Bank of Japan Working Paper Series

Broad Perspective Review

Broad-Perspective Review Series

Linkage between Wage and Price Inflation in Japan

Yoichi Ueno*
youichi.ueno@boj.or.jp

No.24-E-7
June 2024

Bank of Japan
2-1-1 Nihonbashi-Hongokucho, Chuo-ku, Tokyo 103-0021, Japan

* Research and Statistics Department (currently Nagoya Branch)

Linkage between Wage and Price Inflation in Japan*

Yoichi Ueno†

June 2024

Abstract

This paper investigates changes in the linkage between wages and prices in Japan by using a dynamic factor model of disaggregated wages and prices with heteroscedasticity- and autocorrelation-robust inference. The empirical results show that the model is better at identifying the underlying trends in wage and price inflation than models using only aggregate data. In addition, the trend component of services price inflation is the best indicator to gauge the underlying trend in price inflation among indicators examined in this paper. Further, wages and prices decoupled around 1998, but they have recoupled to some extent in the post-COVID-19 era. Lastly, the volatility of the common trend component of wage and price inflation determines the strength of the linkage between wages and prices, and it closely tracks an indicator which shows importance on price inflation when firms revise wages in negotiations.

JEL Classification: E31, E37, J31

Keywords: Price Inflation; Wage Inflation; Unobserved Components Model; Factor Model

---

* The author is grateful to Kosuke Aoki, Takeo Hoshi, Shigenori Shiratsuka, Toyoichiro Shirota, and colleagues at the Bank of Japan for comments and discussions. Any remaining errors are the author's own. Views expressed in the paper are those of the author and do not necessarily reflect those of the Bank of Japan.

† Research and Statistics Department (currently Nagoya Branch; e-mail: youichi.ueno@boj.or.jp)

I. Introduction

Empirical studies on wages and prices in Japan show that the linkage between the two broke around the late 1990s, so wage inflation became a much less important determinant of price inflation in the pre-COVID-19 era (e.g., Hoshi and Kashyap, 2021). However, in the post-COVID-19 era, data and anecdotal information on firms' wage- and price-setting behavior have shown that the virtuous cycle between wages and prices has become more solid (Bank of Japan, 2024). Ueda (2024) also argues that the linkage between wages and prices has recently strengthened in both directions, from prices to wages and from wages to prices.

This paper investigates changes in the linkage between wages and prices described above by using an advanced empirical framework and provides new empirical evidence. The main findings of the paper are: (a) the multivariate unobserved components with stochastic volatility and outlier adjustments (MUCSVO) models (Stock and Watson, 2016) are better at identifying the underlying trends in wage and price inflation in Japan than models using only aggregate data; (b) the moving average of the trend component of services price inflation estimated from a MUCSVO model is the best indicator to gauge the underlying trend in price inflation among indicators examined in this paper; (c) heteroscedasticity- and autocorrelation-robust (HAR) inference using trend components shows that wages and prices decoupled around 1998, but they have recoupled to some extent in the post-COVID-19 era; and (d) the volatility of the common trend component of wage and price inflation has determined the strength of the linkage and closely tracked an indicator which shows the importance of price inflation when firms revise wages in negotiations.

The analysis builds on three strands of literature. First, the models employed in this paper feature cross-sectional smoothing by using many series for wages and prices and time-series smoothing through an unobserved components model to assess wage and price inflation developments. In the literature, a range of cross-sectional and time-series smoothing techniques has been considered to estimate underlying consumer price inflation, including alternative cross-sectional weights on disaggregated price changes such as trimmed means or medians (Bryan and Cecchetti, 1994; and Shiratsuka, 2015) and simple distributed lags of inflation such as the 4-quarter moving average (Atkeson and Ohanian, 2001). These approaches can serve as forecast benchmarks for the estimates from econometric models. There has been an increase in recent years in research on unobserved components models or dynamic factor models of wage and price inflation (e.g., Stock and Watson, 2007; Reis and Watson, 2010; Stock and Watson, 2016; Rudd, 2020; Almuzara and Sbordone, 2022; Kiley, 2023; and Almuzara, Audoly, and Melcangi, 2023). To the author's best knowledge, this paper is the first application of the framework in Stock and Watson (2016) and Kiley (2023) to the Japanese data.

Second, the subject of this paper, the linkage between wages and prices, has long been a subject of interest in the literature (e.g., Gordon, 1975; Blanchard, 1986; Kuroda and Yamamoto, 2014; Peneva and Rudd, 2017; Muto and Shintani, 2020; Yoshikawa, 2022; Kiley, 2023; Fukunaga et al., 2023; Lorenzoni and Werning, 2023; Nakamura et al., 2024; and Ozaki et al., 2024), with Hoshi and Kashyap (2021) being the most closely related to this paper. They examine how the connection between wages and prices in Japan has changed over time by computing the Pearson's correlation coefficient between the trend components of price and wage inflation estimated using a simple univariate unobserved components model. They report that even though the correlation is positive and quite stable before 2000, it drops substantially after 1998. They argue that this shows prices and wages became decoupled around 1998. While the analysis in Hoshi and Kashyap (2021) is restricted to the macro level, through an examination at the sectoral level, Kuroda and Yamamoto (2014) also argue that synchronicity between wages and prices is not observed in industry from the late-1990s to 2011.

Peneva and Rudd (2017) also employ the estimated trend components of price and wage inflation in the United States to analyze changes in these dynamics from 1965 to 2012. Based on the estimation results, they conclude that the dynamics have changed significantly since the mid-1990s: the estimated trends of price inflation and labor cost growth during the 1960s and 1970s increased in a persistent and roughly contemporaneous manner, but they have both been essentially constant since the mid-1990s. In the United States, high price inflation in the post-COVID-19 era has been accompanied by higher nominal wage growth, and the interaction of price and wage inflation has attracted substantial public attention. To address these issues, Kiley (2023) considers the informational role of wages in the trend component of price inflation using a MUCSVO model.

Third, this paper employs the HAR inference developed by Kiefer and Vogelsang (2002a, 2022b), Sun (2004), Phillips, Wang, and Zhang (2019) and others. HAR-based t-statistics plays an important role in examining the relationship between the estimated trend components of price and wage inflation. Since the trend components are assumed to follow a random walk process, there is the potential for mistaking a spurious relationship as genuine when using standard t-statistics. However, the HAR approach can overcome the potential for spurious relationships among stochastic trends.

Building on these works, this paper examines the time-variation of the strength of the linkage between wage and price inflation in Japan. Specifically, as a first step, I examine which MUCSVO model and trend component perform best in gauging trends in wage and price inflation using data on disaggregated consumer prices and sectoral wages from 1981 to 2023. For the evaluation, the accuracy and forecasting performance of the estimated trend components are examined. Second, the linkage between the trend components of wage and price inflation estimated from the best model is analyzed by the HAR inference. Third and finally, the empirical results are compared with current wage and price developments to understand the background of the time-variation in the strength of the linkage.

The rest of the paper is structured as follows. Section II presents the model and HAR inference employed in the analysis. Section III provides the empirical results. Section IV discusses the relationship between the empirical results and firms' behavior in price and wage setting. Section V concludes.

II. Empirical Framework

A. Multivariate Unobserved Components with Stochastic Volatility and Outlier Adjustments (MUCSVO) Model

Stock and Watson (2016) propose the MUCSVO model to extract the trend component of inflation from a set of price series. Kiley (2023) applies the model to price and wage inflation series. In the framework, both price and wage inflation are expressed as the sum of a common trend component, a common transient component, and sector-specific trend components and transient components. The factor loadings for price and wage inflation on the common components vary over time, to allow for changes in the relationship of a series to the common components. In addition, the latent common and sector-specific components have stochastic volatility, and the model allows for heavy tails (outliers) in the common and sectoral transitory components.

The model is formally given by a set of equations for price inflation for classification $i = 1{:}N_\pi$, $\pi_{i,t}$, and wage inflation for industry $j = 1{:}N_w$, $w_{j,t}$ at period t:

$$\pi_{i,t} = \alpha_{i,\tau,t}\tau_{c,t} + \alpha_{i,\epsilon,t}\epsilon_{c,t} + \tau_{i,t} + \epsilon_{i,t}, \quad (1)$$

$$w_{j,t} = \alpha_{j,\tau,t}\tau_{c,t} + \alpha_{j,\epsilon,t}\epsilon_{c,t} + \tau_{j,t} + \epsilon_{j,t}, \quad (2)$$

$$\tau_{c,t} = \tau_{c,t-1} + \sigma_{\Delta\tau,c,t} \times \eta_{\tau,c,t}, \quad (3)$$

$$\tau_{k,t} = \tau_{k,t-1} + \sigma_{\Delta\tau,k,t} \times \eta_{\tau,k,t} \quad \text{for } k = i \text{ or } j, \quad (4)$$

$$\epsilon_{c,t} = \sigma_{\epsilon,c,t} \times s_{c,t} \times \eta_{\epsilon,c,t}, \quad (5)$$

$$\epsilon_{k,t} = \sigma_{\epsilon,k,t} \times s_{k,t} \times \eta_{\epsilon,k,t} \quad \text{for } k = i \text{ or } j, \quad (6)$$

$$\alpha_{k,\tau,t} = \alpha_{k,\tau,t-1} + \lambda_{k,\tau}\xi_{k,\tau,t} \quad \text{for } k = i \text{ or } j, \quad (7)$$

$$\alpha_{k,\epsilon,t} = \alpha_{k,\epsilon,t-1} + \lambda_{k,\epsilon}\xi_{k,\epsilon,t} \quad \text{for } k = i \text{ or } j, \tag{8}$$

$$\Delta\ln(\sigma^2_{\Delta\tau,c,t}) = \gamma_{\Delta\tau,c}\nu_{\Delta\tau,c,t}, \tag{9}$$

$$\Delta\ln(\sigma^2_{\epsilon,c,t}) = \gamma_{\epsilon,c}\nu_{\epsilon,c,t}, \tag{10}$$

$$\Delta\ln(\sigma^2_{\Delta\tau,k,t}) = \gamma_{\Delta\tau,k}\nu_{\Delta\tau,k,t} \quad \text{for } k = i \text{ or } j, \tag{11}$$

$$\Delta\ln(\sigma^2_{\epsilon,k,t}) = \gamma_{\epsilon,k}\nu_{\epsilon,k,t} \quad \text{for } k = i \text{ or } j. \tag{12}$$

Equations (1) and (2) are the observation equations. The observed price and wage inflation series $\pi_{i,t}$ and $w_{j,t}$ are functions of their own idiosyncratic trend and transitory components ($\tau_{k,t}$ and $\epsilon_{k,t}$ for $k = i \text{ or } j$) and the common trend and transitory components ($\tau_{c,t}$ and $\epsilon_{c,t}$). The factor loadings on the common components are $\alpha_{k,\tau,t}$ and $\alpha_{k,\epsilon,t}$ for $k = i \text{ or } j$. The trend components are random walks with stochastic volatility (denoted by $\sigma_{\Delta\tau,c,t}$ and $\sigma_{\Delta\tau,k,t}$ for $k = i \text{ or } j$), represented by equations (3) and (4). The transitory components, $\epsilon_{c,t}$ and $\epsilon_{k,t}$ for $k = i \text{ or } j$, are serially uncorrelated, equations (5) and (6), in which both innovations, $\sigma_{\epsilon,c,t}$ and $\sigma_{\epsilon,k,t}$ for $k = i \text{ or } j$, are logarithmic random walks with stochastic volatility. Conditional on the stochastic volatility processes, transitory components are modeled as a mixture of the i.i.d. variables $s_{c,t}$ and $s_{k,t}$ for $k = i \text{ or } j$, where $s_{c,t}$ and $s_{k,t}$ equal 1 with probability $(1 - p_l$ for $l = c, i, \text{or } j)$ and equal a draw from a uniform distribution over the interval 2 to 10 with probability p_l. This mixed model allows for outliers in inflation, that is, large one-time shifts in the levels of prices and wages, which occur each period with probability $p_{l,t}$. As discussed in Kiley (2023), for example, the outliers may have been triggered by the COVID-19 pandemic. The outliers can also reflect institutional change, as pointed out in Stock and Watson (2016). The factor loadings $\alpha_{k,\tau,t}$ and $\alpha_{k,\epsilon,t}$ for $k = i \text{ or } j$ are random walks (equations [7] and [8]), as is the natural logarithm of the stochastic volatilities of the shocks, $\ln(\sigma^2_{\Delta\tau,c,t})$, $\ln(\sigma^2_{\epsilon,c,t})$, $\ln(\sigma^2_{\Delta\tau,k,t})$, and $\ln(\sigma^2_{\epsilon,k,t})$, equations (9) to (12). The disturbances ($\eta_{\tau,c,t}$, $\eta_{\epsilon,c,t}$, $\eta_{\tau,k,t}$, $\eta_{\epsilon,k,t}$, $\xi_{k,\tau,t}$, $\xi_{k,\epsilon,t}$, $\nu_{\Delta\tau,c,t}$, $\nu_{\epsilon,c,t}$, $\nu_{\Delta\tau,k,t}$, $\nu_{\epsilon,k,t}$) are i.i.d. standard normal.

In the framework, the aggregate trend component for price inflation, $\tau_{CPI,t}$, is given by

$$\tau_{CPI,t} = \sum_{i=1}^{N_{CPI}} \omega_{CPI,i,t}(\alpha_{i,\tau,t}\tau_{c,t} + \tau_{i,t}).[1] \tag{13}$$

In equation (13), the contribution of series i to the aggregate trend component depends on its expenditure weight, $\omega_{CPI,i,t}$, and the trend component associated with price series i, which depends on the loading, $\alpha_{i,\tau,t}$, on the common trend component, $\tau_{c,t}$, and the sector's idiosyncratic trend component, $\tau_{i,t}$.

[1] CPI is an abbreviation for consumer price index.

In addition to the aggregate trend component, sectoral trend components can be derived in this framework. Specifically, the trend components of goods and services price inflation, $\tau_{goods,t}$ and $\tau_{services,t}$, are

$$\tau_{goods,t} = \frac{\sum_{i\in\Omega_{goods}} \omega_{\pi,i,t}\left(\alpha_{i,\tau,t}\tau_{c,t} + \tau_{i,t}\right)}{\sum_{i\in\Omega_{goods}} \omega_{\pi,i,t}}, \tag{14}$$

$$\tau_{services,t} = \frac{\sum_{i\in\Omega_{services}} \omega_{\pi,i,t}\left(\alpha_{i,\tau,t}\tau_{c,t} + \tau_{i,t}\right)}{\sum_{i\in\Omega_{services}} \omega_{\pi,i,t}}, \tag{15}$$

where Ω_{goods} ($\Omega_{services}$) is the subset of the categories in which items are included in goods (services).

As in the case of price inflation, the aggregate trend component for wage inflation, $\tau_{SCE,t}$, is given by

$$\tau_{SCE,t} = \sum_{j=1}^{N_{SCE}} \omega_{SCE,j,t}\left(\alpha_{j,\tau,t}\tau_{c,t} + \tau_{j,t}\right).[2] \tag{16}$$

Equation (16) has the same structure as equation (13). Specifically, the aggregate trend component is the weighted average of each trend component of wage inflation in industry j, which is the sum of the common trend component multiplied by the factor loading, $\alpha_{j,\tau,t}\tau_{c,t}$, and the industry's idiosyncratic trend component, $\tau_{j,t}$. Each industry share weight, $\omega_{w,j,t}$, is defined as the industry j's share in the number of employees. Similarly, as in price inflation, the trend components of manufacturing and nonmanufacturing wage inflation, $\tau_{manu.,t}$ and $\tau_{nonmanu.,t}$, are given by

$$\tau_{manu.,t} = \frac{\sum_{j\in\Omega_{manu.}} \omega_{SCE,j,t}\left(\alpha_{j,\tau,t}\tau_{c,t} + \tau_{j,t}\right)}{\sum_{j\in\Omega_{manu.}} \omega_{SCE,j,t}}, \tag{17}$$

$$\tau_{nonmanu.,t} = \frac{\sum_{j\in\Omega_{nonmanu.}} \omega_{SCE,j,t}\left(\alpha_{j,\tau,t}\tau_{c,t} + \tau_{j,t}\right)}{\sum_{j\in\Omega_{nonmanu.}} \omega_{SCE,j,t}}, \tag{18}$$

where $\Omega_{manu.}$ ($\Omega_{nonmanu.}$) is the subset of industries in which industries are included in manufacturing (nonmanufacturing).

Several features of the model are noteworthy for descriptions of price and wage inflation data. The trend components allow for persistent shifts in inflation. The presence of common and idiosyncratic trend components further allows for a common trend and for persistent differences across price categories (e.g., falling relative durable goods

[2] SCE is an abbreviation for scheduled cash earnings per employee.

prices and rising relative prices for services) and across price and wage series (e.g., because wage developments differ from price developments due to persistent productivity or other factors). The transitory components, including jump, capture fluctuations around these trends, while the stochastic volatility of trend and transitory components allows for periods of relative stability and substantial movements in the trend components. Finally, the presence of stochastic volatility and time-variation in the loadings on the common components allows for changes over time on the covariance across price and wage inflation.

The definition of the aggregate trends implies that a differential trend in wages can be accounted for in the model without affecting the estimate of trend price inflation due to the allowance in the model for series-specific trends. Although an additional common factor for wages can be included in the model, separate from a common factor for prices, such additional common factors are not introduced to maintain some degree of parsimony as in Kiley (2023).

The models are estimated using Bayesian methods and estimation of the posterior proceeds using Markov Chain Monte Carlo (MCMC) methods. The estimation details follow Kiley (2023) and Stock and Watson (2016), and the reader is referred to Stock and Watson (2015) for details. Detailed estimate results are presented in Appendix 1.

While the above formulation is the case in which data for both price and wage inflation are used simultaneously, the case where data for price and wage inflation are used separately is also examined below. In the latter case, the estimated common components are common among disaggregate data for either price or wage inflation, that is, the common components for price inflation are different from those for wage inflation. This procedure can clarify the importance of additional information of wage inflation for price inflation.

B. HAR Testing for Regression among Stochastic Trends

In the MUCSVO framework, the covariance across price and wage inflation depends on the stochastic volatility and factor loadings on the common components. The covariance movement implies time-variation in the strength of the linkage between the underlying trends in price and wage inflation.

Hoshi and Kashyap (2021) examine the linkage by calculating the Pearson's correlation coefficient between the estimated trend components of price and wage inflation. However, since the stochastic trends are assumed to follow a random walk process in their framework, there is the potential for mistaking a spurious relationship as genuine. In the specific case for two independent random walks, which corresponds to Hoshi and

Kashyap (2021), Ernst, Shepp, and Wyner (2017) resolve the potential theoretically. They show that the sample of limiting correlation coefficient of two independent random walks is highly dispersed by providing an explicit formula for the standard deviation of the sample correlation coefficient between two independent Wiener processes, which are the limiting processes of random walks. This result suggests that the likelihood of the potential should not be neglected if the correlation coefficient between random walks is used.

To fix inference problems in spurious regression among independent random walks, Phillips, Wang, and Zhang (2019) derive the limiting distribution of the HAR-based t-statistics which leads to valid statistical testing for the spurious relationship. In this paper, the HAR-based inference is employed to reexamine the decoupling between the stochastic trend components of wage and price inflation found in Hoshi and Kashyap (2021).[3] Specifically, the following null hypothesis H_0 against the alternative H_1 is tested:

$$H_0 \colon \beta_{YX}[t_1, t_2] = 0$$

$$H_1 \colon \beta_{YX}[t_1, t_2] > 0$$

where $\beta_{YX}[t_1, t_2]$ is estimated by the standardized regression of the variable related to price inflation, Y_t, on the variable related to wage inflation, X_t, using the sample from t_1 to t_2. The variables related to price and wage inflation are actual data or the various trend estimates. Here, a one-sided test is used since the interest of this paper is in whether or not there is a positive linkage between the stochastic trends of price and wage inflation. Standardization is employed to keep comparability with the empirical analysis of Hoshi and Kashyap (2021), and the testing procedure proposed by Phillips, Wang, and Zhang (2019) is followed directly. The least square estimator $\hat{\beta}_{YX}[t_1, t_2]$ is then given by

$$\hat{\beta}_{YX}[t_1, t_2] = \left[\sum_{t=1}^{N_{t_1,t_2}} \tilde{X}_t^2 \right]^{-1} \sum_{t=1}^{N_{t_1,t_2}} \tilde{X}_t \tilde{Y}_t$$

where N_{t_1,t_2} is the number of the time period from t_1 to t_2, and $\tilde{X}_t$ and $\tilde{Y}_t$ are the

[3] When the data of both price and wage inflation are simultaneously used, it is possible to calculate the correlation coefficient between the stochastic trends by using the estimates of the stochastic volatility and time-variation in the factor loadings on the common components. However, the specific procedure for the computation is complicated and some assumptions are needed. In the case where the data of price and wage inflation are used separately for the estimation of the stochastic trends as in Hoshi and Kashyap (2021), the HAR-based inference is preferable since the information on the relationship between the stochastic trends is not delivered in separate MUCSVO models. To uniformly examine the linkage between stochastic trends in several specifications, the HAR-based inference is employed in this paper.

standardized versions of X_t and Y_t calculated using these means and variances in the sample from t_1 to t_2. The HAR-based t-statistics is defined as

$$t_{HAR,YX}[t_1,t_2] \equiv \frac{\hat{\beta}_{YX}[t_1,t_2]}{\left[\sum_{t=1}^{N_{t_1,t_2}} \tilde{X}_t^2\right]^{-1} \left\{N_{t_1,t_2}\widehat{\mathrm{lrvar}}\left(\tilde{X}_t\hat{u}_t\right)\right\}^{\frac{1}{2}}}$$

where $\hat{u}_t \equiv \tilde{Y}_t - \hat{\beta}_{YX}[t_1,t_2]\tilde{X}_t$ for $t = 1,\cdots,N_{t_1,t_2}$,

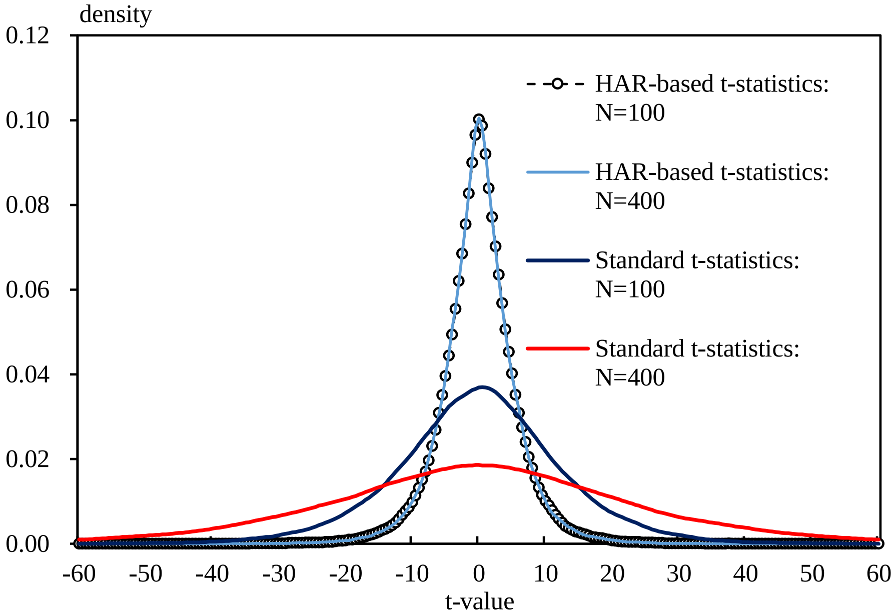
$$\widehat{\mathrm{lrvar}}\left(\tilde{X}_t\hat{u}_t\right) \equiv \sum_{j=-(N_{t_1,t_2}-1)}^{N_{t_1,t_2}-1} k_b\left(\frac{j}{N_{t_1,t_2}}\right)\left[\frac{\sum_{1\leq t,t+j\leq N_{t_1,t_2}} \tilde{X}_t\hat{u}_t\hat{u}_{t+j}\tilde{X}_{t+j}}{N_{t_1,t_2}}\right].$$

Here, $k_b\left(\frac{j}{N_{t_1,t_2}}\right) \equiv k\left(\frac{j}{bN_{t_1,t_2}}\right)$ for a kernel function $k(\cdot)$ and $b \in (0,1]$ is some fixed bandwidth. In this paper, The Bartlett kernel function with $b = 0.2$ is used following Phillips, Wang, and Zhang (2019) and Sun (2004).

The limiting distribution of $t_{YX}[t_1,t_2]$ is shown to be well-defined and gives its appropriate critical values based on Monte Carlo simulations. Figure 1 shows the kernel estimates of the probability densities for the standard t-statistics and HAR-based t-statistics in spurious regressions between two independent random walks calculated based on 100,000 simulations with sample size N=100 and N=400. The density of the standard t-statistics does not converge as the sample size grows, but the density of the HAR-based t-statistics does converge. The asymptotic critical value of a hypothesis test can therefore be calculated in the case of the HAR-based t-statistics.

In addition to the linkage between the aggregate trends of wage and price inflation, the relationships among sectoral trends are investigated in section III. Sectoral examination, as in Kuroda and Yamamoto (2014), clarifies whether the decoupling of wages and prices found by Hoshi and Kashyap (2021) is an aggregate phenomenon or is common to both the macro and sectoral levels. In this regard, Bank of Japan (2013) points out that developments in service sector wages and prices have played a major role in the chronic deflation since the mid-1990s. Analysis of sectoral trends can therefore deepen our understanding of this chronic deflation.

Figure 1: Densities of Different t-statistics in Spurious Regression among Random Walks



Notes: Kernel estimates of the probability densities for t-statistics under different scenarios based on 100,000 simulations.

III. Data and Estimation Results

A. Data and Specifications Considered

The full data set consists of observations on 17 components of price inflation used to construct the consumer price index (CPI) by the Statistics Bureau of Japan and wage inflation across 15 industries of the scheduled cash earnings per employee (SCE) in the *Monthly Labour Survey*.[4] The raw data in the sample are monthly observations from January 1981 to December 2023.[5] The analysis uses quarterly data constructed by averaging the monthly price and wage indexes over the three months in the quarter.[6] Throughout, wage and price inflation is measured in percent change at an annual rate.

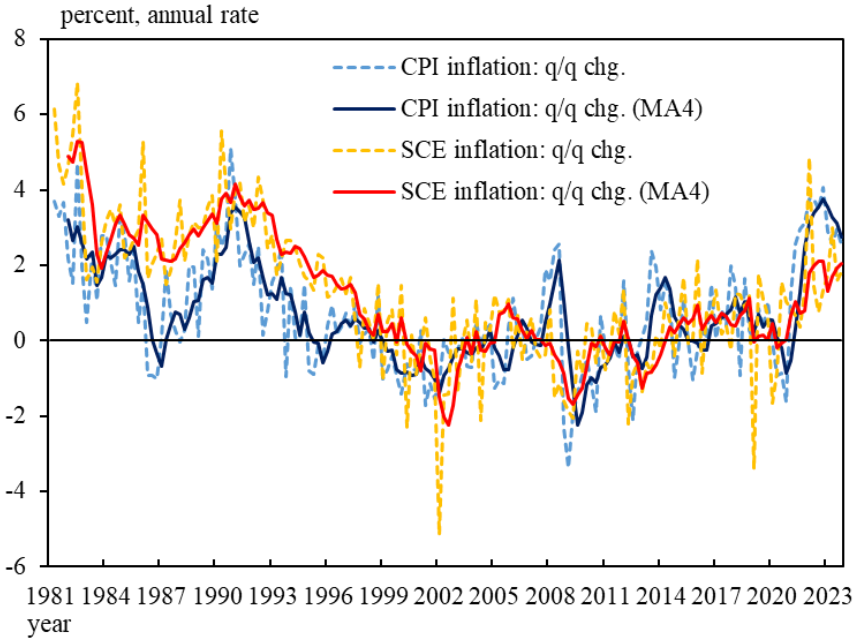
[4] The SCE which relates to establishments with 30 or more employees is used as a wage index since preliminary analysis shows that the SCE contains more information useful in an assessment of trends in price inflation than other indexes such as total cash earnings or contractual cash earnings. Specifically, preliminary analysis following Kiley (2023) indicates that weight on the SCE inflation in the estimate of the aggregate trend component of price inflation is larger than those on other wage indexes, and hence the SCE is the most informative.

[5] The SCE across the complete set of industries begins in the 1981, determining the start date.

[6] Each index is seasonally adjusted using the U.S. Census Bureau's X-13ARIMA-SEATS. For the CPI, the effects of several factors such as consumption tax hikes in 1989, 1997, 2014, and 2019, the introduction of subsidies for high school tuition in 2010, the introduction of free preschool education in 2019, and the reduction in mobile phone charges in 2021 are also adjusted by level shift adjustment together with seasonal adjustment.

Figure 2 shows the history of quarterly change (labeled q/q chg.) for the overall CPI and SCE along with their four-quarter moving averages (labeled MA4). There is substantial trend comovement in prices and wages, along with notable short-run differences (such as the jump in wage inflation during COVID-19, reflecting compositional factors).

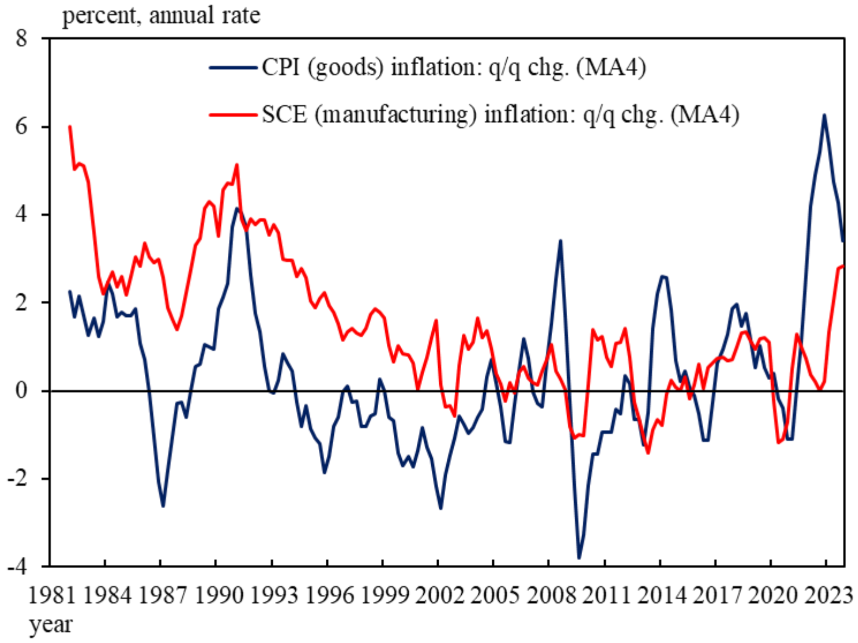
Figure 2: Headline Price and Wage Inflation



Notes: Headline price inflation is the percent change in the CPI. Wage inflation is the percent change in the SCE. The percent change is expressed at an annual rate. Each index is seasonally adjusted using the U.S. Census Bureau's X-13ARIMA-SEATS. For the CPI, the effects of several factors such as consumption tax hikes in 1989, 1997, 2014, and 2019, the introduction of subsidies for high school tuition in 2010, the introduction of free preschool education in 2019, and the reduction in mobile phone charges in 2021, are also adjusted by level shift adjustment together with seasonal adjustment. The SCE relates to establishments with 30 or more employees.
Sources: Statistics Bureau of Japan; Ministry of Health, Labour and Welfare; and author's calculations.

Figures 3 and 4 plot goods price inflation with manufacturing wage price inflation and services price inflation with nonmanufacturing wage price inflation, respectively. In both figures, the series are 4-quarter moving averages. Reflecting the difference in cost structures between manufacturing and nonmanufacturing industries, the comovement in prices and wages is stronger in the services/nonmanufacturing sector than in the goods/manufacturing sector.

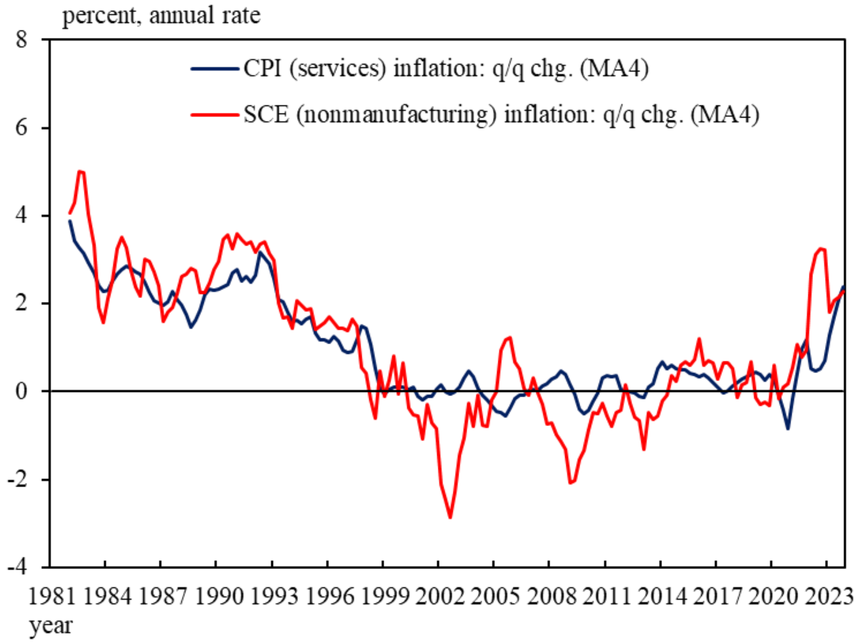
Figure 3: Goods Price Inflation and Wage Inflation in Manufacturing Industry



Notes: Goods price inflation is the percent change in the CPI for goods. Wage inflation in manufacturing industry is the percent change in the SCE in manufacturing industry. Each index is seasonally adjusted in the same way as the aggregate series. The percent change is expressed at an annual rate.

Sources: Statistics Bureau of Japan; Ministry of Health, Labour and Welfare; and author's calculations.

Figure 4: Services Price Inflation and Wage Inflation in Nonmanufacturing Industry



Notes: Services price inflation is the percent change in the CPI for services. Wage inflation in nonmanufacturing industry is the percent change in the SCE in nonmanufacturing industry. Each index is seasonally adjusted in the same way as the aggregate series and expressed at an annual rate.

Sources: Statistics Bureau of Japan; Ministry of Health, Labour and Welfare; and author's calculations.

Following the classification of goods and services used by the Statistics Bureau of Japan, I categorize all the items of the CPI into 17 components.[7] The 17 components and the historical averages of their expenditure share weights are given in Table 1. The 15 industries for the wage indexes are also shown with the historical averages of their employees share weights.[8]

Table 1 also presents the mean, standard deviation, and correlation coefficients with quarterly changes in the CPI excluding fresh food (CPIxF) and the overall SCE for the inflation data on the price and wage indexes used in the analysis. Following Shiratsuka (2015), who shows that the CPIxF performs better as a core price inflation indicator than other indicators, the CPIxF is used to calculate the correlation coefficients here.[9] There are substantial differences in mean of quarterly changes across price and wage measures, reflecting sectoral differences. There are also substantial differences in standard deviation and in the correlation coefficient with the CPIxFE and overall SCE inflation, while the second moments of these series should be carefully interpreted since there is some possibility that each inflation series has a unit root, as described below. These facts suggest the advantages of the structure of the MUCSVO model, which allows for differences in trend rates of inflation across wage and price series and in correlation coefficient with these common factors.

[7] In the 2020-base Consumer Price Index, all items are categorized into twenty-two goods and service groups. By combining a few similar groups into one group, all items are classified into 17 groups. Specifically, "Fresh food, raw meats & cut flowers" and "Other agricultural, aquatic & livestock products" are combined into "Agricultural, aquatic & livestock products." "Meals outside the home (School lunch)" and "Meals outside the home (Eating out)" are combined into "Meals outside the home." "House rent, public, Urban Renaissance Agency & public corporation," "House rent, private," and "Imputed rent" are combined into "Rent." "Services related to medical care & welfare" in "Public services" and "Other services (Services related to medical care & welfare)" in "General services" are combined into "Services related to medical care & welfare." The indexes in other years' base are grouped in the same manner. The price data are constructed basically from the month-on-month change data published by the Statistics Bureau of Japan, not from the year-on-year change data nor from the level data, since the quarter-on-quarter change is the main object of this paper. Specifically, starting from the level data of the 2020-base Consumer Price Index after January 2020, the whole of the data is computed backward using the month-on-month data. Following this procedure, the discontinuous shift due to the change of base year of the CPI does not arise.

[8] The wage and employees data are constructed from wage (scheduled cash earnings) and regular employment indexes, as in Hoshi and Kashyap (2020).

[9] Hogen, Kawamoto, and Nakahama (2015) investigate the business cycle characteristics of various core inflation measures in Japan and find a close link between the CPIxF and the output gap.

Table 1: Price Indexes Considered, with Means, Standard Deviations and Correlation Coefficients with CPIxF and SCE Inflation for 1981:Q2 to 2023:Q4

Price Index	Weight, %	Mean	Standard Deviation	Correlation with: CPIxF Inflation	SCE Inflation
Agricultural, aquatic & livestock products	8.782	1.026	5.821	0.232	0.112
Food products	14.130	0.939	2.233	0.740	0.362
Textiles	5.889	0.666	2.338	0.650	0.561
Petroleum products	3.265	0.512	12.927	0.411	0.073
Other industrial products	14.211	-0.534	2.224	0.595	0.356
Electricity, manufactured & piped gas & water charges	4.797	0.090	6.183	0.270	-0.011
Publications	1.659	1.425	2.260	0.328	0.350
Public services related to domestic duties	3.384	1.019	2.783	0.053	0.081
Services related to medical care & welfare[10]	2.347	1.583	4.714	0.074	0.038
Public services related to forwarding & communication	4.595	0.378	1.874	0.410	0.327
Public services related to education	0.527	2.074	6.409	0.123	0.261
Public services related to culture & recreation	0.739	0.765	5.625	0.196	0.262
General services related to domestic duties	4.408	1.039	1.331	0.696	0.662
General Services related to education	3.181	1.916	1.988	0.544	0.731
General services related to communication, culture & recreation	6.071	0.815	2.746	0.546	0.412
Meals outside the home[11]	6.242	1.114	1.510	0.747	0.481
Rent[12]	15.773	1.014	1.440	0.516	0.748

Notes: Each price index is seasonally adjusted in the same way as in Figure 2. The unit for mean and standard deviation is percent expressed at an annual rate.
Sources: Statistics Bureau of Japan; Ministry of Health, Labour and Welfare; and author's calculations.

[10] Services related to medical care & welfare in public and general services.
[11] Meals outside the home in public and general services.
[12] "House rent, public, Urban Renaissance Agency & public corporation", "House rent, private", and "Imputed rent."

Table 2: Wage Indexes Considered, with Means, Standard Deviations and Correlation Coefficients with CPIxF and SCE Inflation for 1981:Q2 to 2023:Q4

Wage Index	Weight, %	Mean	Standard Deviation	Correlation with: CPIxF Inflation	SCE Inflation
Mining and quarrying of stone gravel	0.073	1.709	6.424	0.180	0.228
Construction	4.735	1.532	3.546	0.469	0.530
Manufacturing	27.445	1.547	1.954	0.513	0.800
Electricity, gas, heat supply and water	0.965	1.397	2.982	0.326	0.459
Railway transport	0.966	1.634	4.052	0.302	0.373
Road passenger transport	1.879	0.813	7.503	0.313	0.291
Road freight transport	3.480	0.888	5.902	0.220	0.245
Wholesale trade	6.484	1.571	3.643	0.305	0.535
Retail trade, general merchandise	2.545	0.884	4.283	0.236	0.314
Retail trade (dry goods, apparel and apparel accessories)	0.435	1.320	20.520	0.000	0.138
Insurance institutions	1.345	1.366	6.332	0.249	0.362
Scientific and development research institutes	0.840	1.350	3.363	0.297	0.443
Accommodations	1.313	0.679	6.159	0.193	0.307
Eating and drinking places	2.596	0.221	12.157	0.130	0.193
Others[13]	44.899	0.965	2.148	0.510	0.891

Notes: Each price index is seasonally adjusted in the same way as in Figure 2. The unit for mean and standard deviation is percentage expressed at an annual rate.
Sources: Statistics Bureau of Japan; Ministry of Health, Labour and Welfare; and author's calculations.

The analysis will consider eight unobserved component models for only price inflation, only wage inflation, or price and wage inflation:

1. The MUCSVO model for the 17 detailed components of the CPI series in Table 1 (labeled MUSCVO-17-0);
2. The MUCSVO model for the 15 detailed SCE series in Table 1 (labeled MUCSVO-0-15);

[13] Data on others is computed by taking the difference between data on "all industries" and those on the other industries.

3. The MUCSVO model for the 17 detailed components of the CPI series and 15 detailed SCE series in Table 1 (labeled MUCSVO-17-15);
4. The MUCSVO model for three components of the CPI series—prices for fresh food, raw meats & cut flowers, other agricultural, aquatic & livestock products, prices for petroleum products, and electricity, manufactured & piped gas & water charges, and prices excluding the above two price indexes (labeled MUCSVO-3-0);
5. The MUCSVO model for two aggregate SCE series, i.e., the SCE for manufacturing industry and for nonmanufacturing industry (labeled MUCSVO-0-2);
6. The MUCSVO model for the above three components of the CPI series and two aggregate SCE series (labeled MUCSVO-3-2);
7. and 8. Univariate versions of a MUCSVO model for the overall CPI and SCE (labeled UCSVO-1-0 and UCSVO-0-1, respectively).

The third model, MUCSVO-17-15, is the baseline model in this paper. The model includes the richest information on price and wage inflation and is superior in performance, as described below. The seventh and eighth models—the UCSVO models—are governed by the same equations as the MUCSVO models, with the deletion of the common factor components and loadings. As there is only one series, there is no difference between the common and the series-specific variables

B. Estimation Results

In the empirical analysis, to validate the use of the MUCSVO framework and the estimated stochastic trends of wage and price inflation, I firstly examine whether wage and price inflation and their trend components have a unit root. Second, I investigate the accuracy and forecasting performance of the trend components, as described below. Based on the estimates of the stochastic trends, I then assess the linkage between wage and price inflation and its time-variation by conducting the HAR-based inference.

1. Unit Root Test

In the MUCSVO framework, price inflation series are assumed to have a unit root. This assumption is confirmed by unit root tests. As shown in Table 3, unit root test statistics proposed by Elliott, Rothenberg, and Stock (1996) and Ng and Perron (2001) are larger than the critical values, which suggests that the null hypothesis of a unit root against the alternative of stationarity cannot be rejected. This is consistent with Hoshi and Kasyhap (2021), which examine inflation series data from 1981 to 2018, and Ng and Perron (2001) covering the period from 1960 to 1997.

Table 3: Unit Root Test Results for Price Inflation Series

Price Index	DF^{GLS}	MZ_{α}^{GLS}	MP_{T}^{GLS}
All items	-0.811	-1.573	15.499
Agricultural, aquatic & livestock products	-1.437	-1.642	13.542
Food products	-0.941	-1.807	13.528
Textiles	-1.132	-2.649	9.249
Petroleum products	-1.250	-1.108	19.984
Other industrial products	-0.992	-2.812	8.238
Electricity, manufactured & piped gas & water charges	-0.883	-0.773	27.464
Publications	-1.299	-1.084	14.148
Public services related to domestic duties[14]	-1.246	-0.722	32.256
Services related to medical care & welfare[15]	-1.393	-2.377	9.664
Public services related to forwarding & communication	-0.151	-0.047	135.826
Public services related to education	0.722	0.523	1210.373
Public services related to culture & recreation	-1.433	-1.521	15.117
General services related to domestic duties	-1.128	-2.826	8.667
General Services related to education	-0.433	-0.451	26.666
General services related to communication, culture & recreation	-0.769	2.171	37.255
Meals outside the home[16]	-0.532	-0.646	33.737
Rent[17]	0.728	0.514	201.259

Notes: DF^{GLS} is modified Dicky-Fuller t-statistics in Elliott, Rothenberg, and Stock (1996). Following Ng and Perron (2001), MZ_{α}^{GLS} is M test statistics, and MP_{T}^{GLS} is a feasible point optimal test statistics. Data are detrended by generalized least squares (GLS). Lag length is selected by modified Akaike Information Criterion (MAIC). Critical values are of DF^{GLS} are -2.580 at 1% level, -1.943 at 5% level, and -1.615 at 10% level. Those of MZ_{α}^{GLS} are -13.8 at 1% level, -8.1 at 5% level, and -5.7 at 10% level. Those of MP_{T}^{GLS} are 1.78 at 1% level, 3.17 at 5% level, and 4.45 at 10% level.

[14] The effects of institutional changes such as the revision of the health insurance act in 1984, of social insurance medical fee payments in 1985, and of the health care insurance system in 1997 and 2003 are adjusted by regressing the corresponding price index inflation on time-dummies.

[15] Services related to medical care & welfare in public and general services. The effects of institutional changes such as the revisions of automotive insurance premiums in 1985, 1986, 2010, and 2013 are adjusted by regressing the corresponding price index inflation on time-dummies.

[16] Meals outside the home in public and general services.

[17] "House rent, public, Urban Renaissance Agency & public corporation", "House rent, private", and "Imputed rent."

Wage inflation series are also assumed to have a unit root in the MUCSVO framework. As shown in Table 4, almost all of the unit root test statistics are larger than the critical value. Only in the case of the SCE series for insurance institutions, are the modified Dicky-Fuller t-statistics smaller than the critical value at the one percent level, and the feasible point optimal test statistics smaller than the critical value at the 10 percent level. However, the M test statistics is larger than the critical value even at the 10 percent level. Therefore, it is highly likely that all of the SCE series have a unit root.

Table 4: Unit Root Test Results for Wage Inflation Series

Wage Index	DF^{GLS}	MZ_{α}^{GLS}	MP_{T}^{GLS}
All industries[18]	-0.328	-0.256	50.096
Mining and quarrying of stone gravel	-1.096	-1.263	18.790
Construction	-0.688	-0.651	22.707
Manufacturing	0.052	0.283	178.141
Electricity, gas, heat supply and water	0.501	0.381	214.699
Railway transport	-1.041	-0.482	41.072
Road passenger transport	-1.066	-0.843	22.213
Road freight transport	-0.822	-0.883	27.563
Wholesale trade	-0.770	-1.117	20.802
Retail trade, general merchandise	-0.954	-0.333	31.880
Retail trade (dry goods, apparel and apparel accessories)	-0.996	-0.189	55.515
Insurance institutions[19]	-3.111***	-5.639	4.400*
Scientific and development research institutes	-0.526	-0.188	35.185
Accommodations	-0.605	-0.347	52.320
Eating and drinking places	-0.875	-1.897	11.603
Others	-0.807	-1.149	21.139

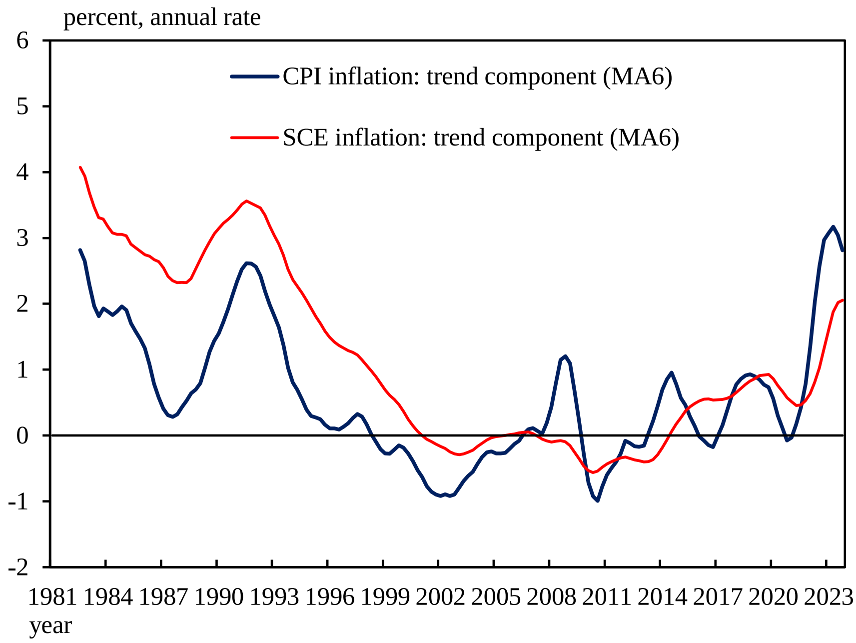
Notes: DF^{GLS} is modified Dicky-Fuller t-statistics in Elliott, Rothenberg, and Stock (1996). Following Ng and Perron (2001), MZ_{α}^{GLS} is M test statistics, and MP_{T}^{GLS} is a feasible point optimal test statistics. Data are detrended by generalized least squares (GLS). Lag length is selected by modified Akaike Information Criterion (MAIC). Critical values are of DF^{GLS} are -2.580 at 1% level, -1.943 at 5% level, and -1.615 at 10% level. Those of MZ_{α}^{GLS} are -13.8 at 1% level, -8.1 at 5% level, and -5.7 at 10% level. Those of MP_{T}^{GLS} are 1.78 at 1% level, 3.17 at 5% level, and 4.45 at 10% level. *, **, and *** denote a statistic significant at the 1%, 5%, and 10% level, respectively.

[18] "All industries" is "All industries excluding Agriculture, Forest, Fishery and Government services."
[19] Includes insurance agents, brokers and services.

In the MUCSVO framework, the trend components of wage and price inflation are modeled as the sum of common and sector-specific trend components, which follow a random walk process. Unit root tests also validate the estimation results. Before presenting the results of unit root tests, major series of the estimated trend components that are the objects of the unit root tests are shown in Figure 5. In the figure, the estimated trend components defined in equations (13) to (18) in the case of the MUCSVO-17-15 model with 6-quarter backward moving averages (labeled MA6) are plotted. The model and measure are selected due to the superior performance over other models and measures. Details of the evaluation of the models and measures are presented in sections III.B.2 and 3. It should be noted from Figure 5 that trend components for the inflation of the CPI services and SCE in nonmanufacturing industry are tightly linked before 1998 and in recent years, while trend components for the inflation of the CPI goods and SCE in manufacturing industry comove only before 1998. Rigorous empirical tests on the relationships between trend components for wage and price inflation are presented in section III.B.4.

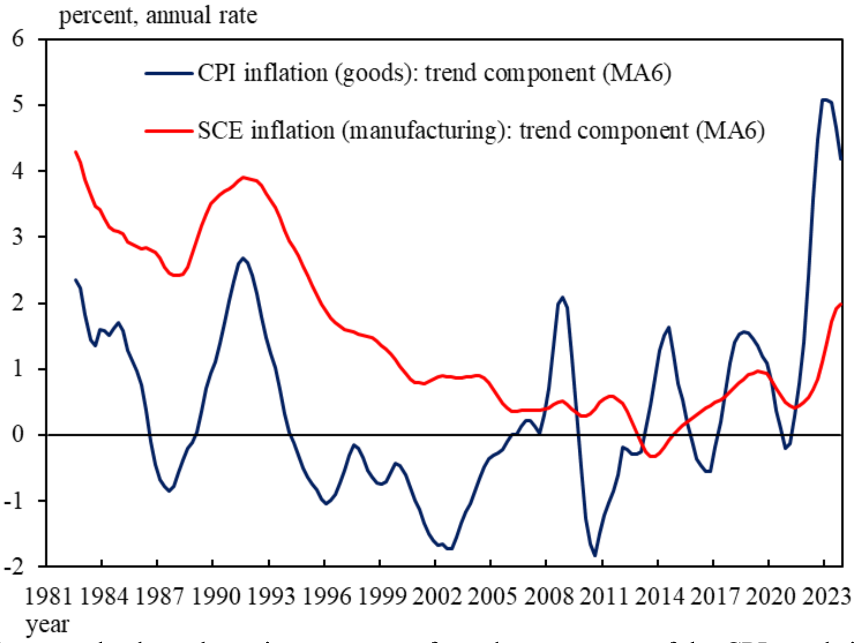
Figure 5: Trend Components from MUCSVO-17-15 Model

(A) Trend Components: Aggregate



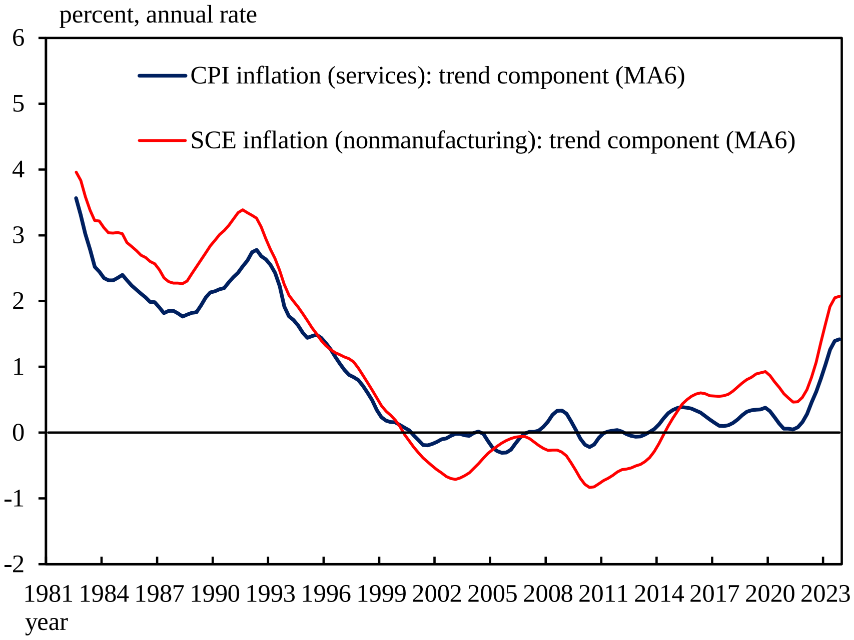
Notes: The 6-quarter backward moving averages of trend components of the overall CPI and SCE inflation are plotted.

(B) Trend Components: Goods and Manufacturing



Notes: The 6-quarter backward moving averages of trend components of the CPI goods inflation and the SCE inflation in manufacturing industry are plotted.

(C)Trend Components: Services and Nonmanufacturing[20]



Notes: The 6-quarter backward moving averages of trend components of the CPI services inflation and the SCE inflation in nonmanufacturing industry are plotted.

[20] In the MUCSVO-17-15 model, the trend component of the CPI services inflation can be influenced by the CPI goods and the SCE in manufacturing industry. Figure A-1 in Appendix 2 shows the trend component of the CPI services inflation when not using data on the CPI goods or the SCE in manufacturing industry. The difference between the two trend components is quite limited.

Table 5 shows the results of the baseline case, i.e., MUCSVO-17-15. All of the trend components for inflation of the CPI, CPI goods, CPI services, SCE, SCE in manufacturing industry, and SCE in nonmanufacturing industry are the objects of unit root tests. The unit root test statistics in all cases are larger than the critical values.

Table 5: Unit Root Test Results for Stochastic Trends of Wage and Price Inflation

Trend Component	DF^{GLS}	MZ_{α}^{GLS}	MP_{T}^{GLS}
CPI: Aggregate	-0.781	-1.412	17.156
CPI: Goods	-1.037	-2.739	8.884
CPI: Services	-0.179	-0.160	52.193
SCE: Aggregate	-0.370	-0.379	41.923
SCE: Manufacturing	-0.382	-0.481	32.102
SCE: Nonmanufacturing	-0.409	-0.421	41.194

Notes: DF^{GLS} is modified Dicky-Fuller t-statistics in Elliott, Rothenberg, and Stock (1996). Following Ng and Perron (2001), MZ_{α}^{GLS} is M test statistics, and MP_{T}^{GLS} is a feasible point optimal test statistics. Data are detrended by generalized least squares (GLS). Lag length is selected by modified Akaike Information Criterion (MAIC). Critical values are of DF^{GLS} are -2.580 at 1% level, -1.943 at 5% level, and -1.615 at 10% level. Those of MZ_{α}^{GLS} are -13.8 at 1% level, -8.1 at 5% level, and -5.7 at 10% level. Those of MP_{T}^{GLS} are 1.78 at 1% level, 3.17 at 5% level, and 4.45 at 10% level.

The estimation results in Tables 3, 4, and 5 justify the use of HAR-based inference described in section II.B when examining the linkage between wage and price inflation using CPI and SCE series or the estimated trend components of wage and price inflation. As well as examining whether price and wage inflation decoupled around 1998, following Hoshi and Kashyap (2021), I further investigate whether they have recoupled in the post-COVID-19 era by employing data up to 2023 in section III.B.4.

2. Accuracy of Trend Estimates

Stock and Watson (2016) show that using sectoral information improves the precision of the estimator of the trend in the U.S. headline inflation. Similarly, I examine whether the MUCSVO models are superior to the UCSVO models in estimating wage and price inflation trends. While the precision of the various estimators cannot be computed directly from the data, since trend inflation is never observed, I use model-based accuracy measures based on the width of posterior uncertainty intervals, as in Stock and Watson (2016). The width of these intervals reflects two distinct sources of uncertainty: (a) signal extraction uncertainty conditional on values of the model's parameters and (b) uncertainty about the model parameters.

Signal extraction uncertainty is smaller in the MUCSVO model than the UCSVO model since the information set for the multivariate model is strictly larger than the univariate model. Parameter uncertainty can be larger in the MUCSVO model since many more parameters are estimated. Therefore, there is no a priori ranking of the width of posterior intervals in the UCVSO and MUCSVO models.

Table 6 shows the average width of 67 and 90 percent posterior intervals for price inflation trends in the UCSVO and MUCSVO models over two subsamples: from 1981 to 1997, and from 1998 to 2023. The posterior intervals for the USCVO-1-0 model are wider than the corresponding intervals for the multivariate models. Specifically, the intervals for the MUCSVO-3-0, MUCSVO-3-2, MUSCVO-17-0, and MUSCVO17-15 models are roughly 60 percent narrower than the intervals for the UCSVO-1-0 model. These results suggest a substantial reduction in uncertainty using the information in the multivariate models, even at the cost of additional complexity. Among the multivariate models, the MUCSVO-3-2, MUSCVO-17-0 and MUSCVO17-15 models perform better than the MUCSVO-3-0 model in the precision of the estimator of the trend. Compared with the estimation results in Stock and Watson (2016), the advantage of the multivariate models over the univariate model is bigger in the case of Japan than the United States.

Compared with the trends of goods price inflation, those of services price inflation are estimated more precisely. In the MUSCVO-17-0 and MUSCVO17-15 models, goods and services prices are not contaminated in each category, and as a result, the precision of the estimated trends can be compared. Posterior intervals for the trends of services price inflation (labeled MUSCVO-17-0-service or MUSCVO-17-15-service) are 60 to 70 percent narrower than intervals for the trends of goods price inflation (labeled MUSCVO-17-0-goods or MUSCVO-17-15-goods).

Table 6: Average Width of Full-Sample Posterior Intervals for Price Inflation Trends

Model and Type of Trend Component Estimate	1981-1997		1998-2023	
	67%	90%	67%	90%
UCSVO-1-0	0.953	1.648	0.856	1.479
UCSVO-1-0-MA4	0.610	1.076	0.547	0.970
UCSVO-1-0-MA6	0.521	0.920	0.461	0.821
MUCSVO-3-0	0.496	0.864	0.431	0.778
MUCSVO-3-0-MA4	0.364	0.628	0.292	0.522
MUCSVO-3-0-MA6	0.333	0.571	0.259	0.460
MUCSVO-3-2	0.357	0.637	0.300	0.564
MUCSVO-3-2-MA4	0.266	0.466	0.211	0.381
MUCSVO-3-2-MA6	0.247	0.430	0.191	0.339
MUCSVO-17-0	0.344	0.598	0.375	0.642
MUCSVO-17-0-MA4	0.266	0.461	0.272	0.469
MUCSVO-17-0-MA6	0.247	0.429	0.243	0.418
MUCSVO17-0-goods	0.544	0.951	0.703	1.208
MUCSVO-17-0-goods-MA4	0.436	0.757	0.507	0.878
MUCSVO-17-0-goods-MA6	0.409	0.710	0.451	0.783
MUCSVO-17-0-service	0.241	0.422	0.200	0.347
MUCSVO-17-0-service-MA4	0.159	0.277	0.159	0.274
MUCSVO-17-0-service-MA6	**0.137**	**0.239**	**0.144**	**0.249**
MUCSVO-17-15	0.365	0.634	0.454	0.734
MUCSVO-17-15-MA4	0.290	0.500	0.321	0.530
MUCSVO-17-15-MA6	0.271	0.465	0.280	0.466
MUCSV-17-15-goods	0.588	1.026	0.828	1.331
MUCSVO-17-15-goods-MA4	0.483	0.834	0.589	0.972
MUCSVO-17-15-goods-MA6	0.455	0.784	0.519	0.865
MUCSVO-17-15-service	0.243	0.422	0.276	0.477
MUCSVO-17-15-service-MA4	0.162	0.278	0.200	0.339
MUCSVO-17-15-service-MA6	0.139	0.240	0.171	0.290

Notes: Minimum average width of full-sample posterior intervals for a given category are in bold. Units are percentage points at an annual rate.

Table 7 shows the average width of 67 and 90 percent posterior intervals for wage inflation trends over the two subsamples. It is noteworthy that the use of prices inflation data improves the precision of the estimator of the wage inflation trends. Specifically, the intervals for the MUCSVO-3-2 and MUSCVO-17-15 models are narrower than other models using only wages inflation data, i.e., the UCSVO-0-1, MUCSVO-0-2 and MUSCVO-0-15 models. This result highlights the potential value of prices in gauging trends in wage inflation.

Table 7: Average Width of Full-Sample Posterior Intervals for Wage Inflation Trends

Model and Type of Trend	1981-1997		1998-2023	
Component Estimate	67%	90%	67%	90%
UCSVO-0-1	0.742	1.324	0.659	1.149
UCSVO-0-1-MA4	0.503	0.894	0.551	0.949
UCSVO-0-1-MA6	0.437	0.774	0.503	0.866
MUCSVO-0-2	0.727	1.253	0.686	1.183
MUCSVO-0-2-MA4	0.549	0.943	0.568	0.974
MUCSVO-0-2-MA6	0.482	0.827	0.518	0.886
MUCSVO-3-2	0.631	1.088	0.628	1.083
MUCSVO-3-2-MA4	0.508	0.873	0.539	0.928
MUCSVO-3-2-MA6	0.459	0.786	0.499	0.859
MUCSVO-0-15	0.698	1.202	0.715	1.232
MUCSVO-0-15-MA4	0.469	0.800	0.524	0.895
MUCSVO-0-15-MA6	0.410	0.698	0.463	0.792
MUCSVO-17-15	0.496	0.847	0.506	0.869
MUCSVO-17-15-MA4	0.425	0.726	0.442	0.757
MUCSVO-17-15-MA6	**0.396**	**0.676**	**0.414**	**0.707**

Notes: Minimum average width of full-sample posterior intervals for a given category are in bold. Units are percentage points at an annual rate.

While the above results indicate the benefit of more information, backward moving averages can also reduce the uncertainty of the estimated trend components. Tables 6 and 7 show that posterior intervals for the estimates of the trend components after moving averaging are narrower than the estimates without moving averaging in all the models. In the baseline case, i.e. the MUCSVO-17-15, 4-quarter and 6-quarter backward moving averages (labeled MA4 and MA6 in the table) are 20 to 40 percent narrower in the estimates of both wage and price inflation trend components. This implies that moving averages can smooth out variations in the estimates caused by misidentifying temporary movements in price and wage inflation as trend components in estimation. In this paper, 4-quarter and 6-quarter backward moving averages are employed to explore the possibility of improving accuracy and forecasting performance. Moving averaging over 6-quarters is not considered since excess smoothing can inappropriately lower the value of the latest information.

3. Forecasting Performance of Trend Estimates

Stock and Watson (2016) define trend inflation as the forecast of inflation over the long run. They evaluate the candidate estimates of trend inflation based on their forecasting performance, which is in turn based on pseudo-out-of-sample forecasts at the one- to three-year horizons as in much of the literature on inflation forecasting using core inflation.

In addition to Stock and Watson (2016)'s forecasting performance measures, this paper uses forecasts from one- to three-years ahead, thereby excluding forecasts up to one-year ahead. This measure is related to concerns raised by Rudd (2020) about the univariate unobserved components/stochastic volatility model proposed in Stock and Watson (2007). Rudd (2020) argues that when some influences on inflation persist for longer than a single period, but not permanently, the model's assumption that deviations of actual inflation from trend are serially uncorrelated is not reasonable. This concern applies to the UCSVO and MUSCVO models as well. Therefore, trend estimates by the UCSVO and MUSCVO models might be affected by temporary factors in certain cases. Comparing the performance of forecasts from one- to three-year ahead with that of forecasts at the one- to three-year horizon is useful in investigating whether the candidate estimates of trend inflation are dependent on temporary factors.

Specifically, forecasting performance is evaluated to compare the average value of wage and price inflation over the next 4, 8, and 12 quarters and from 5 to 12 quarters ahead with the candidate estimates. $\tau_{CPI,t}$, $\tau_{goods,t}$, and $\tau_{service,t}$ and their moving averages from the various models examined in the above are used as the candidate estimates of trend price inflation. Also, in the case of trend wage inflation, $\tau_{SCE,t}$ and its moving averages are used as the candidate estimates. In more detail, $\tau_{CPI,t}$, $\tau_{goods,t}$, $\tau_{service,t}$ and $\tau_{SCE,t}$ are computed recursively using data from the beginning of the sample (1981:Q2) through time t as in Stock and Watson (2016), Kiley (2023), and Almuzara, Audoly, and Melcangi (2023). Time t begins at 1998:Q1 and continues through the end of the sample (2023:Q4).[21] As a result, the one-sided posterior mean estimates of $\tau_{CPI,t}$, $\tau_{goods,t}$, $\tau_{service,t}$ and $\tau_{SCE,t}$, described as $\tau_{CPI,t|t}$, $\tau_{goods,t|t}$,

[21] The pseudo-out-of-sample forecasts are constructed from 1998:Q1 to ensure enough sample size. The pseudo-out-of-sample forecasts at 1998:Q1 are estimated using data from 1981:Q2 to 1998:Q1.

$\tau_{service,t|t}$ and $\tau_{SCE,t|t}$, are calculated and the pseudo-out-of-sample forecasts using the candidate estimates of trend inflation are constructed. In sum, the sample mean squared forecast errors (MSFEs) for the CPI and SCE are constructed as follows:

$$MSFE_{CPI,t}(j,h) = \frac{1}{N_h}\sum_{t=1998:Q1}^{T_h}\left(\frac{1}{h-j+1}\sum_{i=j}^{h}\pi_{CPI,t+i} - \tau_{X,t|t}\right)^2,$$

$$MSFE_{SCE,t}(j,h) = \frac{1}{N_h}\sum_{t=1998:Q1}^{T_h}\left(\frac{1}{h-j+1}\sum_{i=j}^{h}w_{SCE,t+i} - \tau_{Y,t|t}\right)^2,$$

where N_h is the size of sample which is equal to the time periods between 1998:Q1 and T_h as determined by h, $\pi_{CPI,t}$ ($w_{SCE,t}$) is quarter-on-quarter change in the CPI (SCE) at a percentage annual rate; and $\tau_{X,t|t}$ ($\tau_{Y,t|t}$) is the candidate estimate of price (wage) inflation trend.

$\tau_{X,t|t}$ includes $\tau_{CPI,t|t}$, $\tau_{goods,t|t}$, $\tau_{service,t|t}$ and their moving averages as well as the most recent 4-quarter moving average of the inflation of the CPIxFE. The last approach is called a 4-quarter random walk model in Atkeson and Ohanian (2001) and is followed in much of the literature. Shiratsuka (2015) shows that the CPIxF performs better in identifying the underlying trend in price inflation than other indicators. In addition, Shiratsuka (2015) shows that the performance of the CPIxF deteriorates when there are large swings in energy prices and recommends the use of the CPI excluding fresh food and energy and trimmed mean. Following Shiratsuka (2015), the CPIxF is used as a benchmark in this paper. The results for the CPI excluding fresh food and energy and trimmed mean are similar to those for the CPIxF and not reported.

Similarly, $\tau_{Y,t|t}$ includes $\tau_{SCE,t|t}$, its moving averages and the most recent 4-quarter moving average of the SCE inflation. When forecasts at the one- to three-year horizon are used to evaluate the forecasting performance, j =1 and h =4, 8, or 12. When forecasts from one- to three-year ahead are used, j =5 and h =12. The forecasting performance is evaluated by these MSFEs.

Tables 8 and 9 show the MSFEs for the CPI inflation using the various candidate estimates. The tables also show the difference between the forecast's MSFE and the MSFE of the Atkeson-Ohanian approach (labeled CPIxFE inflation-MA4 in the table), together with its standard error. Three results stand out from this forecasting experiment. First, the MUCSVO-17-15 model performs best at one- and three-year horizons and from 1 to 3 years ahead, while at two-year horizon the MUCSVO-17-0 model performs best. This suggests that using sectoral information improves the CPI forecast performance and wage data helps increase the forecast accuracy. Second, among the trend component estimates from the MUCSVO-17-0 and MUCSVO-17-15 models, the trend components of the CPI services price inflation are the best forecast indicator for the headline CPI inflation above the one-year horizon. Third, the 4-quarter and 6-quarter backward moving averages (labeled MA4 and MA6 in the table) of the trend component estimates produce markedly more accurate forecasts than the trend components estimates without moving averaging at three-year horizon and from one- to three-years ahead in almost all cases. This implies that moving averages can reduce the dependence on temporary factors by smoothing out the variation of the trend component estimates. In sum, the 6-quarter moving averages of the trend component of the CPI services price inflation from the MUCSVO-17-15 model seems to be the most effective measure among the candidate estimates in gauging the movements in underlying price inflation excluding temporary factors.[22]

Table 10 and 11 summarize the SCE inflation forecast's results. There are three noteworthy findings. First, as in the CPI's case, the candidate estimates from the multivariate models perform better than those based on the univariate model. Second, moving averages increase the forecast accuracy of the trend estimates in general. Third, in the forecast performance from one- to three-years ahead, MUCSVO-3-2-MA6 is the best indicator for the headline SCE inflation. This implies that the measure is less dependent on temporary factors related to wage dynamics by employing moving averages and with the aid of price data as a useful signal for wage inflation. These results show that the trend component estimates based on MUCSVO-3-2-MA6 are the most useful indicator among the other candidates in forecasting performance.

[22] Ozaki et al. (2024) propose other promising measures in gauging movements in underlying price inflation. In particular, the CPI (low-volatility items) inflation proposed in Ozaki et al. (2024) is as good as the MUCSVO-17-15-services-MA6 inflation in forecasting performance. Details are not reported for conciseness.

Table 8: Mean Squared Forecast Errors for CPI Inflation over 1998-2023

Model and Type of Trend Component Estimate	Up to 1 Year Ahead			Up to 2 Years Ahead		
	MSFE	Difference (standard error)		MSFE	Difference (standard error)	
CPIxF inflation-MA4	1.339	-	-	1.366	-	-
CPIxF inflation-MA6	1.367	0.027	(0.144)	1.303	-0.063	(0.122)
UCSVO-1-0	1.379	0.040	(0.145)	1.375	0.009	(0.161)
UCSVO-1-0-MA4	1.403	0.064	(0.107)	1.295	-0.072	(0.108)
UCSVO-1-0-MA6	1.385	0.045	(0.186)	1.218	-0.148	(0.161)
MUCSVO-3-0	1.216	-0.123	(0.144)	1.328	-0.038	(0.140)
MUCSVO-3-0-MA4	1.355	0.016	(0.073)	1.326	-0.040	(0.071)
MUCSVO-3-0-MA6	1.407	0.068	(0.184)	1.282	-0.085	(0.147)
MUCSVO-3-2	1.180	-0.159	(0.155)	1.313	-0.053	(0.148)
MUCSVO-3-2-MA4	1.303	-0.036	(0.060)	1.289	-0.077	(0.064)
MUCSVO-3-2-MA6	1.359	0.020	(0.171)	1.251	-0.115	(0.142)
MUCSVO-17-0	1.206	-0.133	(0.108)	1.268	-0.098	(0.098)
MUCSVO-17-0-MA4	1.370	0.031	(0.142)	1.267	-0.099	(0.127)
MUCSVO-17-0-MA6	1.399	0.060	(0.241)	1.214	-0.152	(0.188)
MUCSVO-17-0-goods	2.503	1.163***	(0.381)	2.433	1.067***	(0.371)
MUCSVO-17-0-goods-MA4	2.165	0.826***	(0.224)	2.023	0.657***	(0.182)
MUCSVO-17-0-goods-MA6	1.933	0.594***	(0.199)	1.797	0.431***	(0.183)
MUCSVO-17-0-service	1.284	-0.056	(0.362)	**1.040**	**-0.326**	**(0.262)**
MUCSVO-17-0-service-MA4	1.463	0.124	(0.437)	1.096	-0.270	(0.290)
MUCSVO-17-0-service-MA6	1.514	0.175	(0.476)	1.087	-0.279	(0.305)
MUCSVO-17-15	**1.165**	**-0.174**	**(0.115)**	1.223	-0.143	(0.105)
MUCSVO-17-15-MA4	1.347	0.007	(0.139)	1.231	-0.135	(0.131)
MUCSVO-17-15-MA6	1.376	0.037	(0.239)	1.176	-0.190	(0.192)
MUCSVO-17-15-goods	2.373	1.033***	(0.382)	2.287	0.921***	(0.379)
MUCSVO-17-15-goods-MA4	2.115	0.776***	(0.198)	1.944	0.578***	(0.172)
MUCSVO-17-15-goods-MA6	1.889	0.550***	(0.197)	1.721	0.355*	(0.194)
MUCSVO-17-15-service	1.320	-0.020	(0.380)	1.053	-0.313	(0.264)
MUCSVO-17-15-service-MA4	1.492	0.153	(0.450)	1.107	-0.259	(0.292)
MUCSVO-17-15-service-MA6	1.538	0.199	(0.489)	1.097	-0.269	(0.307)

Notes: The entries labeled "MSFE" ("Difference") are the mean square forecast errors (the difference between that row's MSFE and the MSFE for the 4-quarter moving average of the CPIxF inflation, i.e., the Atkeson-Ohanian [2001] approach). HAC standard errors for the difference are in parentheses. Minimum MSFE forecasts for a given horizon are in bold. Units are squared percentage points at an annual rate. *, **, and *** denote a statistical significance at the 10%, 5%, and 1% level, respectively.

Table 9: Mean Squared Forecast Errors for CPI Inflation over 1998-2023

Model and Type of Trend Component Estimate	Up to 3 Years Ahead			From 1 to 3 Years Ahead		
	MSFE	Difference (standard error)		MSFE	Difference (standard error)	
CPIxF inflation-MA4	1.131	-	-	1.588	-	-
CPIxF inflation-MA6	0.939	-0.192*	(0.112)	1.352	-0.236*	(0.131)
UCSVO-1-0	1.281	0.150	(0.099)	1.727	0.139	(0.128)
UCSVO-1-0-MA4	0.925	-0.206	(0.151)	1.295	-0.294	(0.186)
UCSVO-1-0-MA6	0.810	-0.321	(0.198)	1.169	-0.419*	(0.243)
MUCSVO-3-0	1.296	0.166	(0.122)	1.820	0.232	(0.166)
MUCSVO-3-0-MA4	0.985	-0.145**	(0.064)	1.396	-0.192***	(0.082)
MUCSVO-3-0-MA6	0.847	-0.283**	(0.140)	1.223	-0.365**	(0.169)
MUCSVO-3-2	1.309	0.178	(0.120)	1.850	0.262	(0.164)
MUCSVO-3-2-MA4	0.973	-0.157**	(0.069)	1.396	-0.192**	(0.087)
MUCSVO-3-2-MA6	0.841	-0.290**	(0.147)	1.226	-0.362**	(0.180)
MUCSVO-17-0	1.123	-0.007	(0.066)	1.623	0.034	(0.092)
MUCSVO-17-0-MA4	0.870	-0.261**	(0.124)	1.263	-0.325**	(0.152)
MUCSVO-17-0-MA6	0.756	-0.375**	(0.187)	1.123	-0.466**	(0.225)
MUCSVO-17-0-goods	2.487	1.357***	(0.318)	3.079	1.491***	(0.385)
MUCSVO-17-0-goods-MA4	1.684	0.553***	(0.187)	2.089	0.501**	(0.220)
MUCSVO-17-0-goods-MA6	1.340	0.209	(0.232)	1.698	0.110	(0.293)
MUCSVO-17-0-service	0.641	-0.489**	(0.229)	1.050	-0.538***	(0.215)
MUCSVO-17-0-service-MA4	0.638	-0.493*	(0.265)	1.019	-0.569**	(0.270)
MUCSVO-17-0-service-MA6	0.640	-0.491*	(0.288)	1.015	-0.573*	(0.294)
MUCSVO-17-15	1.077	-0.054	(0.071)	1.560	-0.028	(0.087)
MUCSVO-17-15-MA4	0.831	-0.299**	(0.132)	1.208	-0.380***	(0.158)
MUCSVO-17-15-MA6	0.716	-0.415**	(0.197)	1.068	-0.520**	(0.237)
MUCSVO-17-15-goods	2.327	1.196***	(0.324)	2.886	1.298***	(0.391)
MUCSVO-17-15-goods-MA4	1.602	0.472***	(0.186)	1.977	0.389*	(0.233)
MUCSVO-17-15-goods-MA6	1.269	0.139	(0.251)	1.601	0.012	(0.324)
MUCSVO-17-15-service	0.652	-0.478**	(0.227)	1.062	-0.527***	(0.210)
MUCSVO-17-15-service-MA4	0.641	-0.489*	(0.261)	1.021	-0.568**	(0.263)
MUCSVO-17-15-service-MA6	**0.637**	**-0.493***	**(0.284)**	**1.011**	**-0.577****	**(0.289)**

Notes: The entries labeled "MSFE" ("Difference") are the mean square forecast errors (the difference between that row's MSFE and the MSFE for the 4-quarter moving average of the CPIxF inflation, i.e., the Atkeson-Ohanian [2001] approach). HAC standard errors for the difference are in parentheses. Minimum MSFE forecasts for a given horizon are in bold. Units are squared percentage points at an annual rate. *, **, and *** denote a statistical significance at the 10%, 5%, and 1% level, respectively.

Table 10: Mean Squared Forecast Errors for SCE Inflation over 1998-2023

Model and Type of Trend Component Estimate	Up to 1 Year Ahead			Up to 2 Years Ahead		
	MSFE	Difference (standard error)		MSFE	Difference (standard error)	
SCE inflation-MA4	0.668	-	-	0.701	-	-
SCE inflation-MA6	0.663	-0.005	(0.063)	0.693	-0.008	(0.049)
UCSVO-0-1	0.660	-0.009	(0.090)	0.600	-0.101	(0.083)
UCSVO-0-1-MA4	0.649	-0.019	(0.090)	0.589	-0.112	(0.088)
UCSVO-0-1-MA6	0.684	0.016	(0.105)	0.606	-0.095	(0.100)
MUCSVO-0-2	0.671	0.003	(0.093)	0.570	-0.132*	(0.078)
MUCSVO-0-2-MA4	**0.632**	**-0.036**	**(0.088)**	**0.547**	**-0.154***	**(0.086)**
MUCSVO-0-2-MA6	0.651	-0.017	(0.103)	0.560	-0.141	(0.100)
MUCSVO-3-2	0.674	0.006	(0.098)	0.578	-0.123	(0.085)
MUCSVO-3-2-MA4	0.651	-0.017	(0.095)	0.561	-0.140	(0.093)
MUCSVO-3-2-MA6	0.666	-0.003	(0.108)	0.572	-0.129	(0.105)
MUCSVO-0-15	0.787	0.119	(0.094)	0.720	0.019	(0.077)
MUCSVO-0-15-MA4	0.727	0.059	(0.096)	0.664	-0.037	(0.091)
MUCSVO-0-15-MA6	0.761	0.093	(0.118)	0.686	-0.015	(0.111)
MUCSVO-17-15	0.673	0.005	(0.109)	0.623	-0.078	(0.105)
MUCSVO-17-15-MA4	0.712	0.044	(0.117)	0.648	-0.054	(0.117)
MUCSVO-17-15-MA6	0.754	0.086	(0.133)	0.673	-0.028	(0.137)

Notes: The entries labeled "MSFE" ("Difference") are the mean square forecast errors (the difference between that row's MSFE and the MSFE for the 4-quarter moving average of the SCE inflation, i.e., the Atkeson-Ohanian [2001] approach). HAC standard errors for the difference are in parentheses. Minimum MSFE forecasts for a given horizon are in bold. Units are squared percentage points at an annual rate. *, **, and *** denote a statistical significance at the 10%, 5%, and 1% level, respectively.

Table 11: Mean Squared Forecast Errors for SCE Inflation over 1998-2023

Model and Type of Trend Component Estimate	Up to 3 Years Ahead			From 1 to 3 Years Ahead		
	MSFE	Difference (standard error)		MSFE	Difference (standard error)	
SCE inflation-MA4	0.771	-	-	1.068	-	-
SCE inflation-MA6	0.692	-0.079	(0.051)	0.968	-0.099	(0.068)
UCSVO-0-1	0.561	-0.210**	(0.107)	0.774	-0.294**	(0.144)
UCSVO-0-1-MA4	0.525	-0.246**	(0.117)	0.732	-0.335**	(0.158)
UCSVO-0-1-MA6	0.519	-0.252*	(0.132)	0.712	-0.356**	(0.179)
MUCSVO-0-2	0.528	-0.244***	(0.103)	0.710	-0.358***	(0.144)
MUCSVO-0-2-MA4	0.487	-0.285***	(0.116)	0.674	-0.393***	(0.159)
MUCSVO-0-2-MA6	**0.479**	**-0.293****	**(0.134)**	0.657	-0.410**	(0.182)
MUCSVO-3-2	0.537	-0.234**	(0.109)	0.719	-0.349***	(0.142)
MUCSVO-3-2-MA4	0.494	-0.277**	(0.119)	0.675	-0.393***	(0.159)
MUCSVO-3-2-MA6	0.484	-0.288**	(0.136)	**0.657**	**-0.411****	**(0.183)**
MUCSVO-0-15	0.678	-0.094	(0.092)	0.883	-0.185	(0.126)
MUCSVO-0-15-MA4	0.612	-0.159	(0.121)	0.826	-0.242	(0.163)
MUCSVO-0-15-MA6	0.602	-0.169	(0.152)	0.803	-0.265	(0.202)
MUCSVO-17-15	0.560	-0.212*	(0.124)	0.758	-0.310**	(0.157)
MUCSVO-17-15-MA4	0.549	-0.222	(0.150)	0.743	-0.325	(0.199)
MUCSVO-17-15-MA6	0.558	-0.214	(0.180)	0.745	-0.323	(0.235)

Notes: The entries labeled "MSFE" ("Difference") are the mean square forecast errors (the difference between that row's MSFE and the MSFE for the 4 quarter moving average of the SCE inflation, i.e., the Atkeson-Ohanian [2001] approach). HAC standard errors for the difference are in parentheses. Minimum MSFE forecasts for a given horizon are in bold. Units are squared percentage points at an annual rate. *, **, and *** denote a statistical significance at the 10%, 5%, and 1% level, respectively.

4. HAR Test

In sections III.B.2 and 3, the MUCSV-17-15 model was shown to be superior to other models in the accuracy and forecasting performance of the trend estimates. In addition, the MUCSV-17-15 model is useful in analyzing the sectoral dynamics of wages and prices as well the aggregate dynamics, since the model has a rich structure. Here, by exploiting these advantages of the MUCSV-17-15 model, I investigate time-variation on the strength of the linkage between the underlying trends in price and wage inflation using the HAR test. Specifically, after first confirming the argument in Hoshi and Kashyap (2021) that there is a break in the linkage between wages and prices around 1998, I analyze whether or not wages and prices have recoupled in the post-COVID-19 era.

Table 12 shows the estimation results where $\hat{\beta}_{YX}$ is the coefficient of the regression of Y on X after standardization using their mean and variance, $t_{HAR,YX}$ is the HAR-based t-statistics of $\hat{\beta}_{YX}$, and its p-value is based on a 100,000 Monte Carlo simulation. Here, $\hat{\beta}_{YX}$ is equivalent to the correlation coefficient between Y and X since the standardization is employed. As shown in the table, Y are $\tau_{CPI,t}$, $\tau_{goods,t}$, and $\tau_{service,t}$ based on the MUCSVO-17-15 model, $\tau_{CPI,t}$ based on the UCSVO-1-0 model, and $\pi_{CPI,t}$, $\pi_{goods,t}$, $\pi_{service,t}$. X are $\tau_{SCE,t}$, $\tau_{manu.,t}$, and $\tau_{nonmanu.,t}$ based on the MUCSVO-17-15 model, $\tau_{SCE,t}$ based on the UCSVO-0-1 model, and $w_{SCE,t}$, $w_{manu.,t}$, $w_{nonmanu.,t}$. Estimation results using raw data and the trend estimates based on the UCSVO models are also shown to clarify the advantage of the use of the MUCSVO-17-15 when the linkage between wages and prices is examined.

First of all, focusing on the estimation results based on the MUCSVO-17-15 model,[23] the linkage between the trend of wage and price inflation in the aggregate level is tight before 1998 as the high value of the correlation coefficient (0.902) and its significance (p-value:0.062) imply. This tight linkage is also observed in the sectoral level. The correlation coefficient between the trends of goods price inflation and wage inflation in manufacturing industry is 0.834, and significant at the 10 percent level. The correlation coefficient between the trends of services price inflation and wage inflation in nonmanufacturing industry is 0.930, and significant at the 5 percent level. The correlation coefficient is larger than that of the other sector, reflecting that this sector is more labor intensive.

For the two samples covering the period during 1998-2019, all the estimated correlation coefficients in the aggregate and sectoral levels are smaller than those from the sample before 1998. In addition, none of the correlation coefficients is statistically significant even at the 10 percent level.[24] These results provide comprehensive support for the arguments in Hoshi and Kashyap (2021) and Kuroda and Yamamoto (2014) that wages and prices became disconnected after 1998.

The estimation results from the sample covering the post-COVID-19 era (2014-2023) indicate that the linkage between wages and prices recovered to some extent. The correlation coefficient between the aggregate trends of price and wage inflation is 0.770 and statistically significant at the 10 percent level. In the service or nonmanufacturing

[23] For simplicity, the trend component estimates without moving averaging are used here, but the estimation results are similar if the moving averages of the trend component estimates are used. The estimation results using the moving averages of trend component estimates are not reported for conciseness.

[24] In the empirical analysis for the periods during 1998-2019, the length of the sample period is chosen to be 6 years following Hoshi and Kashyap (2021).

sector, the correlation coefficient is 0.933 and statistically significant at the 5 percent level. This is almost equivalent to the estimated values for the sample before 1998. However, in the goods or manufacturing sector, the increase in the correlation coefficient is not large enough to reach the value before 1998. The correlation coefficient is estimated to be 0.633 and the p-value is 0.115. There seems to be room for the recovery of the linkage between wages and prices, while the goods or manufacturing sector has become more embedded within competitive global markets than before 1998, and as a result the effect of labor costs has weakened.

It is difficult to identify the exact recovery point of the linkage of wages and prices after COVID-19, but the comparison of the empirical results for the periods covering 2014-2019 and 2014-2023 implies that wages and prices dynamics have changed after 2020, particularly in the service or nonmanufacturing sector. In sum, the estimation results based on the MUCSVO-17-15 model show that wages and prices decoupled around 1998, but they have become recoupled in the post-COVID-19 era.

As shown in the middle of Table 12, the correlation coefficients estimated from the raw data (seasonally adjusted in the same way as in Figure 2) are smaller than those calculated using the trend estimates based on the MUCSVO-17-15 model in almost all cases. As a result, the correlation coefficients are not statistically significant for the sample covering the post-COVID-19 era and the recoupling of wages and prices is not observed. This arises from the fact that transient components included in the raw data make it difficult to identify the linkage between wages and prices.

While the UCSVO models can exclude transient components from wages and prices, the correlation coefficients estimated based on the UCSVO models at the bottom of Table 12 are in line with those estimated from the raw data. As shown in sections III.B.2 and C, the accuracy and forecasting performance of the UCSVO models is inferior to the MUCSVO-17-15 model. This shows that the USCVO models seem not to be able to gauge the genuine relationship between wages and prices as precisely as the MUCSVO-17-15 model. These empirical exercises also show the advantage of the MUSCVO-17-15 model.

Table 12: HAR Test for Linkage between Wage and Price Inflation over 1981-2023

Y	X		1981-1997	1998-2013	2014-2019	2014-2023
MUCSVO-17-15						
		$\hat{\beta}_{YX}$	0.902*	0.227	0.277	0.770*
$\tau_{CPI,t}$	$\tau_{SCE,t}$	$t_{HAR.YX}$	8.287	1.118	1.035	7.517
		p-value	0.062	0.388	0.394	0.075
		$\hat{\beta}_{YX}$	0.834*	-0.310	0.408	0.633
$\tau_{goods,t}$	$\tau_{manu.,t}$	$t_{HAR,YX}$	7.193	-2.442	1.686	5.933
		p-value	0.082	0.713	0.337	0.115
		$\hat{\beta}_{YX}$	0.930**	0.364	0.214	0.933**
$\tau_{service,t}$	$\tau_{nonmanu.,t}$	$t_{HAR,YX}$	11.284	2.677	0.660	10.412
		p-value	0.028	0.269	0.430	0.034
UCSVO						
		$\hat{\beta}_{YX}$	0.767*	0.170	0.004	0.704
$\tau_{CPI,t}$	$\tau_{SCE,t}$	$t_{HAR,YX}$	6.493	1.265	0.015	3.998
		p-value	0.099	0.375	0.496	0.192
Raw Data						
		$\hat{\beta}_{YX}$	0.558**	0.194	0.142	0.432
$\pi_{CPI,t}$	$w_{SCE,t}$	$t_{HAR,YX}$	10.277	1.962	1.151	3.175
		p-value	0.037	0.320	0.383	0.237
		$\hat{\beta}_{YX}$	0.401*	0.183	0.356	0.220
$\pi_{goods,t}$	$w_{manu.,t}$	$t_{HAR,YX}$	7.258	1.674	2.532	1.967
		p-value	0.081	0.341	0.274	0.320
		$\hat{\beta}_{YX}$	0.564	0.030	-0.183	0.120
$\pi_{service,t}$	$w_{nonmanu.,t}$	$t_{HAR,YX}$	3.843	0.225	-1.490	0.770
		p-value	0.201	0.475	0.642	0.422

Notes: $\tau_{CPI,t}$ and $\tau_{SCE,t}$ are the trend estimates of the quarter-on-quarter (q/q) change in CPI (all items) and SCE ("All industries excluding Agriculture, Forest, Fishery and Government services") based on the UCSVO models and the MUCSVO-17-15 model. $\tau_{goods,t}$, $\tau_{service,t}$, $\tau_{manu.,t}$, and $\tau_{nonmanu.,t}$ are the trend estimates of the q/q change in goods, and services prices in CPI and SCE in manufacturing and nonmanufacturing industries based on the MUCSVO-17-15 model. $\pi_{CPI,t}$, $\pi_{goods,t}$, and $\pi_{service,t}$ are the q/q change in all items, goods, and services prices in CPI respectively. All the variables' units are a percentage annual rate. $\hat{\beta}_{YX}$ is the coefficient of regression of Y on X after standardization using their mean and variance, $t_{HAR,YX}$ is the HAR-based t-statistics of $\hat{\beta}_{YX}$, and its p-value is based on a 100,000 Monte Carlo simulation. *, **, and *** denote a statistic significance at the 10%, 5%, and 1% level, respectively.

IV. Discussion

What is behind the recoupling of wages and prices? The estimation results of the MUCSVO 17-15 model provide some reduced form of evidence, while identifying the cause is beyond the scope of this paper. In the model setting, the linkage of wages and prices becomes tight when their movements are driven mainly by a common factor, but not by idiosyncratic factors.

For a detailed analysis, the following approximation of the variances of the trend components of the CPI and SCE inflation are useful:

$$Var_{t-1}(\tau_{CPI,t}) \approx Var_{t-1}\left(\sum_{i=1}^{N_{CPI}} \omega_{CPI,i,t}\alpha_{i,\tau,t}\tau_{c,t}\right) + Var_{t-1}\left(\sum_{i=1}^{N_{CPI}} \omega_{CPI,i,t}\tau_{i,t}\right),$$

$$Var_{t-1}(\tau_{SCE,t}) \approx Var_{t-1}\left(\sum_{i=1}^{N_{SCE}} \omega_{SCE,j,t}\alpha_{j,\tau,t}\tau_{c,t}\right) + Var_{t-1}\left(\sum_{i=1}^{N_{SCE}} \omega_{SCE,j,t}\tau_{i,t}\right),$$

where $Var_{t-1}(\cdot)$ is the variance operator conditioned on information set at period $t-1$. In this approximation, $\alpha_{i,\tau,t}$ is dealt with as if it is a non-stochastic parameter.

Figure 6 plots the following two variables calculated using the above equations;

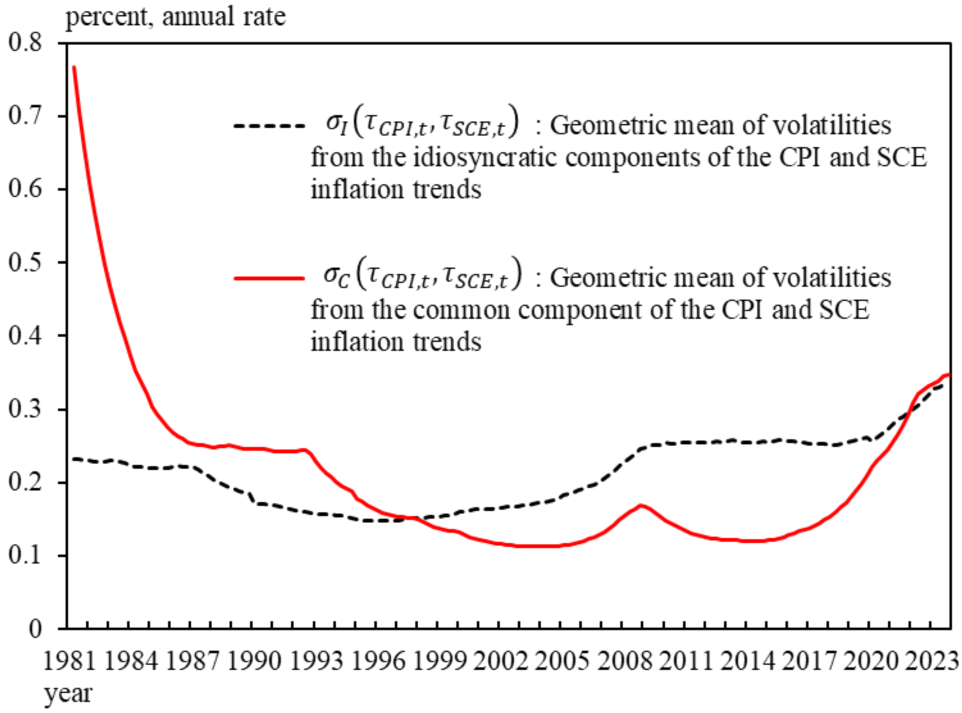
$$\sigma_C(\tau_{CPI,t}, \tau_{SCE,t}) \equiv \left(Var_{t-1}\left(\sum_{i=1}^{N_{CPI}} \omega_{CPI,i,t}\alpha_{i,\tau,t}\tau_{c,t}\right)Var_{t-1}\left(\sum_{j=1}^{N_{SCE}} \omega_{SCE,j,t}\alpha_{j,\tau,t}\tau_{c,t}\right)\right)^{\frac{1}{4}},$$

$$\sigma_I(\tau_{CPI,t}, \tau_{SCE,t}) \equiv \left(Var_{t-1}\left(\sum_{i=1}^{N_{CPI}} \omega_{CPI,i,t}\tau_{i,t}\right)Var_{t-1}\left(\sum_{j=1}^{N_{SCE}} \omega_{SCE,j,t}\tau_{j,t}\right)\right)^{\frac{1}{4}},$$

where $\sigma_C(\tau_{CPI,t}, \tau_{SCE,t})$ is the geometric mean of volatilities from the common component of the CPI and SCE inflation trends and $\sigma_I(\tau_{CPI,t}, \tau_{SCE,t})$ is the geometric mean of volatilities from the idiosyncratic components of the CPI and SCE inflation trends. If the former dominates the latter, the correlation coefficient between $\tau_{CPI,t}$ and $\tau_{SCE,t}$ becomes larger, which suggests that the linkage between wages and prices becomes increasingly tight.

As shown in Figure 6, $\sigma_C(\tau_{CPI,t}, \tau_{SCE,t})$ dominated $\sigma_I(\tau_{CPI,t}, \tau_{SCE,t})$ until the late 1990s, but the situation reversed around 1998, and $\sigma_I(\tau_{CPI,t}, \tau_{SCE,t})$ maintained the dominant position until 2019. In the post COVID-19-era, as $\sigma_C(\tau_{CPI,t}, \tau_{SCE,t})$ has increased, they are equally matched in size. This implies that the effects of the common and idiosyncratic factors are of the same magnitude and as a consequence, the linkage recovers to some extent. This empirical exercise confirms the results of the HAR test in section III.B.4.

Figure 6: Volatilities from Common and Idiosyncratic Factors

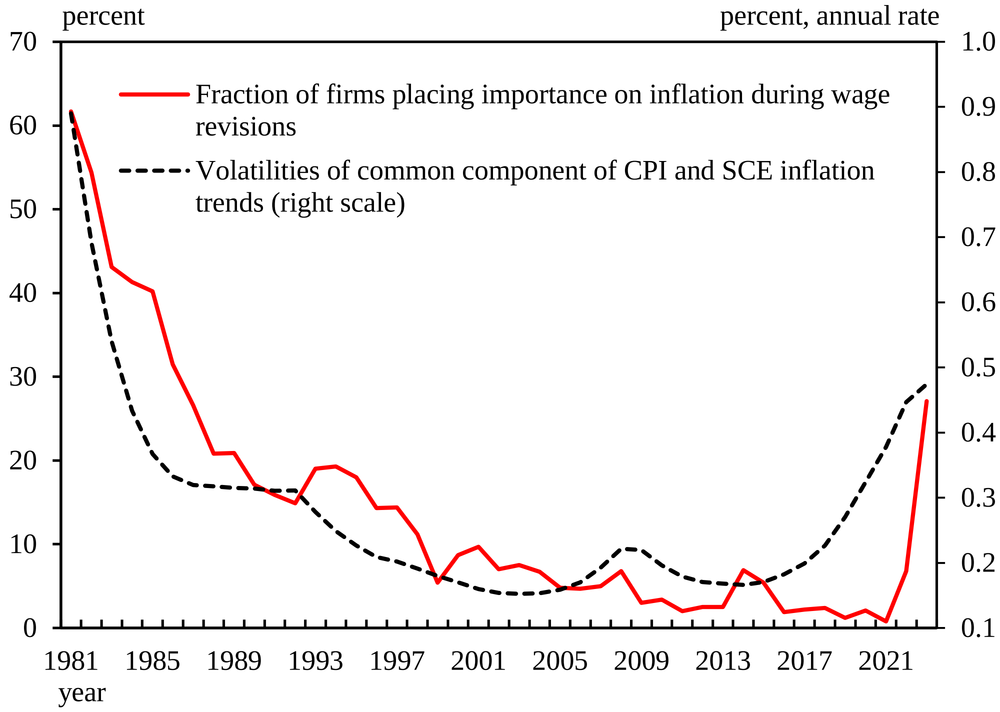


Notes: The geometric mean of volatilities from the common and idiosyncratic component of the CPI and SCE inflation trends are derived using the estimation results based on the MUCSVO-17-15 model.

The increase in the volatility of the common trend component of the CPI and SCE inflation during recent years seems to reflect the change in firms' behavior in price and wage setting. Among many things, one notable example of the change is the recent annual spring labor-management wage negotiations. As shown in Figure 7 based on the empirical results and a survey conducted by the Ministry of Health, Labour and Welfare, the proportion of firms that place importance on price inflation when revising wages in wage negotiations has continued to decline since 1980, as low inflation or moderate deflation persisted, but began to increase rapidly in the post-COVID-19 era. The volatility of the common trend component closely tracks this proportion of firms.

Hofmann, Peersman, and Straub (2012) argue that the degree of wage indexation is one of the most important factors that determine wage and price dynamics in the United States. They show empirically that wages and prices move in the same direction at longer horizons after both demand and supply shocks when the degree of wage indexation is high. If nominal wage growth closely follows the inflation rate because of explicit or implicit wage indexation, shocks can trigger mutually reinforcing feedback effects between wages and prices. The empirical results shown in Figure 7, illustrating how the volatility of the common trend component becomes larger as the degree of wage indexation gets higher, indicates that the mechanism emphasized in Hofmann, Peersman, and Straub (2012) also works in Japan.

Figure 7: Fraction of Firms Placing Importance on Price Inflation during Wage Revisions



Notes: "Fraction of firms placing importance on price inflation during age revisions" is calculated by dividing the total number of respondents citing inflation by the total number of respondents in the survey. Respondents are allowed to select up to three factors: the most important criteria and two additions. Respondents are companies that have implemented or plan to implement wage revisions.
Source: Ministry of Health, Labour and Welfare.

Taking importance for macroeconomic fluctuations into account, Carrillo, Peersman, and Wauters (2022) investigate the mechanism behind the time-varying degree of wage indexation observed in the United States. They show that a utility-maximizing worker in a simple economy with staggered labor contract endogenously choose to index their wage to past price inflation when shocks to productivity drive output fluctuations, but do not do so when aggregate demand shocks dominate. Specific examples are as follows: if negative productivity shocks or cost-push shocks induce high inflation, a worker with a high degree of wage indexation is more insured against these shocks than one with a low degree of wage indexation. However, where aggregate demand shock is a major factor in fluctuations in the economy, wage indexation does not give any advantage to a utility-maximizing worker.

Stylized facts for Japan and for the United States are generally consistent with the prediction by the model proposed in Carrillo, Peersman, and Wauters (2022) that the degree of wage indexation is high when the economy is hit by a large cost-push shock and low when energy prices are stable. For instance, "fraction of firms placing importance on price inflation during age revisions" in Figure 7 recorded its highest value, 76.8 percent, in 1974 just after the first oil crisis.

Rational inattention theory proposed by Sims (2003) also provides an explanation for phenomena like the tendency of inflation-indexation clauses in labor contracts to become more prevalent when price inflation is variable, but to disappear when price inflation stabilizes. Even if variation in price inflation increases, agents with the inflation-indexation clauses can allocate information-processing capacity to some forms of information monitoring other than inflation monitoring.

However, as pointed out in Ueda (2024), factors other than energy prices, such as labor market conditions and monetary policy stance, seem to be also important for the relationship between wages and prices, since the proportion of firms was low in other periods when energy prices increased rapidly, for instance the period just before the global financial crisis in 2008.[25]

The changes in firms' behavior in price and wage setting are also observed in the empirical analysis by Fukunaga, Kido, and Suita (2024). The historical decomposition in that paper indicates that various types of global shocks, including downward cost pressure due to globalization, continuously pushed down Japanese consumer prices until the late 2010s, and then their contributions reversed, significantly pushing up prices in the post-COVID-19 era. In addition, they show that nominal wages, which had not been much affected by global shocks, have also been significantly pushed up by global shocks in the recent period. These results imply that the change in the propagation of global shocks also plays some role in strengthening the linkage between wages and prices.

In addition to global shocks, the time-variation of price markups and wage markdowns of Japanese firms may be also reflected in the recoupling of wages and prices. Aoki,

[25] Specifically, Ueda (2024) points out as follows: "there were several phases when prices rose triggered by a rise in import prices… However, there was no substantial change in firms' wage- and price-setting behavior. For example, in the late 2000s, wages hardly increased at all, even when prices rose. One of the reasons for this difference between these past phases and the current phase is that import prices rose quite significantly this time. Another important factor is that during the current phase, labor market conditions have been tightening notably, causing a change in the wage and price formation mechanisms… I believe that the Bank's patient conduct of large-scale monetary easing was also effective in this tightening by strongly stimulating aggregate demand."

Hogen, and Takatomi (2023) argue that there is a reasonable possibility that the trends of price markups and wage markdowns of Japanese firms have recently changed. They point out that price markups and wage markdowns have greatly varied since the mid-2000s, but the recent environment surrounding wages and prices in Japan implies that price markups and wage markdowns have stabilized in the post-COVID-19 era. Specifically, it is possible that price markups have bottomed out, whereas wage markdowns have stopped increasing. Under stable markup and markdown rules, price inflation is determined only by nominal wage growth and labor productivity growth. In other words, the linkage between wages and prices could strengthen when price markups and wage markdowns stabilize.

In sum, the recoupling between wages and prices is related to recent changes in the degree of wage indexation, the propagation of global shocks, and markups and markdowns of Japanese firms. As shown in Ozaki et al. (2024), against this background, spillover from prices to wages has recently increased, whereas the rise in nominal wages has led to inflationary pressure on goods and services to only a small degree.[26] The restricted spillover from wages to prices could be the source of the incomplete recovery of the volatility of the common trend component, as shown in Figure 7. For the linkage between wages and prices to further progress, it might require an appropriate pass-through of labor costs to selling prices with change in the mindset and behavior based on the assumption that wages and prices will not increase easily, which had taken hold in society during deflation.

V. Conclusion

This paper has investigated changes in the linkage between wages and prices by using the MUCSVO models and HAR-based inference. The empirical analysis in the paper leads to four conclusions. First, the MUCSVO models perform better at identifying the underlying trends in wage and price inflation in Japan. Second, the trend component of services price inflation is the best indicator to gauge the underlying trend in price inflation among indicators examined in this paper. Third, wages and prices decoupled around 1998, but they have recoupled to some extent in the post-COVID-19 era. Fourth, the volatility of the common trend component of wage and price inflation has determined the strength of the linkage and closely tracked an indicator which shows the importance of price inflation when firms revise wages in negotiations.

---

[26] Fukunaga et al. (2023) provide similar empirical results.

The last point highlights a topic which future research should explore. As pointed out in Ueda (2024), labor market conditions are one of the main factors determining the degree of wage indexation in Japan. Komiya (1990) mentions a related historical episode: under a conspicuous easing in labor market conditions from the second half of 1974 until 1976, labor unions were confronted with a choice between substantial wage increases through a high degree of wage indexation on the one hand, and security of employment on the other; in 1976, they finally decided in favor of secure employment. Structural analysis on the time-varying degree of wage indexation which adopts these characteristics of the Japanese labor market can contribute to deepening our understanding of the key to the virtuous cycle between wages and prices.

Appendix 1: Estimation Details

The Bayesian estimation approach is identical to that in Stock and Watson (2015), and the reader is referred to that reference for details. As described in the main text, the model is given by the following set of equations for price inflation for classification $i = 1{:}\,N_\pi$, $\pi_{i,t}$, and wage inflation for industry $j = 1{:}\,N_w$, $w_{j,t}$ at period t:

$$\pi_{i,t} = \alpha_{i,\tau,t}\tau_{c,t} + \alpha_{i,\epsilon,t}\epsilon_{c,t} + \tau_{i,t} + \epsilon_{i,t}, \quad (1)$$

$$w_{j,t} = \alpha_{j,\tau,t}\tau_{c,t} + \alpha_{j,\epsilon,t}\epsilon_{c,t} + \tau_{j,t} + \epsilon_{j,t}, \quad (2)$$

$$\tau_{c,t} = \tau_{c,t-1} + \sigma_{\Delta\tau,c,t} \times \eta_{\tau,c,t}, \quad (3)$$

$$\tau_{k,t} = \tau_{k,t-1} + \sigma_{\Delta\tau,k,t} \times \eta_{\tau,k,t} \quad \text{for } k = i \text{ or } j, \quad (4)$$

$$\epsilon_{c,t} = \sigma_{\epsilon,c,t} \times s_{c,t} \times \eta_{\epsilon,c,t}, \quad (5)$$

$$\epsilon_{k,t} = \sigma_{\epsilon,k,t} \times s_{k,t} \times \eta_{\epsilon,k,t} \quad \text{for } k = i \text{ or } j, \quad (6)$$

$$\alpha_{k,\tau,t} = \alpha_{k,\tau,t-1} + \lambda_{k,\tau}\xi_{k,\tau,t} \quad \text{for } k = i \text{ or } j, \quad (7)$$

$$\alpha_{k,\epsilon,t} = \alpha_{k,\epsilon,t-1} + \lambda_{k,\epsilon}\xi_{k,\epsilon,t} \quad \text{for } k = i \text{ or } j, \quad (8)$$

$$\Delta\ln\left(\sigma^2_{\Delta\tau,c,t}\right) = \gamma_{\Delta\tau,c}\nu_{\Delta\tau,c,t}, \quad (9)$$

$$\Delta\ln\left(\sigma^2_{\epsilon,c,t}\right) = \gamma_{\epsilon,c}\nu_{\epsilon,c,t}, \quad (10)$$

$$\Delta\ln\left(\sigma^2_{\Delta\tau,k,t}\right) = \gamma_{\Delta\tau,k}\nu_{\Delta\tau,k,t} \quad \text{for } k = i \text{ or } j, \quad (11)$$

$$\Delta\ln\left(\sigma^2_{\epsilon,k,t}\right) = \gamma_{\epsilon,k}\nu_{\epsilon,k,t} \quad \text{for } k = i \text{ or } j. \quad (12)$$

The jump processes $s_{c,t}$ and $s_{k,t}$ equal 1 with probability ($1 - p_l$ for $l = c, i, \text{or } j$) and equal a draw from a uniform distribution over the interval 2 to 10 with probability p_l. This uniform distribution is approximated by an equally spaced grid of 9 points. Priors for $\gamma_{\Delta\tau,c}$, $\gamma_{\epsilon,c}$, $\gamma_{\Delta\tau,k}$, and $\gamma_{\epsilon,k}$ are Uniform over the interval 0 to 0.20. These priors are approximated by an equally spaced grid of 5 points. Priors for p_l are Beta (2.5, 37.5). Priors for the initial conditions of the trends and stochastic volatility are loose.

The posteriors are approximated by MCMC draws, with 50,000 draws following a 5,000-draw burn-in period. Results are saved every 10 draws, resulting in 5,000 draws for the approximations. The following tables summarize estimates of the posteriors for $\gamma_{\Delta\tau,c}$, $\gamma_{\epsilon,c}$, $\gamma_{\Delta\tau,k}$, and $\gamma_{\epsilon,k}$ and p_l for the MUCSVO-3-2 model (the small model with price and wage inflation), the MUCSVO-17-0 model (the large model with only price inflation), the MUCSVO-0-15 model (the large model with only wage inflation), and the MUCSVO-17-15 models (the baseline model with both price and wage inflation). The results for other models are omitted due to limitations of space.

Table A-1: Prior and Posterior Distributions for $\gamma_{\Delta\tau,c}$

Value	Prior Probability	Posterior Probability for Each Model MUCSVO-3-2	MUCSVO-17-0	MUCSVO-0-15	MUCSVO-17-15
0.00	0.20	0.025	0.000	0.001	0.000
0.05	0.20	0.043	0.000	0.009	0.000
0.10	0.20	0.137	4.0e-4	0.101	2.0e-4
0.15	0.20	0.309	0.061	0.358	0.067
0.20	0.20	0.487	0.939	0.531	0.932

Table A-2: Prior and Posterior Distributions for $\gamma_{\epsilon,c}$

Value	Prior Probability	Posterior Probability for Each Model MUCSVO-3-2	MUCSVO-17-0	MUCSVO-0-15	MUCSVO-17-15
0.00	0.20	0.148	0.000	0.245	2.0e-4
0.05	0.20	0.158	6.0e-4	0.252	0.029
0.10	0.20	0.230	0.052	0.219	0.190
0.15	0.20	0.252	0.338	0.163	0.382
0.20	0.20	0.212	0.610	0.122	0.399

Table A-3: Prior and Posterior Distributions for p_c (selected quantiles)

Model	16%	50%	83%
MUCSVO-3-2	0.021	0.038	0.062
MUCSVO-17-0	0.014	0.029	0.049
MUCSVO-0-15	0.063	0.094	0.134
MUCSVO-17-15	0.025	0.044	0.069

Table A-4: Prior and Posterior Distributions for $\gamma_{\epsilon,i}$ in MUCSVO-3-2 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probabilities					
CPI					
Items excluding the below	0.174	0.175	0.196	0.214	0.241
Fresh food, raw meats & cut flowers, other agricultural, aquatic & livestock products	0.221	0.226	0.202	0.190	0.162
Petroleum products, and electricity, manufactured & piped gas & water charges	0.000	0.000	0.001	0.042	0.957
SCE					
Manufacturing	0.215	0.209	0.216	0.195	0.165
Nonmanufacturing	0.191	0.193	0.202	0.213	0.201

Table A-5: Prior and Posterior Distributions for $\gamma_{\Delta\tau,k}$ in MUCSVO-3-2 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probabilities					
CPI					
Items excluding the below	0.277	0.244	0.204	0.160	0.115
Fresh food, raw meats & cut flowers, other agricultural, aquatic & livestock products	0.665	0.258	0.063	0.011	0.003
Petroleum products, and electricity, manufactured & piped gas & water charges	0.200	0.204	0.194	0.196	0.206
SCE					
Manufacturing	0.323	0.254	0.188	0.132	0.103
Nonmanufacturing	0.012	0.029	0.154	0.338	0.467

Table A-6: Prior and Posterior Distributions for p_k in MUCSVO-3-2 Model

	16%	50%	83%
CPI			
Items excluding the below	0.014	0.028	0.049
Fresh food, raw meats & cut flowers, other agricultural, aquatic & livestock products	0.008	0.016	0.029
Petroleum products, and electricity, manufactured & piped gas & water charges	0.023	0.046	0.082
SCE			
Manufacturing	0.024	0.044	0.072
Nonmanufacturing	0.025	0.042	0.065

Table A-7: Prior and Posterior Distributions for $\gamma_{\epsilon,i}$ in MUCSVO-17-0 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probabilities					
CPI					
Agricultural, aquatic & livestock products	0.680	0.251	0.052	0.014	0.002
Food products	0.279	0.245	0.208	0.160	0.107
Textiles	0.000	0.000	2.0e-4	0.077	0.923
Petroleum products	0.001	0.005	0.027	0.190	0.776
Other industrial products	0.213	0.213	0.189	0.182	0.203
Electricity, manufactured & piped gas & water charges	0.191	0.191	0.194	0.194	0.231
Publications	0.000	0.000	2.0e-4	0.026	0.974
Public services related to domestic duties	0.345	0.317	0.194	0.102	0.043
Services related to medical care & welfare	0.246	0.225	0.208	0.184	0.138
Public services related to forwarding & communication	0.246	0.232	0.205	0.165	0.152
Public services related to education	0.000	0.000	0.000	0.010	0.990
Public services related to culture & recreation	0.000	0.000	0.000	0.019	0.981
General services related to domestic duties	0.297	0.287	0.198	0.138	0.079
General Services related to education	0.000	0.000	0.003	0.124	0.873
General services related to communication, culture & recreation	0.000	0.000	0.000	0.028	0.972
Meals outside the home	0.008	0.011	0.031	0.143	0.808
Rent	0.001	0.004	0.040	0.282	0.673

Table A-8: Prior and Posterior Distributions for $\gamma_{\Delta\tau,k}$ in MUCSVO-17-0 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probabilities					
CPI					
Agricultural, aquatic & livestock products	0.231	0.229	0.200	0.188	0.152
Food products	0.003	0.004	0.006	0.056	0.931
Textiles	0.234	0.241	0.210	0.170	0.146
Petroleum products	0.009	0.011	0.055	0.274	0.650
Other industrial products	0.001	0.001	0.002	0.074	0.921
Electricity, manufactured & piped gas & water charges	0.000	0.000	0.000	0.026	0.974
Publications	0.030	0.028	0.027	0.049	0.866
Public services related to domestic duties	0.223	0.230	0.210	0.180	0.158
Services related to medical care & welfare	0.000	0.000	0.000	0.001	0.999
Public services related to forwarding & communication	2.0e-4	0.008	0.097	0.296	0.599
Public services related to education	0.346	0.307	0.197	0.100	0.050
Public services related to culture & recreation	0.210	0.187	0.168	0.157	0.277
General services related to domestic duties	0.001	0.005	0.043	0.267	0.684
General Services related to education	0.019	0.040	0.139	0.343	0.460
General services related to communication, culture & recreation	0.252	0.234	0.207	0.168	0.138
Meals outside the home	0.172	0.162	0.149	0.182	0.335
Rent	0.000	0.001	0.049	0.304	0.646

Table A-9: Prior and Posterior Distributions for p_k in MUCSVO-17-0 Model

	16%	50%	83%
CPI			
Agricultural, aquatic & livestock products	0.008	0.016	0.029
Food products	0.017	0.033	0.055
Textiles	0.010	0.022	0.038
Petroleum products	0.044	0.070	0.104
Other industrial products	0.019	0.038	0.065
Electricity, manufactured & piped gas & water charges	0.021	0.043	0.084
Publications	0.031	0.056	0.090
Public services related to domestic duties	0.166	0.203	0.245
Services related to medical care & welfare	0.022	0.043	0.075
Public services related to forwarding & communication	0.019	0.039	0.068
Public services related to education	0.193	0.223	0.254
Public services related to culture & recreation	0.095	0.127	0.163
General services related to domestic duties	0.013	0.025	0.044
General Services related to education	0.072	0.104	0.141
General services related to communication, culture & recreation	0.010	0.021	0.037
Meals outside the home	0.030	0.053	0.085
Rent	0.015	0.031	0.054

Table A-10: Prior and Posterior Distributions for $\gamma_{\epsilon,i}$ in MUCSVO-0-15 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probabilities					
SCE					
Mining and quarrying of stone gravel	0.000	0.041	0.244	0.378	0.337
Construction	0.000	0.057	0.485	0.328	0.130
Manufacturing	0.362	0.343	0.180	0.085	0.031
Electricity, gas, heat supply and water	0.021	0.189	0.284	0.265	0.241
Railway transport	0.419	0.347	0.148	0.061	0.025
Road passenger transport	0.000	0.047	0.384	0.360	0.208
Road freight transport	0.199	0.330	0.241	0.152	0.078
Wholesale trade	0.000	0.007	0.153	0.392	0.448
Retail trade, general merchandise	0.000	0.001	0.013	0.158	0.829
Retail trade (dry goods, apparel and apparel accessories)	0.000	0.000	0.017	0.207	0.776
Insurance institutions	0.000	0.001	0.030	0.210	0.758
Scientific and development research institutes	0.516	0.279	0.129	0.056	0.019
Accommodations	0.194	0.222	0.203	0.195	0.186
Eating and drinking places	0.028	0.092	0.288	0.360	0.233
Others	0.020	0.143	0.319	0.324	0.194

Table A-11: Prior and Posterior Distributions for $\gamma_{\Delta\tau,k}$ in MUCSVO-0-15 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probability					
SCE					
Mining and quarrying of stone gravel	0.273	0.262	0.204	0.153	0.108
Construction	0.310	0.265	0.199	0.135	0.091
Manufacturing	0.309	0.273	0.213	0.127	0.078
Electricity, gas, heat supply and water	0.280	0.273	0.206	0.153	0.089
Railway transport	0.278	0.275	0.208	0.144	0.095
Road passenger transport	0.267	0.256	0.207	0.150	0.121
Road freight transport	0.275	0.260	0.204	0.155	0.105
Wholesale trade	0.290	0.255	0.213	0.151	0.091
Retail trade, general merchandise	0.284	0.256	0.207	0.154	0.099
Retail trade (dry goods, apparel and apparel accessories)	0.250	0.240	0.210	0.173	0.128
Insurance institutions	0.272	0.246	0.210	0.158	0.114
Scientific and development research institutes	0.281	0.240	0.205	0.158	0.116
Accommodations	0.291	0.250	0.206	0.146	0.108
Eating and drinking places	0.234	0.223	0.206	0.190	0.147
Others	0.334	0.271	0.193	0.126	0.076

Table A-12: Prior and Posterior Distributions for p_k in MUCSVO-0-15 Model

	16%	50%	83%
SCE			
Mining and quarrying of stone gravel	0.023	0.040	0.063
Construction	0.010	0.020	0.035
Manufacturing	0.022	0.038	0.058
Electricity, gas, heat supply and water	0.012	0.024	0.043
Railway transport	0.014	0.027	0.046
Road passenger transport	0.034	0.053	0.079
Road freight transport	0.021	0.039	0.063
Wholesale trade	0.017	0.030	0.049
Retail trade, general merchandise	0.024	0.042	0.068
Retail trade (dry goods, apparel and apparel accessories)	0.034	0.056	0.086
Insurance institutions	0.009	0.018	0.033
Scientific and development research institutes	0.009	0.018	0.032
Accommodations	0.031	0.052	0.078
Eating and drinking places	0.016	0.030	0.048
Others	0.021	0.037	0.058

Table A-13: Prior and Posterior Distributions for $\gamma_{\epsilon,i}$ in MUCSVO-17-15 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probabilities					
CPI					
Agricultural, aquatic & livestock products	0.649	0.265	0.068	0.014	0.005
Food products	0.342	0.286	0.187	0.119	0.065
Textiles	0.000	0.000	0.001	0.092	0.907
Petroleum products	0.047	0.045	0.053	0.191	0.664
Other industrial products	0.210	0.214	0.189	0.191	0.196
Electricity, manufactured & piped gas & water charges	0.240	0.237	0.198	0.172	0.154
Publications	0.000	0.000	0.002	0.030	0.968
Public services related to domestic duties	0.388	0.291	0.185	0.096	0.041
Services related to medical care & welfare	0.000	0.000	0.000	0.026	0.974
Public services related to forwarding & communication	0.283	0.255	0.206	0.150	0.106
Public services related to education	0.000	0.000	0.000	0.016	0.984
Public services related to culture & recreation	0.000	0.000	0.000	0.023	0.977
General services related to domestic duties	0.360	0.290	0.174	0.113	0.063
General Services related to education	0.000	0.000	0.006	0.137	0.857
General services related to communication, culture & recreation	0.000	0.000	0.007	0.071	0.922
Meals outside the home	0.098	0.087	0.130	0.222	0.462
Rent	0.000	0.004	0.061	0.378	0.557
SCE					
Mining and quarrying of stone gravel	0.000	0.025	0.214	0.379	0.382
Construction	0.000	0.104	0.523	0.272	0.101
Manufacturing	0.160	0.317	0.282	0.159	0.082
Electricity, gas, heat supply and water	0.001	0.121	0.307	0.296	0.275
Railway transport	0.439	0.321	0.154	0.061	0.025
Road passenger transport	0.000	0.048	0.387	0.355	0.210
Road freight transport	0.075	0.149	0.295	0.287	0.194
Wholesale trade	0.000	0.007	0.174	0.411	0.409
Retail trade, general merchandise	0.000	0.000	0.011	0.190	0.799
Retail trade (dry goods, apparel and apparel accessories)	0.000	0.000	0.016	0.175	0.809
Insurance institutions	0.000	0.001	0.028	0.229	0.742
Scientific and development research institutes	0.520	0.280	0.123	0.054	0.023
Accommodations	0.015	0.091	0.187	0.309	0.398
Eating and drinking places	0.015	0.081	0.264	0.371	0.270
Others	0.042	0.170	0.335	0.298	0.155

Table A-14: Prior and Posterior Distributions for $\gamma_{\Delta\tau,k}$ in MUCSVO-17-15 Model

Value	0.00	0.05	0.10	0.15	0.20
Prior Probability	0.20	0.20	0.20	0.20	0.20
Posterior Probabilities					
CPI					
Agricultural, aquatic & livestock products	0.251	0.245	0.209	0.168	0.128
Food products	0.000	0.000	0.001	0.027	0.972
Textiles	0.216	0.217	0.213	0.195	0.158
Petroleum products	0.004	0.010	0.053	0.232	0.701
Other industrial products	0.000	0.000	0.006	0.092	0.902
Electricity, manufactured & piped gas & water charges	0.000	0.000	0.000	0.027	0.973
Publications	0.004	0.007	0.008	0.036	0.946
Public services related to domestic duties	0.280	0.253	0.206	0.154	0.108
Services related to medical care & welfare	0.135	0.142	0.200	0.257	0.266
Public services related to forwarding & communication	0.000	0.005	0.094	0.290	0.611
Public services related to education	0.386	0.310	0.181	0.087	0.036
Public services related to culture & recreation	0.169	0.143	0.130	0.138	0.420
General services related to domestic duties	0.003	0.005	0.043	0.262	0.688
General Services related to education	0.141	0.170	0.209	0.240	0.240
General services related to communication, culture & recreation	0.207	0.181	0.171	0.164	0.278
Meals outside the home	0.036	0.032	0.065	0.221	0.647
Rent	0.000	0.008	0.136	0.394	0.462
SCE					
Mining and quarrying of stone gravel	0.274	0.244	0.202	0.163	0.118
Construction	0.288	0.242	0.200	0.156	0.114
Manufacturing	0.257	0.249	0.215	0.160	0.119
Electricity, gas, heat supply and water	0.290	0.269	0.197	0.148	0.097
Railway transport	0.276	0.258	0.213	0.147	0.106
Road passenger transport	0.237	0.228	0.212	0.180	0.142
Road freight transport	0.258	0.242	0.213	0.164	0.123
Wholesale trade	0.282	0.261	0.209	0.152	0.096
Retail trade, general merchandise	0.275	0.242	0.211	0.154	0.118
Retail trade (dry goods, apparel and apparel accessories)	0.226	0.211	0.215	0.193	0.154
Insurance institutions	0.261	0.254	0.211	0.158	0.115
Scientific and development research institutes	0.285	0.265	0.203	0.143	0.104
Accommodations	0.281	0.262	0.194	0.153	0.110
Eating and drinking places	0.210	0.213	0.202	0.203	0.172
Others	0.318	0.279	0.206	0.122	0.075

Table A-15: Prior and Posterior Distributions for p_k in MUCSVO-17-15 Model

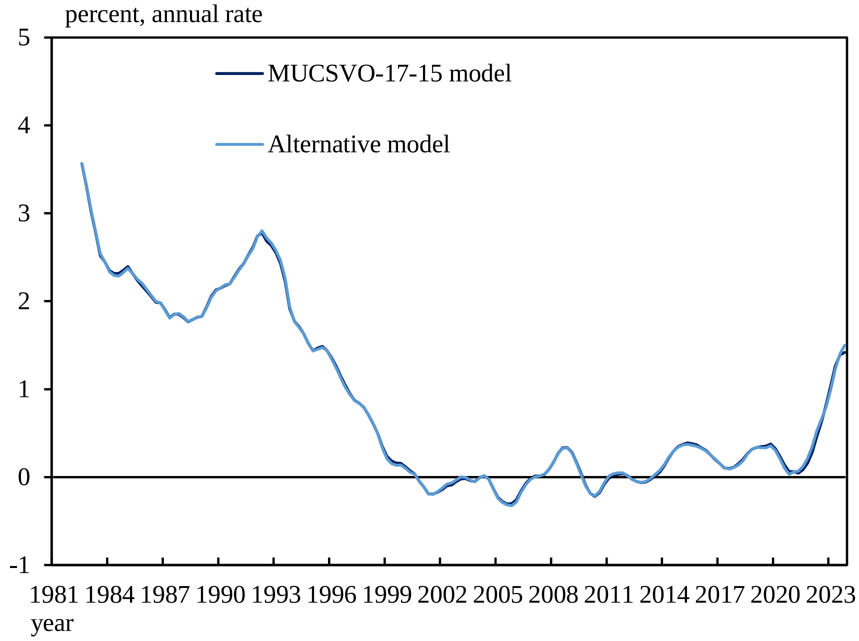
	16%	50%	83%
CPI			
Agricultural, aquatic & livestock products	0.008	0.016	0.029
Food products	0.014	0.027	0.047
Textiles	0.010	0.020	0.036
Petroleum products	0.041	0.067	0.101
Other industrial products	0.017	0.034	0.058
Electricity, manufactured & piped gas & water charges	0.018	0.037	0.065
Publications	0.025	0.045	0.074
Public services related to domestic duties	0.161	0.198	0.238
Services related to medical care & welfare	0.152	0.207	0.256
Public services related to forwarding & communication	0.017	0.033	0.059
Public services related to education	0.190	0.219	0.251
Public services related to culture & recreation	0.086	0.118	0.155
General services related to domestic duties	0.010	0.020	0.035
General Services related to education	0.045	0.070	0.099
General services related to communication, culture & recreation	0.010	0.021	0.038
Meals outside the home	0.026	0.044	0.068
Rent	0.011	0.024	0.041
SCE			
Mining and quarrying of stone gravel	0.023	0.041	0.064
Construction	0.009	0.019	0.035
Manufacturing	0.023	0.039	0.061
Electricity, gas, heat supply and water	0.015	0.030	0.049
Railway transport	0.015	0.028	0.047
Road passenger transport	0.033	0.053	0.078
Road freight transport	0.033	0.052	0.079
Wholesale trade	0.015	0.028	0.045
Retail trade, general merchandise	0.021	0.037	0.060
Retail trade (dry goods, apparel and apparel accessories)	0.035	0.058	0.087
Insurance institutions	0.009	0.018	0.032
Scientific and development research institutes	0.008	0.017	0.031
Accommodations	0.019	0.037	0.059
Eating and drinking places	0.015	0.028	0.047
Others	0.026	0.042	0.064

Appendix 2: Alternative Specification of MUCSVO Model

In the baseline model, i.e., the MUCSVO-17-15 model, the trend component of the CPI services inflation can be influenced by the CPI goods and the SCE in manufacturing industry. In this appendix, the effect of using the CPI goods and the SCE in manufacturing in the estimate of the trend component of the CPI services inflation is investigated.

Specifically, Figure A-1 shows the estimate of the trend component of the CPI services inflation when not using data on the CPI goods or the SCE in manufacturing industries in the estimation.[27] The empirical result shows that the difference between the estimates of the trend components of the CPI services in the MUCSVO model and the alternative model is quite limited. This implies that data on the CPI goods and the SCE in manufacturing industry has little influence on the estimates of the trend component of the CPI services inflation in the baseline model.

Figure A-1: Trend Components of CPI Service Inflation



Notes: The 6-quarter backward moving averages of trend components of the CPI services inflation from the MUCSVO-17-15 model and alternative model are plotted.

[27] Data on the SCE in the "Others" industry category, as in Tables 2, 4, and A-10 to A-15 above, is not used either when focusing on nonmanufacturing industries since it is not clear what industries are included in the "Others" category.

References

Almuzara, Martin, Richard Audoly, and Davide Melcangi, "A Measure of Core Wage Inflation," Federal Reserve Bank of New York Staff Reports No.1067, 2023 (Revised January 2024).

Almuzara, Martin, and Argia Sbordone, "Inflation Persistent: How Much Is There and Where Is It Coming From?," Federal Reserve Bank of New York Liberty Street Economics, April 20, 2022 (available at https://libertystreeteconomics.newyorkfed.org/2022/04/inflation-persistence-how-much-is-there-and-where-is-it-coming-from/).

Aoki, Kosuke, Yoshihiko Hogen, and Kosuke Takatomi, "Price Markups and Wage Setting Behavior of Japanese Firms," Bank of Japan Working Paper Series No.23-E-5, 2023.

Atkeson, Andrew, and Lee Ohanian, "Are Phillips Curves Useful for Forecasting Inflation?," *Federal Reserve Bank of Minneapolis Quarterly Review*, 25(1), 2001.

Bank of Japan, "Background Note regarding the Bank's Thinking on Price Stability," 2013.

———, "Changes in the Monetary Policy Framework," 2024 (available at https://www.boj.or.jp/en/mopo/mpmdeci/mpr_2024/k240319a.pdf).

Blanchard, Olivier, "The Wage Price Spiral," *The Quarterly Journal of Economics*, 101(3), 1986, pp. 543-565.

Bryan, Michael, and Stephen Cecchetti, "Measuring Core Inflation," in Gregory Mankiw, ed. *Monetary Policy*, Chicago: University of Chicago Press, 1994, pp. 195-219.

Carrillo, Julio, Gert Peersman, and Joris Wauters, "Endogenous Wage Indexation and Aggregate Shocks," *Journal of Macroeconomics*, 72, 2022.

Elliott Graham, Thomas Rothenberg, and James Stock, "Efficient Tests for an Autoregressive Unit Root," *Econometrica*, 64(4), 1996, pp. 813-836.

Ernst, Philip, Larry Shepp, and Abraham Wyner, "Yule’s "Nonsense Correlation" Solved!," *The Annals of Statistics*, 45(4), 2017, pp. 1789-1809.

Fukunaga, Ichiro, Kakuho Furukawa, Shunsuke Haba, Yoshihiko Hogen, Yosuke Kido, Tomohiro Okubo, Kotaro Suita, and Kosuke Takatomi, "Wage Developments in Japan: Four Key Issues for the Post-COVID-19 Wage Growth," Bank of Japan Working Paper Series No.23-E-4, 2023.

Fukunaga, Ichiro, Yosuke Kido, and Kotaro Suita, "Japan's Inflation under Global Inflation Synchronization," Bank of Japan Working Paper Series No.24-E-4, 2024.

Gordon, Robert, "Alternative Responses of Policy to External Supply Shocks," *Brookings Papers on Economic Activity*, 1, 1975, pp. 183-206.

Hofmann, Boris, Gert Peersman, and Roland Straub, "Time Variation in U.S. Wage Dynamics," *Journal of Monetary Economics*, 59(8), 2012, pp. 769-783.

Hogen, Yoshihiko, Takuji Kawamoto, and Moe Nakahama, "Core Inflation and the Business Cycle," *Bank of Japan Review Series* 2015-E-6, Bank of Japan, 2015.

Hoshi, Takeo, and Anil Kashyap, "The Great Disconnect: The Decoupling of Wage and Price Inflation in Japan," NBER Working Paper 27332, 2020.

———, "The Great Disconnect: The Decoupling of Wage and Price Inflation in Japan," in Takeo Hoshi and Phillip Lipscy, ed. *The Political Economy of the Abe Government and Abenomics Reforms*, Cambridge: Cambridge University Press, 2021, pp. 170-199.

Kiefer, Nicholas, and Timothy Vogelsang, "Heteroskedasticity-Autocorrelation Robust Testing Using Bandwidth Equal to Sample Size," *Econometric Theory* 18(6), 2002a, pp. 1350–1366.

———, "Heteroskedasticity-Autocorrelation Robust Standard Errors Using the Bartlett Kernel Without Truncation," *Econometrica* 70(5), 2002b, pp. 2093-2095.

Kiley, Michael, "The Role of Wages in Trend Inflation: Back to the 1980s?," Finance and Economics Discussion Series 2023-022, Board of Governors of the Federal Reserve System, 2023.

Komiya, Ryutaro, *The Japanese Economy: Trade, Industry, and Government*, Tokyo: University of Tokyo Press, 1990.

Kuroda, Sachiko, and Isamu Yamamoto, "Is Downward Wage Flexibility the Primary Factor of Japan's Prolonged Deflation?," *Asian Economic Policy Review*, 9(1), 2014, pp. 143-158.

Lorenzoni, Guido, and Iván Werning, "Wage-Price Spirals," BPEA Conference Draft, September 28-29, 2023.

Muto, Ichiro, and Kohei Shintani, "An Empirical Study on the New Keynesian Wage Phillips Curve: Japan and the US," *The B.E. Journal of Macroeconomics*, 20(1), 2020.

Nakamura, Koji, Shogo Nakano, Mitsuhiro Osada, and Hiroki Yamamoto, "What Caused the Pandemic-Era Inflation?: Application of the Bernanke-Blanchard Model to Japan," Bank of Japan Working Paper Series No.24-E-1, 2024.

Ng, Serena, and Pierre Perron, "Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power," *Econometrica*, 69(6), 2001, pp. 1519-1554.

Ozaki, Tatsuya, Masahiro Jimbo, Tomoyuki Yagi, and Akihito Yoshii, "Recent Developments in the Linkage between Wages and Prices," *Bank of Japan Review Series* 2024-E-2, Bank of Japan, 2024.

Peneva, Ekaterina, and Jeremy Rudd, "The Passthrough of Labor Costs to Price Inflation," *Journal of Money, Credit and Banking*, 49(8), 2017, pp. 1777-1802.

Phillips, Peter, Xiaohu Wang, and Yonghui Zhang, "HAR Testing for Spurious Regression in Trend," *Econometrics* 2019, 7(4):50, 2019.

Reis, Ricardo, and Mark Watson, "Relative Goods' Prices, Pure Inflation, and the Philips Correlation," *American Economic Journal: Macroeconomics*, 2(3), 2010, pp. 128-157.

Rudd, Jeremy, "Underlying Inflation: Its Measurement and Significance," FEDS Notes, Board of Governors of the Federal Reserve System, September 18, 2020 (available at https://doi.org/10.17016/2380-7172.2624).

Shiratsuka, Shigenori, "Performance of Core Indicators of Japan's Consumer Price Index," *Bank of Japan Review Series* 2015-E-7, Bank of Japan, 2015.

Sims, Christopher, "Implication of Rational Inattention," *Journal of Monetary Economics*, 50(3), 2003, pp. 665-690.

Stock, James, and Mark Watson, "Why has U.S. Inflation Become Harder to Forecast?," *Journal of Money, Credit and Banking*, 39(s1), 2007, pp. 3-33.

――, "Core Inflation and Trend Inflation ─Appendix─," 2015 (Revised January 2016)

――, "Core Inflation and Trend Inflation," *Review of Economics and Statistics*, 98(4), 2016, pp. 770-784.

Sun, Yixiao, "A Convergent t-Statistics in Spurious Regressions," *Econometric Theory*, 20(5), 2004, pp. 943-962.

Ueda, Kazuo, "Virtuous Cycle between Wages and Prices and the Bank of Japan's Monetary Policy," Speech at a Meeting Held by the Yomiuri International Economic Society in Tokyo, 2024.

U.S. Census Bureau, "X-13ARIMA-SEATS Reference Manual, version 1.1," 2023 (available at https://www2.census.gov/software/x-13arima-seats/x13as/unix-linux/documentation/docx13as.pdf).

Yoshikawa, Hiroshi, *Reconstruction of Macroeconomics: Methods of Statistical Physics, and Keynes' Principle of Effective Demand*, Singapore: Springer Singapore, 2022.