
V(Chugoku)		0.094	0.014	0.000	0.094	0.014	0.000
V(Shikoku)		0.081	0.013	0.000	0.081	0.013	0.000
V(Kyushu)		0.107	0.016	0.000	0.107	0.016	0.000
V(Okinawa)		0.471	0.062	0.000	0.471	0.062	0.000
Test							
Wald Chi^2(13)=		1125.520	–	0.000	1125.820	–	0.000
Equality of f (Chi^2(9))=		92.790	–	0.000	92.790	–	0.000
Log likelihood=		-914.975	–	–	-914.965	–	–

Note: V refers to variance of v in equation (1). The Wald test examines the null hypothesis of all parameters for f, money (m1 or m2), gni, and call/jgb being statistically zero, and the Chi^2 test analyzes if the parameters for f are identical across regions.

Table 7. Regional Difference Index of Consumer Prices (2005)

Region	Index
Hokkaido	102.6
Tohoku	98.5
Kanto	102.9
Hokuriku	100.7
Tokai	99.8
Kinki	101.4
Chugoku	98.7
Shikoku	96.7
Kyushu	96.8
Okinawa	95.2

Note: Country average =100.
Source: Ministry of Internal Affairs and Communications.

Table 8. Convergence in Regional Prices

Groups	b	t values	t values for checking convergence in the rest
Quarterly data			
Subgroup A (Hokkaido, Tohoku, Kanto, Hokuriku, Tokai, Kinki, Chugoku)	0.253	0.821	-0.255
Subgroup B (Shikoku, Kyushu, Okinawa)	–	–	–
Annual data			
Subgroup A (Hokkaido, Kanto, Hokuriku)	-0.075	-0.255	0.821
Subgroup B (Tohoku, Tokai, Kinki, Chugoku, Shikoku, Kyushu, Okinawa)	–	–	–

Note: Sample period: 1975-2005.

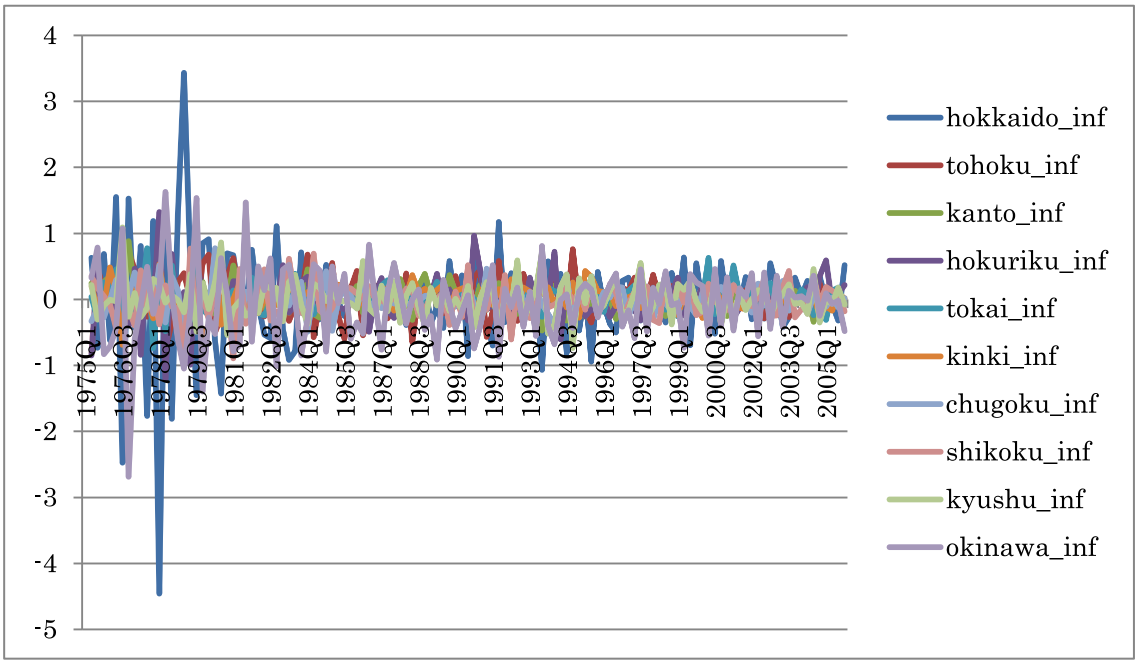
Table 9. Dynamic SURE (DSURE) and Panel Cointegration Tests

DSURE Estimation	Parameter	Std Err
Hokkaido	0.282	0.065
Tohoku	0.234	0.038
Kanto	0.283	0.025
Hokuriku	0.325	0.031
Tokai	0.231	0.030
Kinki	0.239	0.043
Chugoku	0.248	0.036
Shikoku	0.314	0.064
Kyushu	0.299	0.049
Okinawa	0.314	0.039
Homogeneity test	Chi^2	P-value
	38.840	0.000
Panel cointegration test	Stat	
Group rho	-3.287	
Group pp	-3.454	
Group adf	-1.762	

Note: Income elasticity is calculated for each region by the Dynamic Seemingly Unrelated Regression (DSURE) method (Mark, Ogaki and Sul 2005), and the poolability test is conducted by the Hausman type test (Phillips and Sul 2003). Panel cointegration tests are based on Pedroni (1999) which takes account of the time effect and allows for heterogeneous parameters for each region. The statistics for the cointegration tests are distributed as the standard normal, and thus the 5% critical value is -1.65.

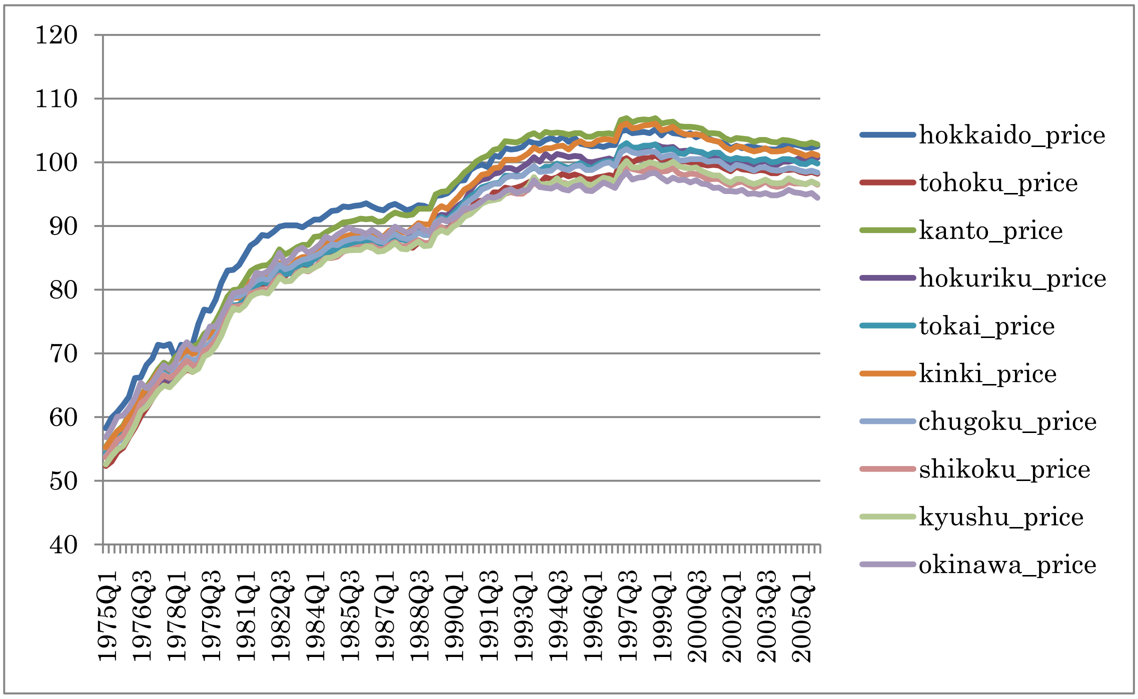
Figures

Figure 1. Idiosyncratic Components in Regional Inflation



Note: The cross-section average inflation is removed from regional inflation.

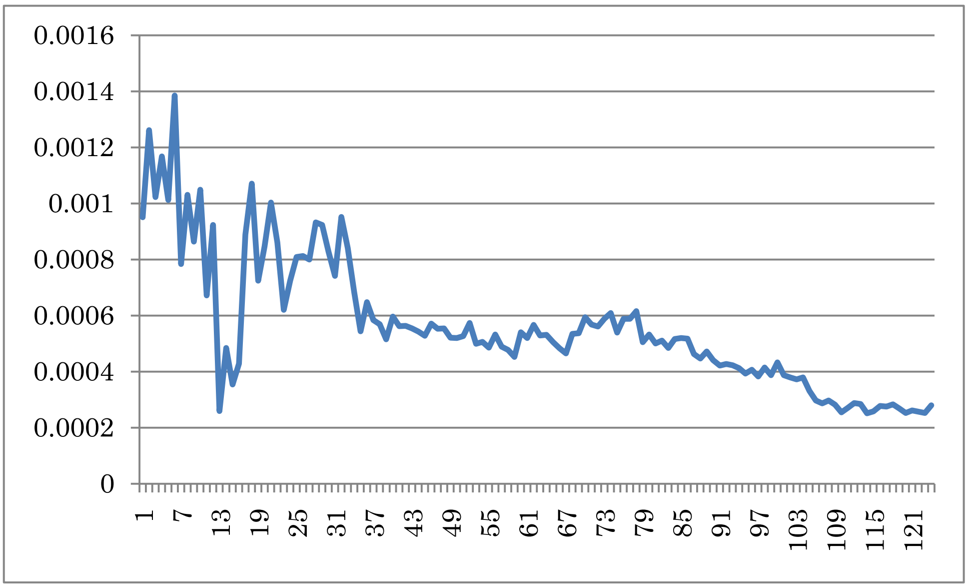
Figure 2. Japanese Regional Prices



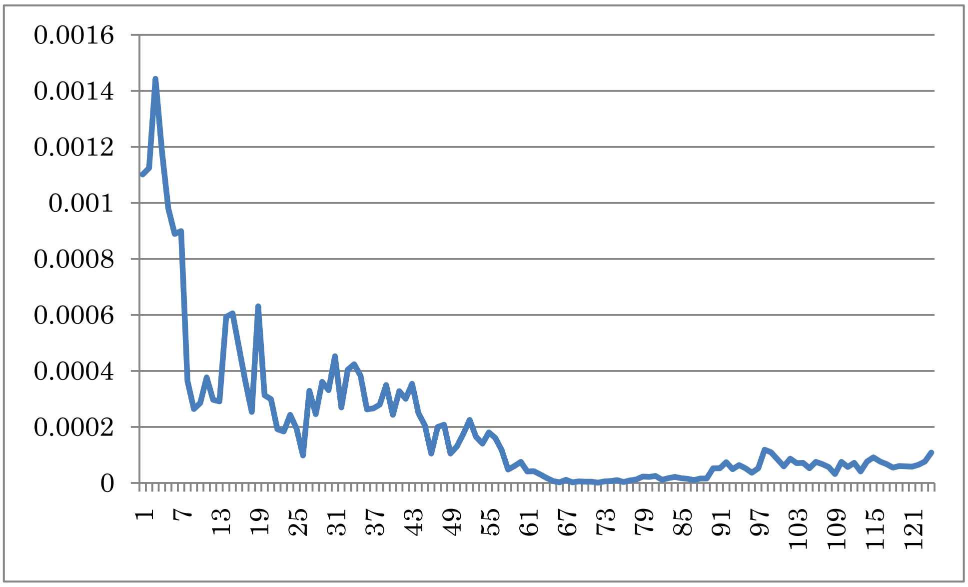
Note: The data are constructed on the basis of the differences in regional inflation in 2005.

Figure 3. Transition

Subgroup A



SubgroupB



Note: The figure is based on our calculation of H_t in equation (7) using quarterly data.