Bank of Japan Working Paper Series

Nonlinear Input Cost Pass-through to Consumer Prices: A Threshold Approach

Takatoshi Sasaki*
takatoshi.sasaki@boj.or.jp

Hiroki Yamamoto*
hiroki.yamamoto@boj.or.jp

Jouchi Nakajima**
nakajima-j@ier.hit-u.ac.jp

No.23-E-9
May 2023

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

* Monetary Affairs Department
** Institute of Economic Research, Hitotsubashi University and Monetary Affairs Department, Bank of Japan

Nonlinear Input Cost Pass-through to Consumer Prices: A Threshold Approach*

Takatoshi Sasaki† Hiroki Yamamoto‡ Jouchi Nakajima§

May 2023

Abstract

This paper examines a possible nonlinearity in the pass-through to CPI inflation of increases in firms' input costs. Using Japanese data, the paper empirically investigates whether the degree of the pass-through rises when increases in costs exceed a certain threshold. Three main empirical results are obtained. First, there is a statistically significant nonlinearity in that the pass-through to CPI inflation of increases in producer prices, exchange rates, and wages rises once the increase in each of these variables exceeds a certain threshold. Second, our nonlinear model is superior to the linear model used in previous studies in terms of in-sample model fit and out-of-sample forecasting performance, suggesting that the linear model underestimates the degree of the pass-through of an input-cost increase that exceeds the threshold while overestimating that of a smaller input-cost increase. Third, the estimated impact of the nonlinear pass-through of increases in producer prices and exchange rates on CPI inflation is often transitory, whereas that of wage growth tends to be persistent due to the observed higher inertia in wage growth. These results suggest that whether a nonlinearity will arise in the pass-through of wage growth is one of the most important issues for future developments in CPI inflation.

JEL classification: C24, E31, E58

Keywords: Inflation, Pass-through, Nonlinearity, Threshold model

---

* The authors are grateful to Luiggi Donayre, Toyoichiro Shirota, Benjamin Wong, seminar participants at the 30th SNDE Annual Symposium, and staff members of the Bank of Japan for their valuable comments and discussions. The authors also thank Atsuki Hirata for excellent research assistance. All remaining errors are attributable to the authors. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Japan.

† Monetary Affairs Department, Bank of Japan (E-mail: takatoshi.sasaki@boj.or.jp)

‡ Monetary Affairs Department, Bank of Japan (E-mail: hiroki.yamamoto@boj.or.jp)

§ Institute of Economic Research, Hitotsubashi University (E-mail: nakajima-j@ier.hit-u.ac.jp) and Monetary Affairs Department, Bank of Japan

1. Introduction

In 2022, against the backdrop of several factors such as the surge in global commodity prices and the depreciation of the yen, firms in Japan faced a rapid and large increase in their input costs and many of them ended up raising their selling prices. As a consequence, the year-on-year inflation rate of the consumer price index (CPI) reached as high as that in the early 1980s and recorded the highest level of CPI inflation in around four decades, as can be seen in Panel 1. There have been a number of studies examining the relationship between firms' input costs, such as crude oil prices and exchange rates, and the CPI, many of which assume in their empirical analysis a linear relation between changes in these costs and CPI inflation (see for example, Campa and Goldberg, 2005). However, the recent price-setting behavior of firms suggests a possible nonlinearity in the impact (i.e., pass-through) of the cost increases to CPI inflation, such that the degree of pass-through depends on the magnitude of increases in the input costs. For instance, we may consider that firms keep their selling prices unchanged as long as an increase in their input costs is less than a certain threshold; once the increase is more than the threshold, the firms end up raising the prices. In this case, the degree of the pass-through of the increase in input costs to CPI inflation rises once the increase exceeds the threshold.

The possibility of nonlinearity in the pass-through to inflation suggests that linear models used in previous studies could underestimate the degree of the cost pass-through to inflation for periods when the cost variables increase rapidly and markedly. Against the backdrop of the recent high inflation across the globe, the nonlinear dynamics of inflation have attracted attention from both academics and policymakers as one of the most important issues from the perspective of monetary policy conduct (Taylor, 2000; BIS, 2022; Borio et al., 2023; Gopinath, 2023).

A growing body of literature on the nonlinear pass-through has used so-called threshold models.[1] For example, Colavecchio and Rubene (2020) develop a regression model in which the degree of the exchange-rate pass-through to inflation rises when changes in the exchange rate exceed a threshold. Their study sets the threshold equal to one standard deviation of changes in the exchange rate during the estimation sample period and finds nonlinearity in the exchange-rate pass-through in the euro area. Caselli and Roitman (2019) report that the degree of the exchange-rate pass-through to inflation for emerging market

---

[1] In addition to those with threshold models, there have been empirical studies on the nonlinearity of pass-through that use time series models with regime switching. See, for example, Shintani et al. (2013), who use a smooth transition model in which the values of model parameters evolve gradually with regime switching, and show that the degree of the exchange-rate pass-through to inflation depends on the past inflation rate in the U.S.

economies increases when changes in the exchange rate exceed the threshold. Likewise, Ben Cheikh et al. (2018) point out that the degree of the exchange-rate pass-through increases during periods of economic expansion in the euro area. As for Japan, Yagi et al. (2022) show that the pass-through of changes in raw material costs and exchange rates tends to rise during periods of high volatility in upstream costs and exchange rates, as well as in periods of economic expansion.

Many previous studies estimate the degree of the nonlinear pass-through for only one cost variable. However, we can consider the possibility of nonlinear pass-through for each of multiple cost variables. If the pass-through is indeed nonlinear for some of them, the econometric approach employed in the previous studies leads to a biased estimate. Moreover, most of the previous studies choose a fixed value for the threshold of the cost variable. For example, Colavecchio and Rubene (2020) set the threshold for changes in the exchange rate to be one standard deviation of the changes during the estimation sample period. However, the existence and levels of thresholds are unknown a priori.

This paper develops a threshold model for the nonlinear pass-through of multiple cost variables in order to estimate correctly the degree of the nonlinear pass-through to inflation and proposes an econometric approach to estimate the degree of the pass-through, including thresholds for multiple cost variables. We then investigate whether a nonlinearity is present in the pass-through of cost variables (i.e., producer prices, exchange rates, and wages) to CPI inflation, using Japanese data.

Our main empirical results are threefold. First, there is a statistically significant nonlinearity in the pass-through of increases in producer prices, exchanges rates, and wages to CPI inflation. The degree of the pass-through rises significantly once the cost increases exceed their respective estimated thresholds. This implies that a rapid and large cost increase could push inflation up in a nonlinear manner through not only the large size of the cost increase itself but also the associated increase in the degree of its pass-through.

Second, our nonlinear model is superior to the linear model used in previous studies in terms of in-sample model fit and out-of-sample forecasting performance. The linear model underestimates the pass-through of an input-cost increase that exceeds the threshold while overestimating that of a smaller input-cost increase. Moreover, using a linear model to forecast inflation could underestimate the future path of inflation in the face of a rapid and large increase in input costs.

Third, the historical decomposition of the year-on-year CPI inflation rate based on our estimated nonlinear model shows that the estimated impact of nonlinear pass-through of increases in producer prices and exchange rates on inflation is often transitory, while that of wage growth tends to be persistent due to the observed higher inertia in wage growth. This empirical result suggests that if wage growth increases in the future, the nonlinear pass-through of wage growth will be one of the most important issues for future developments in CPI inflation after the nonlinear pass-through of producer prices and exchange rates emerged in 2022.

The remainder of the paper is organized as follows. Section 2 describes our econometric approach and data for the nonlinear pass-through. Section 3 presents the empirical results of the nonlinear input-cost pass-through to CPI inflation. Section 4 concludes.

2. Econometric approach and data

This section explains the formulation of our approach to specifying the nonlinear pass-through. Panel 2 shows an illustration of our threshold model. A standard linear model assumes that the degree of the pass-through is constant, not depending on the magnitude of increases in a cost variable. By contrast, following previous studies such as Colavecchio and Rubene (2020) among others, our nonlinear model addresses the possibility that the degree of the pass-through rises once the increase in the cost variable exceeds its threshold as the cost-push pressure to inflation is kinked upward above the threshold. Our baseline model assumes that the nonlinearity of the pass-through emerges only for increases in cost variables. As a part of robustness checks, we consider both nonlinearities for increases and decreases in cost variables, setting not only an upper threshold but also a lower threshold below which the pass-through can vary in a nonlinear manner.

2-1. Econometric model

We consider the following threshold regression model:

$$y_t = c + \sum_{i=1}^{k} \beta_i \cdot x_{i,t-h} + \sum_{i=1}^{k} \gamma_i \cdot (x_{i,t-h} \cdot I[x_{i,t-h} > d_i \sigma_i]) + \varepsilon_t \tag{1}$$

where y_t is the year-on-year change in the CPI as the dependent variable. The explanatory variables $x_{i,t-h}$ are the year-on-year growth rates of firms' input costs and the level of economic slack in the economy.[2] $I[\cdot]$ is the indicator function that takes a value of 1 if the condition specified in the brackets $[\cdot]$ is satisfied, otherwise a value of 0. σ_i is the standard

[2] When we run the regression, we standardize each explanatory variable by the mean and variance within the sample period. The coefficients excluding the constant term are re-scaled to the variation before standardization in the estimation result in Section 3.

deviation of the i-th explanatory variable (x_{it}) within the sample period.

The second term on the right-hand side of Eq. (1) accounts for the traditional linear pass-through. The third term captures the additional pass-through emerging when the growth rate of the i-th cost variable exceeds its threshold $(d_i\sigma_i)$. Thus, the degree of the pass-through is β_i when the growth rate of the cost variable is below the threshold, and changes to $(\beta_i + \gamma_i)$ when the growth rate is above the threshold. If γ_i is statistically significant from zero, therefore, it implies the existence of a nonlinear pass-through for increases in the cost variable. As in the third term, the threshold is defined as $d_i\sigma_i$, which is the standard deviation of each cost variable mupltipled by d_i. This set-up enables us to easily define the range of thresholds for multiple variables, each of which has a different variance. Our estimated d_i measures the thresholds in units of the standard deviations (σ_i).

Most previous studies using the threshold models described above set pre-determined levels for the thresholds. For example, Colavecchio and Rubne (2020), who study the exchange-rate pass-through in the euro area, estimate the model by assuming that the degree of the pass-through rises when the magnitude of the currency appreciation or depreciation is larger than one standard deviation of the variable. This assumption is equivalent to imposing a restriction that $d_i = 1$ in Eq. (1). Our study refrains from these pre-arranged thresholds and instead simultaneously estimates both the coefficients and the unknown levels thresholds. Specifically, under a reasonable assumption that d_i lies within the range from 0.5 to 2.0, we estimate the thresholds based on a grid search with a step size of 0.1, ($d_i = 0.5, 0.6, \ldots, 2.0$), and select the one that minimizes the root-mean-squared errors (RMSE).[3] We set the upper bound value of d_i equal to 2.0, considering that because we have few samples in which increases in the cost variables are larger than two standard deviations, the estimation would become unstable when the thereholds are over two standard deviations.

Our approach is closely related to Caselli and Roitman (2019) in that these authors estimate a threshold level to investigate the nonlinear exchange-rate pass-through for emerging economies. Their study uses a grid-search approach to estimate the threshold by searching across the range of the currency deprecitiaon from 1% to 50% year-on-year growth rate with a step size of 1%, and chooses the one that maximizes the likelihood. However, their analysis does not consider cost variables other than exchange rates, which could lead to a biased estimate. In contrast, our paper employs the nonlinearities for multiple cost variables and estimates the model.

---

[3] Hansen (2000) and Donayre et al. (2018) discuss in detail the threshold models and the grid-search approach to estimate the threshold.

We address two caveats concerning our estimation model. First, we assume the pass-through and thresholds are time-invariant throughout the sample period. That is, we assume that no structural break exists regarding the pass-through. The length of the sample period in our empirical analysis is about 30 years. A structural break could occur in such a relatively long period. Previous studies on the pass-through to Japanese CPI inflation have pointed to the possibility of structural breaks (Otani et al., 2003; Shioji et al., 2007; Hara et al., 2015). However, incorportaing the possibility of both nonlinear pass-through and structural break into a single estimation model will leave an insufficient degrees of freedom to estimate. Therefore, we focus only on the nonlinearity of pass-through and assume that the model structure is time-invariant over the sample period.

Second, our model does not take inflation inertia into account. Several previous studies, such as Forbes et al. (2022), include the lagged CPI inflation rate as one of explanatory variables to address inflation persistence in an empirical model of CPI inflation. By contrast, we follow previous research, including Colavecchio and Rubene (2020), and do not include the lagged dependent variable in the right-hand side of Eq. (1). This specification implies that the current rate of inflation is not explicitly influenced by its past rate. Compared to the predicted value from a model that incorporates inflation inertia, our model yields a dynamics in which CPI inflation rises more rapidly in periods when cost-push pressure increases and falls more rapidly when it weakens.

One theoretical hypothesis underlying the nonlinearity of the pass-through from the cost variables to CPI inflation is the menu cost in firms' price adjustments (Ball and Mankiw, 1994).[4] Firms raise their selling prices only when increases in their costs are too large to absorb, while they keep prices unchanged in response to a small cost increase because the benefit from price adjustments is smaller than the menu cost.

2-2. Data

This section describes the data used in our empirical analysis. For the dependent variable, we use the year-on-year rate of change in the CPI (less fresh food) and that in the CPI (less fresh food and energy), which are plotted in Panel 1.[5] We also use the disaggregated series of the CPI to examine the nonlinear pass-through for each item. Specifically, we employ the price changes of 19 categories, based on the classification by the Ministry of Internal Affairs

---

[4] Menu costs are a metaphorical idea that includes both explicit costs, such as changing price tags and menu lists, and implicit costs, such as costs for price negotiations.

[5] The CPI figures are the 2020-base series and exclude the effects of the consumption tax hikes.

and Communications.[6] Regarding wage growth, we use the average hourly wage, which is the index of "contractual cash earnings" (establishments with 30 or more employees, all industries) divided by the index of "total hours worked." We also use the year-on-year growth rates of the Corporate Goods Price Index and the exchange rate (U.S. dollar/yen), and the unemployment rate as a proxy variable for slack in the economy.[7] Panel 3 plots the time series of these variables.

We prepare two estimation periods, (i) from 1976:Q1 to 1999:Q4 and (ii) from 1991:Q1 to 2019:Q4, to analyze changes in the parameter estimates between these two periods. For the former period, we start our estimation from 1976 to obtain a stable estimation result by excluding the first oil shock, which was accompanied by a significant increase in CPI inflation and producer prices. For the latter, the end of our sample period is set in 2019:Q4, to exclude large fluctuations in each variable amid the COVID-19 pandemic.

We choose the lag length (h) for our explanatory variables in Eq. (1), as selecting the one that maximizes in-sample fit with respect to AIC, from $h = 1, \ldots, 4$. The models with 1-quarter and 2-quarter lags are selected for the CPI (less fresh food) and the CPI (less fresh food and energy), respectively.

3. Estimation results

3-1. Results in the baseline model

As a baseline model, we use the CPI inflation (less fresh food and energy) as the dependent variable with three explanatory variables, specifically the year-on-year growth rates of producer prices, exchange rates, and wages. We also compare the results from our nonlinear model with those of a linear model, which omits the third term in the right-hand side of Eq. (1), to capture the nonlinear pass-through.

Panel 4 shows the estimation results for our baseline model.[8] The coefficients that represent the nonlinear pass-through of producer prices, exchange rates, and wages are

---

[6] We follow Takahashi and Tamanyu (2022) in classifying the CPI basket into 20 disaggregated categories and follow Kishaba and Okuda (2023) in excluding prices related to "house rent," which are presumably influenced by factors unrelated to economic activity. We augment data for "meals outside home" included in the "public services" before 2015 with the price series of "school lunch."

[7] The output gap, released by the Bank of Japan, is often used as a slack variable in the real economy. We employ the unemployment rate instead, because the series of the output gap starts from the year 1983, which would make it impossible for us to estimate the pass-through back to the 1970s. Although the precise slack variable should be the unemployment gap, we did not adopt it due to model uncertainty of the natural rate of unemployment.

[8] Details of the estimation results are reported in Appendix Panel 1.

positive and statistically significant at the 5% level. This result implies that the degree of the pass-through rises once the growth rates of the cost variables exceed their respective estimated thresholds. Comparing the results with the standard linear model, we find that the coefficients of the linear model are larger than the coefficients of "below the threshold" in the nonlinear model, and also smaller than those of the "above threshold (total)," which is the sum of the pass-through "below threshold" and "additional pass-through." Thus, a linear model estimating the pass-through that fails to take into account its possible nonlinearity, can underestimate the degree of the pass-through of an input-cost increase that exceeds its threshold while overestimating that of a smaller input-cost increase. This finding suggests the linear model possibly underestimates the future path of inflation when cost-push pressures are significantly large.

Next, we compare the pass-through in the nonlinear model for the two sample periods. The estimated pass-through of wages between 1991 and 2019 is lower than that between 1976 and 1999, while that of exchange rates between 1991 and 2019 is slightly higher than that between 1976 and 1999. The pass-through from producer prices does not exhibit a major change.[9] In addition, the constant term between 1991 and 2019, which represents the average CPI inflation rate that is achieved when all the explanatory variables grow at their average year-on-year changes over the estimation period, declined from that between 1976 and 1999. This result presumably captures the price-setting behavior of "not changing the price tag," often referred to as the "norm," which is currently observed in tandem with the decline in the inflation rate.

Panel 5 shows the estimated thresholds between 1991 and 2019. The estimate of d_i is 0.8, 1.5, and 1.2 for producer prices, exchange rates and wages, respectively.[10] As of 2022:Q4, the year-on-year growth rates of producer prices and exchange rates have stayed above the estimated thresholds, indicating that the nonlinear pass-through contributes to a

[9] Yagi et al. (2022), using Japanese data until the end of the year 2021, point out that the pass-through rate of raw material and other costs, excluding those attributable to the exchange rate, has not made a significant change at the final demand stage. They make an additional point that the pass-through rate of raw material has increased somewhat at the intermediate demand stage and even for some items at the final demand stage. Our study focuses on the pass-through to CPI inflation, i.e. the final demand stage, and we leave the analysis from the production stage perspective for future research. It should be repeated that the current paper uses data until the end of the year 2019 to exclude large fluctuations in each variable amid the global outbreak of COVID-19.

[10] We should note that the period when the wage growth exceeded the estimated threshold is mostly limited to the early 1990s. Despite our assumption mentioned in the section 2.1 that the model structure is time-invariant over the sample period, there is a possibility of structural breaks after the early 1990s. Thus, it remains uncertain whether the pass-through of wage growth will materialize in the coming years as it emerged in the early 1990s, even when wage growth exceeds the estimated threshold.

higher CPI inflation. On the other hand, the year-on-year growth rate of wages remains below the estimated threshold, which implies that the positive impact of wages on CPI inflation is still limited.

3-2. Model comparison

The upper figure of Panel 6 shows the historical decomposition of the CPI inflation (less fresh food and energy) based on our nonlinear model estimated for the 1991–2019 period. For the out-of-sample period 2020–2022, we extrapolate the values of CPI inflation up to 2022:Q4 based on the nonlinear model estimated with the actual value of each explanatory variable. The figure shows that the nonlinear pass-through captures the positive impact of the surge in global commodity prices on the CPI inflation for the period before the Global Financial Crisis and the similar impact of the yen's depreciation for the period after the introduction of the Quantitative and Qualitative Monetary Easing policy by the Bank of Japan. We note that, on the one hand, the duration of the nonlinear pass-through effects from producer prices and exchange rates lasts for approximately one to two years, while on the other hand, the impact of wages on CPI inflation contributed persistently as an upward pressure on prices in the first half of the 1990s. Since the 2000s, the sluggish growth of wages turned to mainly exert downward pressures on prices. These results imply that the estimated nonlinear pass-through of increases in producer prices and exchange rates is often transitory, while that of wage growth tends to be persistent due to the observed higher inertia in wage growth.

The lower figure of Panel 6 shows the historical decomposition based on the linear model. The value predicted by the linear model does not track the surges of CPI inflation in 2008–2009 or 2013–2014 as well as the forecast based on the nonlinear model, even though the contribution of the pass-through from producer prices and exchange rates in the linear model is larger. When we compare the forecasts of these two models for the year 2022, we find that the forecast of the nonlinear model tracks effectively the surge in the CPI inflation with the contribution of the nonlinear part of the model, while the forecast of the linear model is lower than the realized value as it does not take nonlinearity into consideration.

Next, we conduct a model comparison between nonlinear and linear models in terms of model fit and forecasting accuracy. We use the AIC and RMSE as the criteria of in-sample fit and out-of-sample accuracy, respectively. Panel 7 shows that the nonlinear model is superior to the linear model for both criteria.[11] In evaluating the forecast accuracy, it would

[11] It should be noted from Panel 6 that a linear model sometimes yields a superior fit for periods such as

be desirable to remove temporary policy factors from our dependent variable. The panel also shows that the results of model performance remain the same when we change the dependent variable to the Bank of Japan's staff estimates of CPI inflation less fresh food, energy, the effects of policies concerning the provision of free education, travel subsidy programs and mobile phone charges.

3-3. Robustness checks

This section conducts robustness checks of the baseline results. First, we examine our model by changing the dependent variable to the CPI inflation (less fresh food). We use the same three explanatory variables as the baseline model. Panel 8 confirms that a statistically significant nonlinearity exists for the cost variables, and Panel 9 shows that the estimated thresholds are at approximately the same level as in the baseline result.[12]

Second, we add the unemployment rate to the explanatory variables of the baseline model as a proxy for slack in the economy. Its estimation result is shown in Panel 10. We find that the nonlinear impact on CPI inflation is statistically significant in both the cost and slack variables.[13] This result implies that the positive impact on CPI inflation increases in a nonlinear manner when aggregate demand improves sufficiently enough for the unemployment rate to fall below the estimated threshold. In this extended model, however, given the high correlation between firms' input costs and slack variables, we should be cautious in interpreting the estimated values of coefficients. It would make the interpretation clearer to obtain the coefficient by including identified demand and supply shocks with respect to the firms' cost variables in the set of independent variables. We leave this for future research.

Third, we extend the nonlinear estimation by adding both upper and lower thresholds. Specifically, we estimate the following equation:

---

the year 2009-2011.

[12] Details of the estimation results are reported in Appendix Panel 2.

[13] Details of the estimation results are reported in Appendix Panel 3.

$$y_t = c + \sum_{i=1}^{k} \beta_i \cdot x_{i,t-h} + \sum_{i=1}^{k} \gamma_i \cdot (x_{i,t-h} \cdot I[x_{i,t-h} > d_i^U \sigma_i]) + \sum_{i=1}^{k} \delta_i \cdot (x_{i,t-h} \cdot I[x_{i,t-h} < d_i^L \sigma_i]) + \varepsilon_t \quad (2)$$

In this equation, d_i^L and d_i^U are the lower and upper thresholds, respectively. Under a reasonable assumption that they lie within the range from -1.5 to -0.5, and from 0.5 to 1.5, respectively, we estimate these unknown thresholds by a grid-search with a step size of 0.1, along with the pass-through coefficients.

Panel 11 shows the estimation results of Eq. (2).[14] While the results for the upward nonlinearity of the pass-through are almost the same as the baseline results, the coefficient (δ_i), which represents the downward nonlinearity of the pass-through, is not statistically significant at the 5% level. This indicates that a large decline in firms' input costs may not necessarily lead to a large, nonlinear reduction in prices.

Finally, we examine the nonlinearity of the pass-through for each of the items that constitute the total CPI basket. We estimate Eq. (1), using the year-on-year inflation rate of individual CPI items as the dependent variable and the same set of three cost variables as the baseline specification. Note that we use the economy-wide series of producer prices and wages for simplicity, not the ones that take into account input-output structures of production for each item. Panel 12 shows the estimation result for each item. The panel highlights the items whose coefficient of the nonlinear pass-through is positive and statistically significant at the 1% level.

The items associated with nonlinear pass-through for producer prices and exchange rates include "food products," "other industrial products" (including household appliances), and "eating out services." Prices of these goods and services have been raised due to the surge in global commodity prices and the yen's depreciation in 2022. The items with nonlinear pass-through for wages include a good part of "general services," which are relatively labor-intensive industries.

[14] Details of the estimation results are reported in Appendix Panel 4.

4. Concluding remarks

We have examined a possible nonlinearity in the pass-through to CPI inflation of increases in firms' input costs. We have obtained three main empirical results. First, there is a statistically significant nonlinearity in that the pass-through to CPI inflation of increases in producer prices, exchange rates, and wages rises once the increase in each of these variables exceeds a certain threshold. Second, our nonlinear model is superior to the linear model used in previous studies in terms of in-sample model fit and out-of-sample forecasting performance, suggesting that the linear model underestimates the pass-through of an input-cost increase that exceeds the threshold while overestimating that of a smaller input-cost increase. Third, the estimated impact of nonlinear pass-through of increases in producer prices and exchange rates to inflation is often transitory, whereas that of wage growth tends to be persistent due to the observed higher inertia in wage growth. These results suggest that wage growth is one of the key factors in achieving the Bank of Japan's "price stability target" in a sustainable and stable manner.

Finally, we raise three issues for future research. First, the nonlinear input-cost pass-through is related to important questions of whether the Phillips curve has flattened and whether a substantial improvement in the output gap could possibly push inflation up in a nonlinear manner (Hooper et al., 2020). Forbes et al. (2022) provide an empirical analysis for the nonlinearity of the Phillips curve. We leave these questions to future research, because this paper does not estimate the Phillips curve since our estimation does not include inflation expectations as an explanatory variable. Second, a strand of theoretical and empirical research on how prices and wages synchronize is yet to be fully developed (Lorenzoni and Werning, 2023), which would be an interesting agenda for future research. Third, our empirical model does not take into account either the possibility of structural breaks or the effect of inflation inertia. Since 2022, moves towards raising selling prices have been spreading among many business types and firms that were previously cautious about changing prices (Ikeda et al., 2023). Thus, firms' price-setting behavior might have become more proactive than observed in our estimation period. In addition, sustained growth in prices and wages might raise inflation expectations and promote a gradual change in the price- and wage-setting behavior of firms. It would be valuable to construct a theoretical and empirical model that addresses these changes.

References

Ball, L., and N. Mankiw (1994), "Asymmetric price adjustment and economic fluctuations," *Economic Journal*, 104, pp. 247–261.

Bank for International Settlements (2022), *Annual Economic Report 2022*.

Ben Cheikh, N., Y. Ben Zaied, H. Bouzgarrou, and P. Nguyen (2018), "Nonlinear exchange rate pass-through: Does business cycle matter?" *Journal of Economic Integration*, 33(2), pp. 1234–1261.

Borio, C., M. Lombardi, J. Yetman, and E. Zakrajšek (2023), "The two-regime view of inflation," BIS Papers, No. 133.

Campa, J. M., and L. S. Goldberg (2005), "Exchange rate pass-through into import prices," *Review of Economics and Statistics*, 87(4), pp. 679–690.

Caselli, F., and A. Roitman (2019), "Nonlinear exchange-rate pass-through in emerging markets," *International Finance*, 22, pp. 279–306.

Colavecchio, R., and I. Rubene (2020), "Non-linear exchange rate pass-through to euro area inflation: A local projection approach," ECB Working Paper, No. 2362.

Donayre, L., Y. Eo, and J. Morley (2018), "Improving likelihood-ratio-based confidence intervals for threshold parameters in finite samples," *Studies in Nonlinear Dynamics & Econometrics*, 22, 1, pp.1–11.

Forbes, K., J. Gagnon, and C. Collins (2022), "Low inflation bends the Phillips curve around the world," *Economia*, 45, pp. 52–72.

Gopinath, Gita (2023), "Crisis and monetary policy," *Finance and Development*, March 2023.

Hansen, B. E. (2000), "Sample splitting and threshold estimation," *Econometrica*, 68, pp. 575–603.

Hara, N., K. Hiraki, and Y. Ichise (2015), "Changing exchange rate pass-through in Japan: Does it indicate changing pricing behavior?" Bank of Japan Working Paper Series, No. 15-E-4.

Hooper, P., F. Mishkin, and A. Sufi (2020), "Prospects for inflation in a high pressure economy: Is the Phillips curve dead or is it just hibernating?" *Research in Economics*, 74, pp. 26–62.

Ikeda, S., and T. Kondo, Y. Kurachi, T. Matsuda, and T. Yagi (2023), "Firms' recent price-setting stance: Evidence from the *Tankan*," Bank of Japan Review, No.2023-E-2.

Kishaba, Y. and T. Okuda (2023), "The slope of the Phillips curve for service prices in Japan: Regional panel data approach," Bank of Japan Working Paper Series, No.23-E-8.

Lorenzoni, G., and I. Werning (2023), "Wage price spirals," Manuscript.

Otani, A., S. Shiratsuka, and T. Shirota (2003), "The decline in the exchange rate pass-through: Evidence from Japanese import prices," Monetary and Economic Studies, 21, 3, pp. 53-81.

Shintani, M., A. Terada-Hagiwara, and T. Yabu (2013), "Exchange rate pass-through and inflation: A nonlinear time series analysis," *Journal of International Money and Finance*, 32, pp. 512–527.

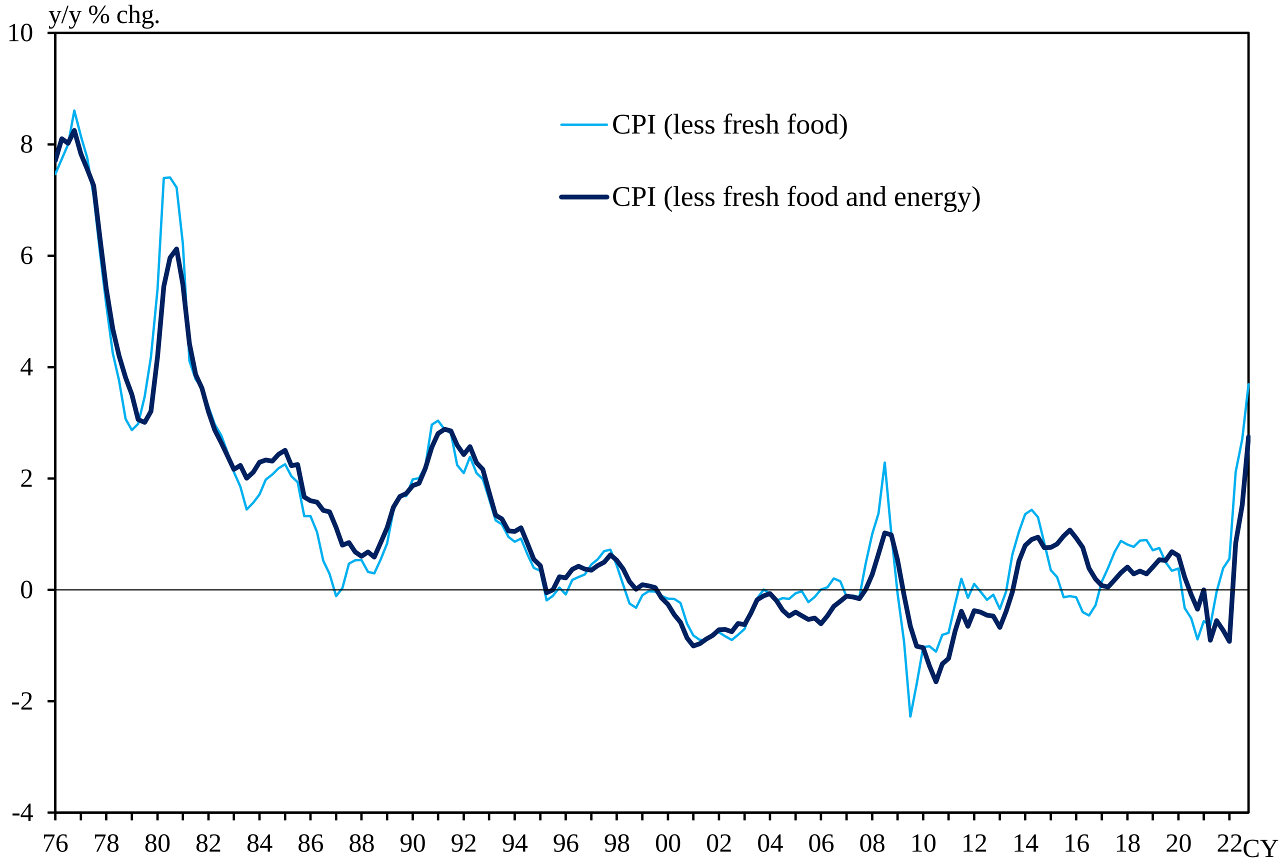
Shioji, E., V. T. Khai, and H. Takeuchi (2007), "Macroeconomic implications of declines in nominal exchange rate pass-through rates," RIETI Discussion Papers, 07-J-024.

Takahashi, Y., and Y. Tamanyu (2022), "Households' perceived inflation and CPI inflation: the case of Japan," Bank of Japan Working Paper Series, No. 22-E-1.

Taylor, J. B. (2000), "Low inflation, pass-through, and the pricing power of firms," *European Economic Review*, 44, pp. 1389–1408.

Yagi, T., Y. Kurachi, M. Takahashi, K. Yamada, and H. Kawata (2022), "Pass-through of cost-push pressures to consumer prices," Bank of Japan Working Paper Series, No. 22-E-17.

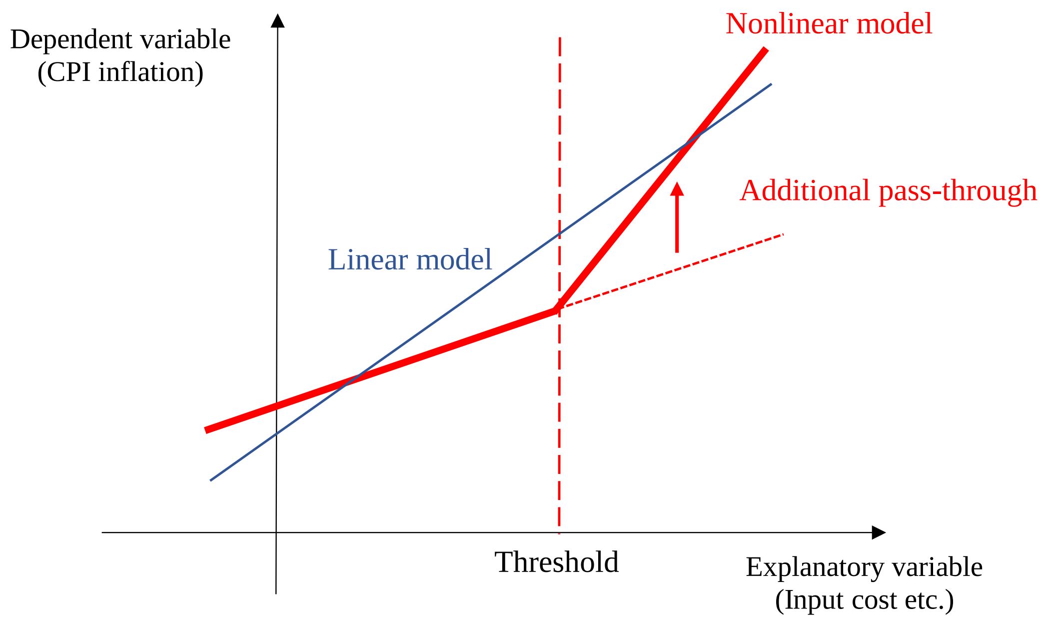
Panel 1: Consumer Price Index (CPI) Inflation



Note: The CPI figures are calculated as the log differences of the seasonally adjusted 2020-base series and exclude the effects of the consumption tax hikes.

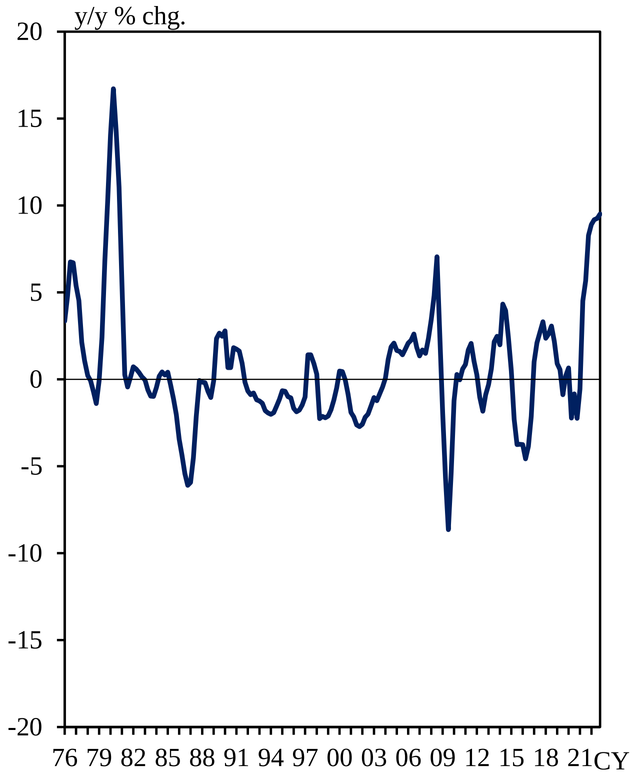
Sources: Ministry of Internal Affairs and Communications; Bank of Japan

Panel 2: Nonlinear Pass-through

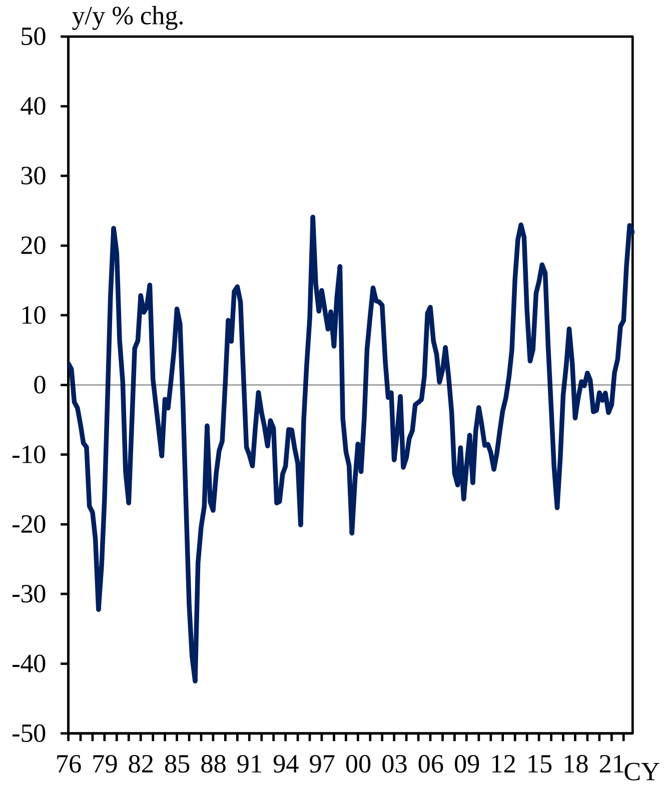


Panel 3: Data

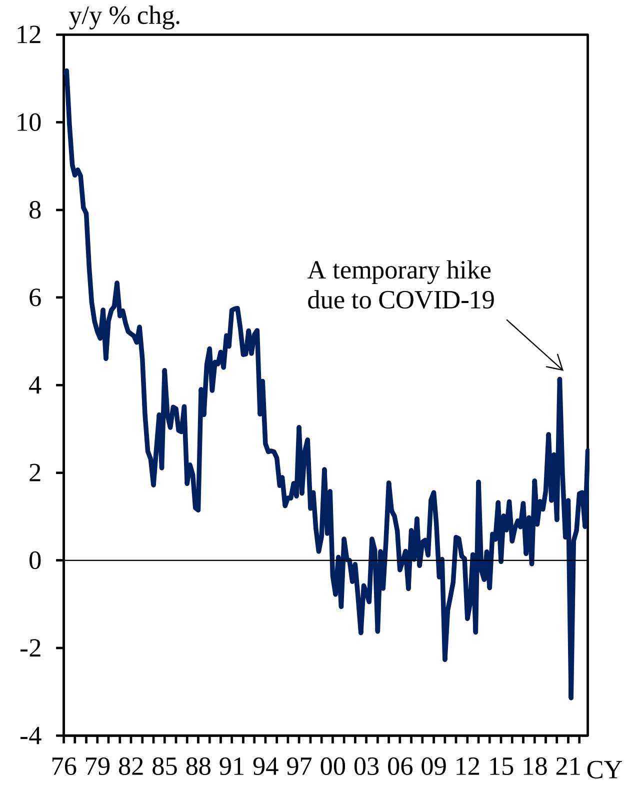
(1) Producer prices



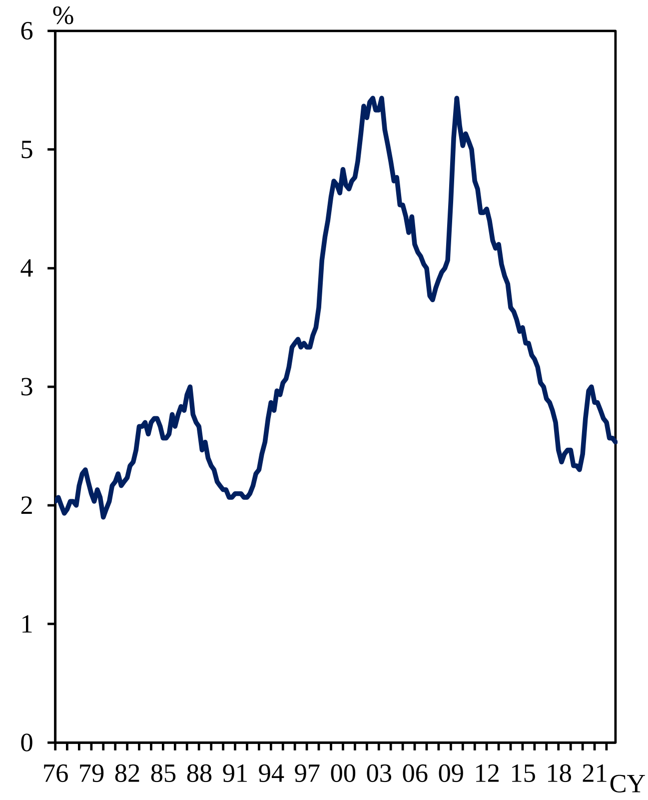
(2) Exchange rates



(3) Wages



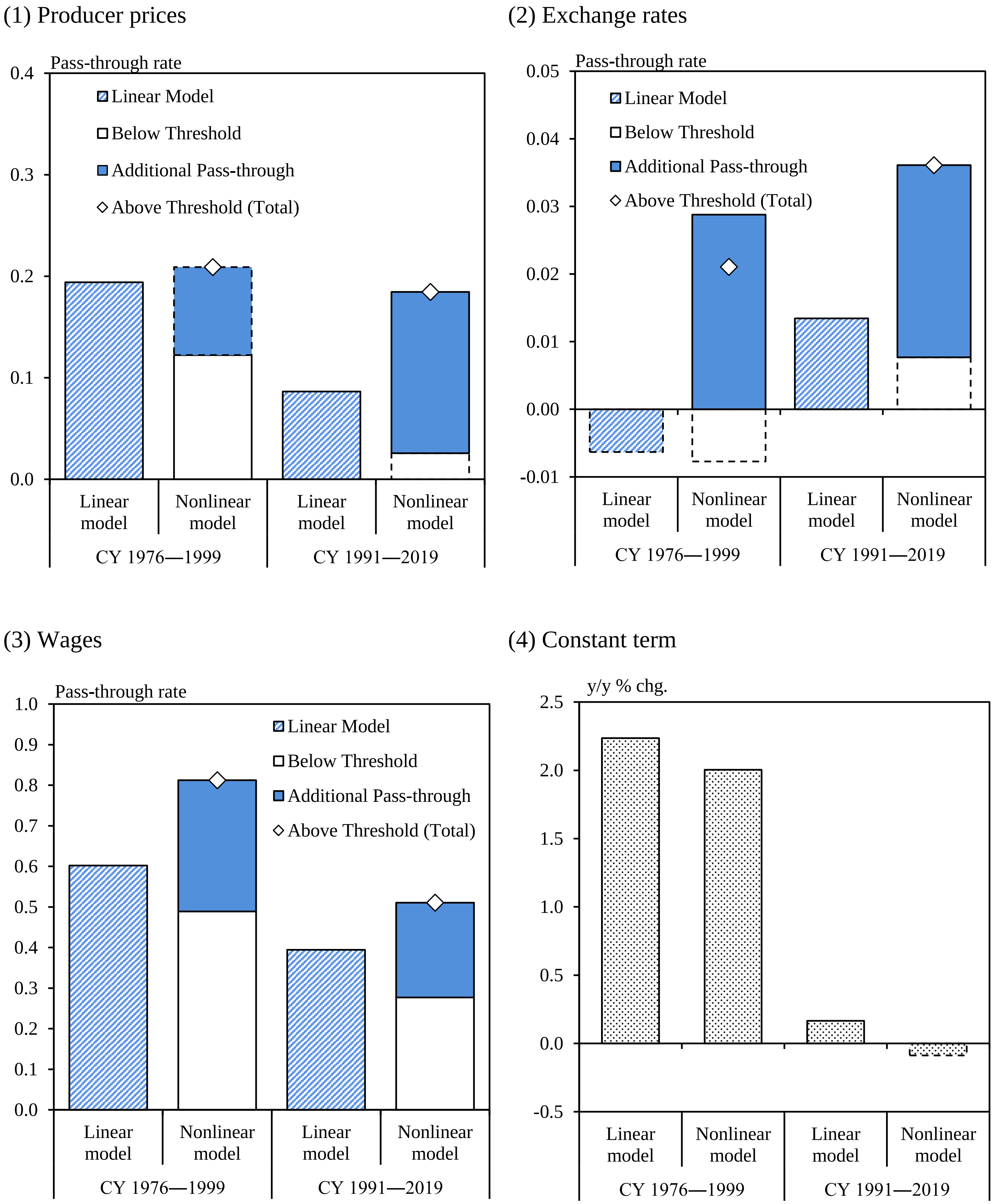
(4) Unemployment rate (economic slack)



Notes: 1. (3) is the year-on-year change in average hourly wage, calculated as contractual cash earnings divided by total hours worked.
2. (1), (2), and (3) are calculated as the log differences. (3) and (4) are seasonally adjusted.

Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 4: Estimated Coefficients for CPI Inflation (less fresh food and energy)



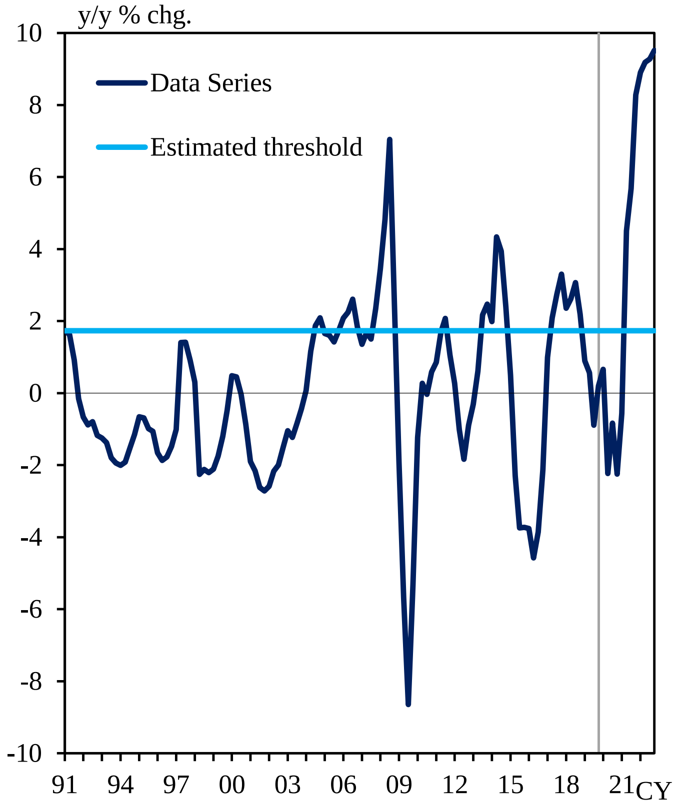
Notes: 1. The solid line indicates that the results are statistically significant at the 5% level based on Newey-West standard errors, while the broken line indicates that the result is not statistically significant.

2. "Above Threshold (Total)" indicates the sum of the pass-through "below" and "above" thresholds.

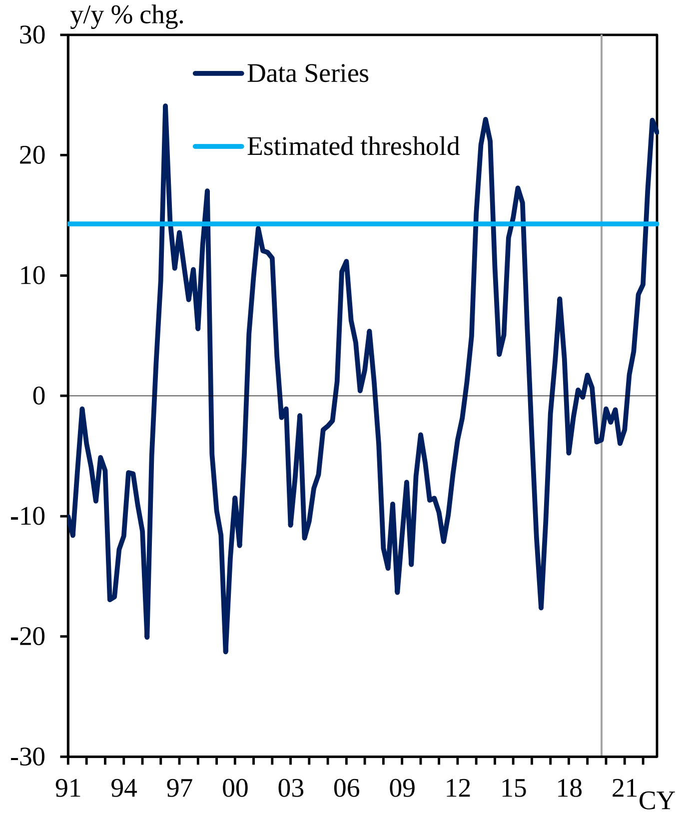
Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 5: Estimated Thresholds for CPI Inflation (less fresh food and energy)

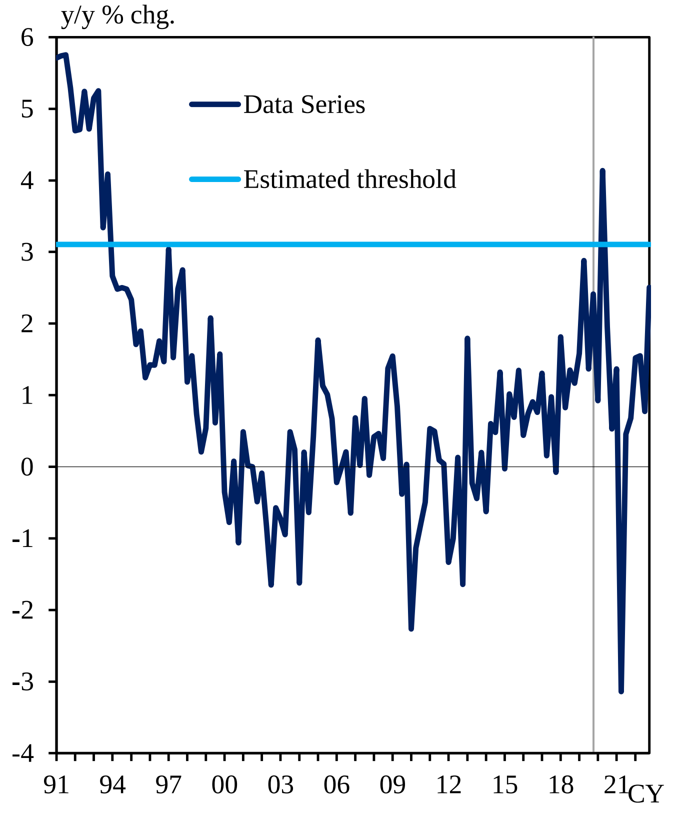
(1) Producer prices



(2) Exchange rates



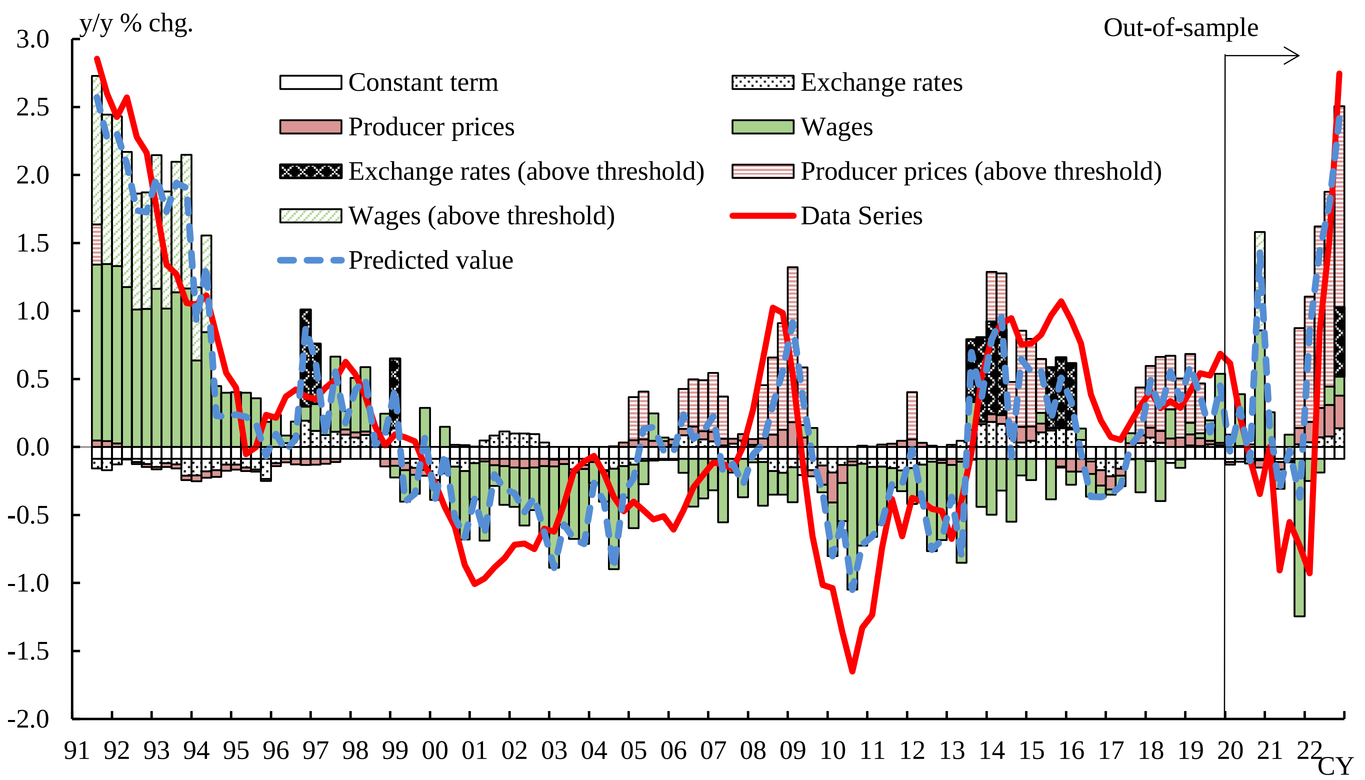
(3) Wages



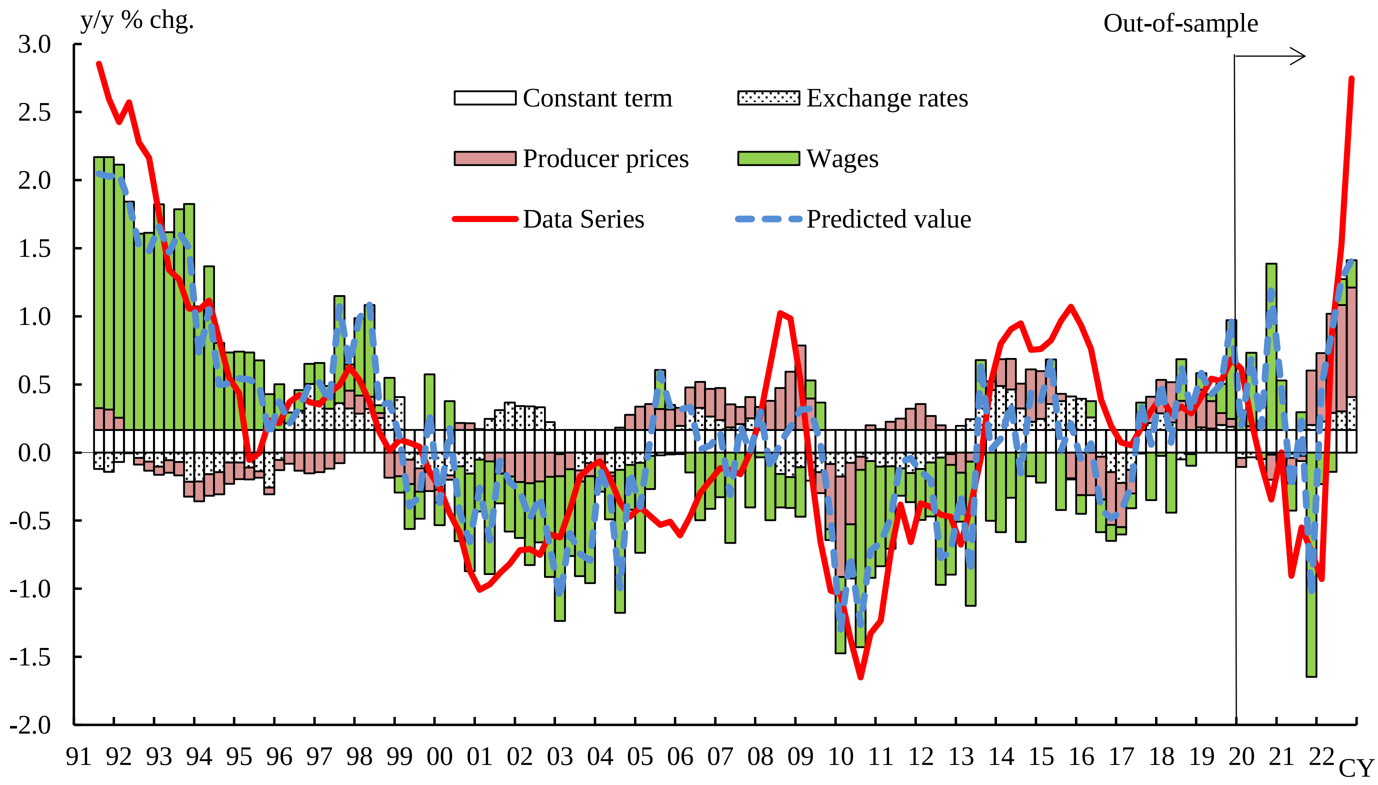
Note: The estimation period is from 1991 to 2019. The gray lines in the figures show the end of the estimation period.
Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 6: Decomposition of CPI Inflation (less fresh food and energy)

(1) Decomposition based on the nonlinear model



(2) Decomposition based on the linear model



Notes: 1. We extrapolate CPI inflation until 2022/Q4 based on our baseline model with its sample period (from 1991 to 2019).
2. We display the contribution from coefficients which are not statistically significant at the 5% level.

Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 7: Model Comparison

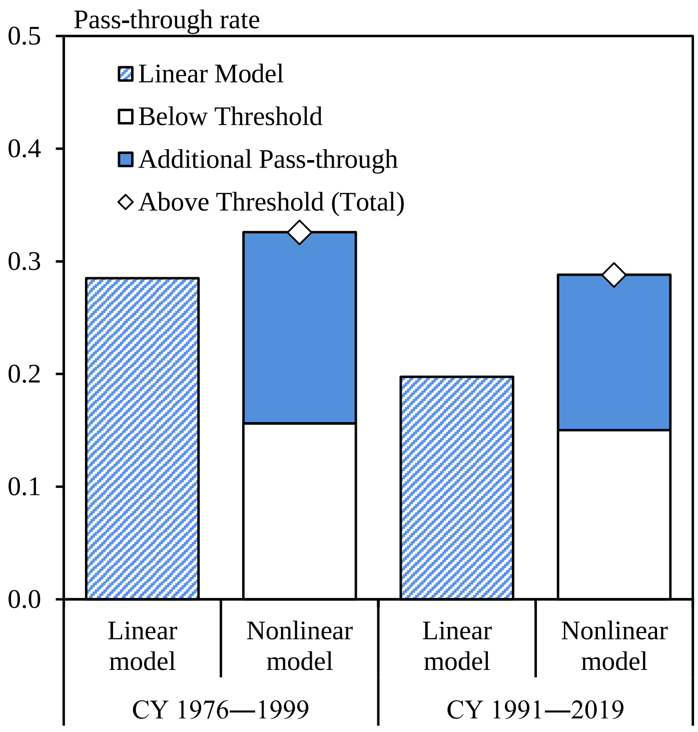
Dependent variable	Model	In-sample Fit (AIC) CY 1991 - 2019	Out-of-sample Forecasting Performance (RMSE) CY 2020 - 2022
CPI inflation (less fresh food and energy)	Nonlinear	138.7	0.820
	Linear	169.9	0.819
(Robustness check) CPI inflation (less fresh food, energy and temporary factors)	Nonlinear	148.3	0.596
	Linear	173.2	0.780

Notes: 1. The figures for CPI inflation (less fresh food, energy and temporary factors) are staff estimates and exclude the effects of policies concerning the provision of free education, travel subsidy programs and mobile phone charges.
2. The colored rows for the nonlinear model indicate that the nonlinear model is superior to the linear model.

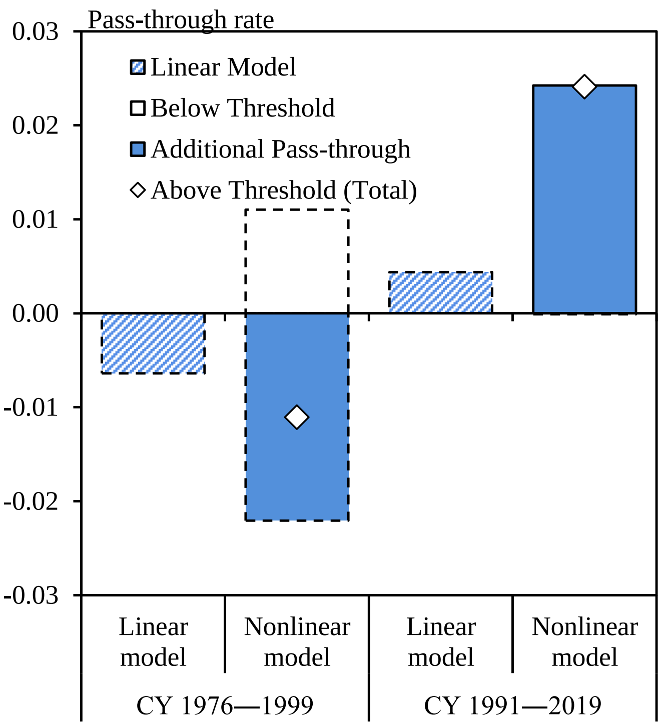
Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 8: Estimated Coefficients for CPI Inflation (less fresh food)

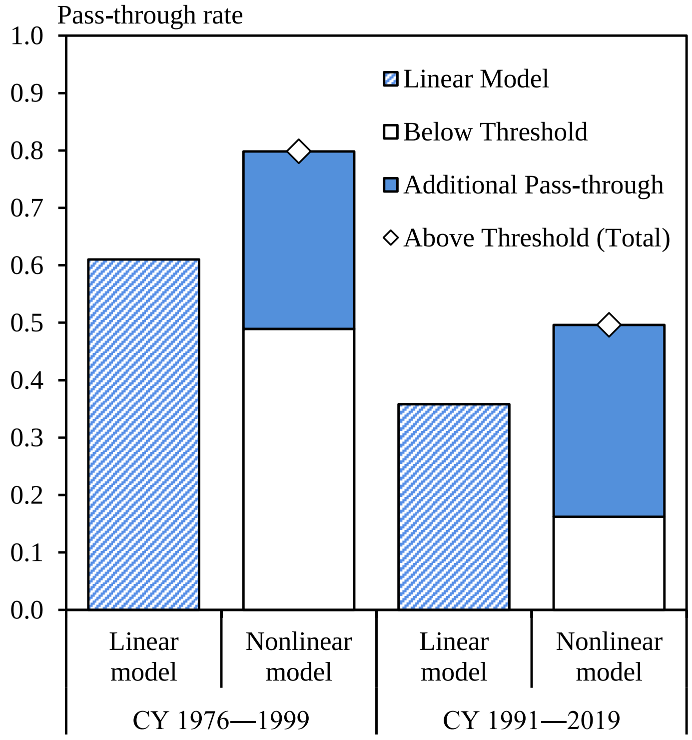
(1) Producer prices



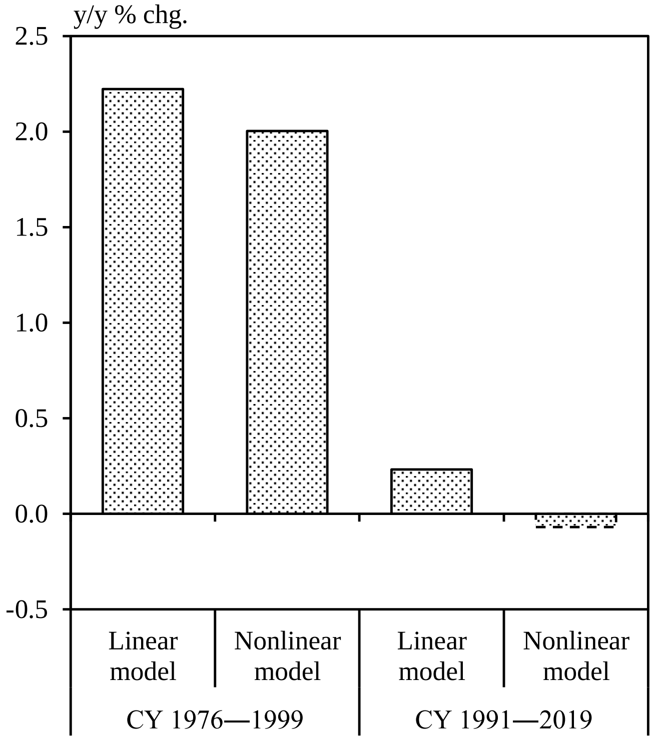
(2) Exchange rates



(3) Wages



(4) Constant term

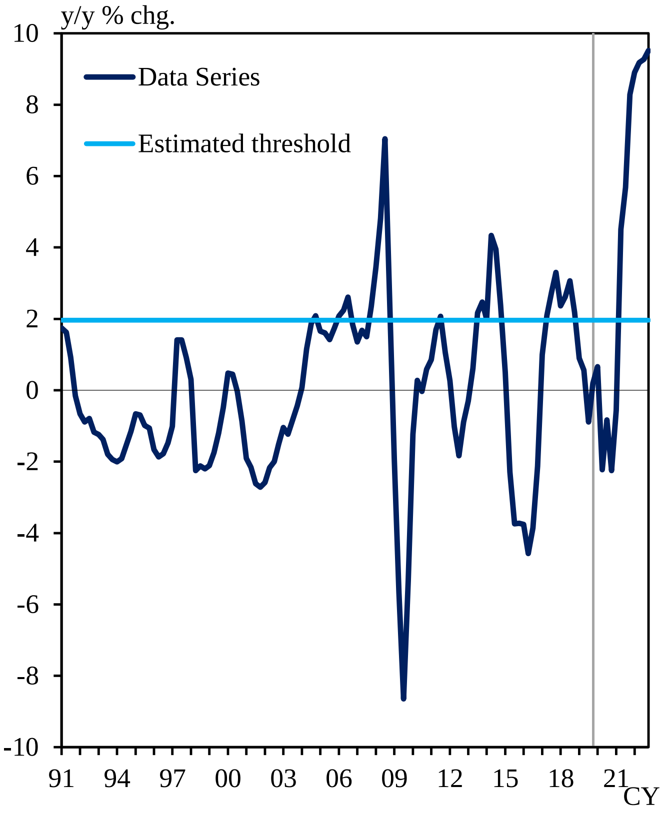


Notes: 1. The solid line indicates that the results are statistically significant at the 5% level based on Newey-West standard errors, while the broken line indicates that the result is not statistically significant.
2. "Above Threshold (Total)" indicates the sum of the pass-through "below" and "above" thresholds.

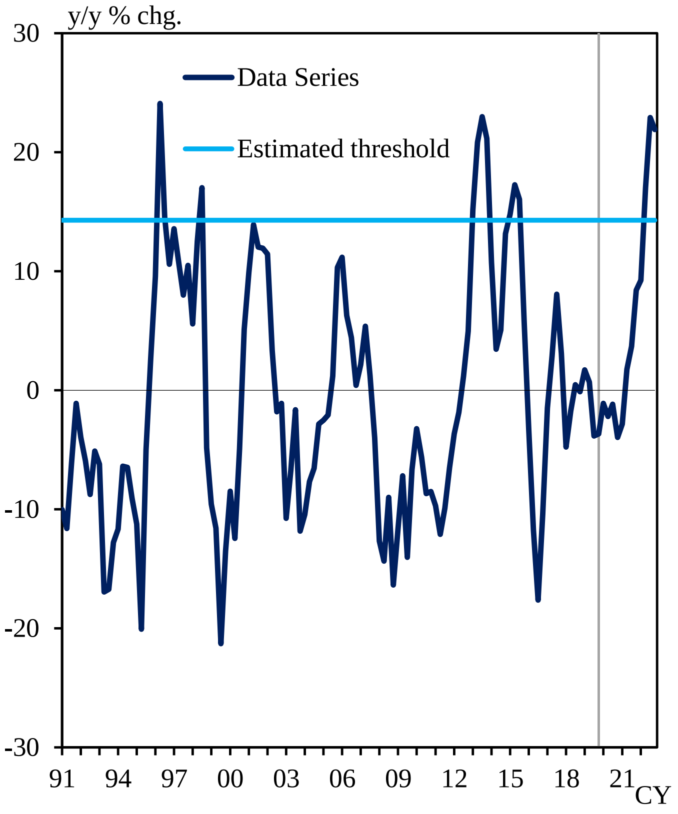
Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 9: Estimated Thresholds for CPI Inflation (less fresh food)

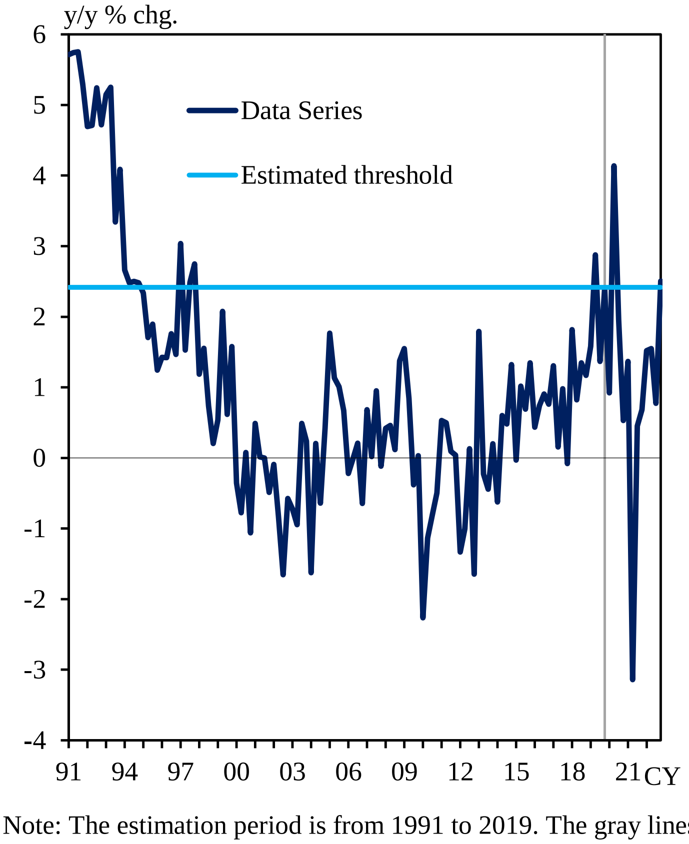
(1) Producer prices



(2) Exchange rates



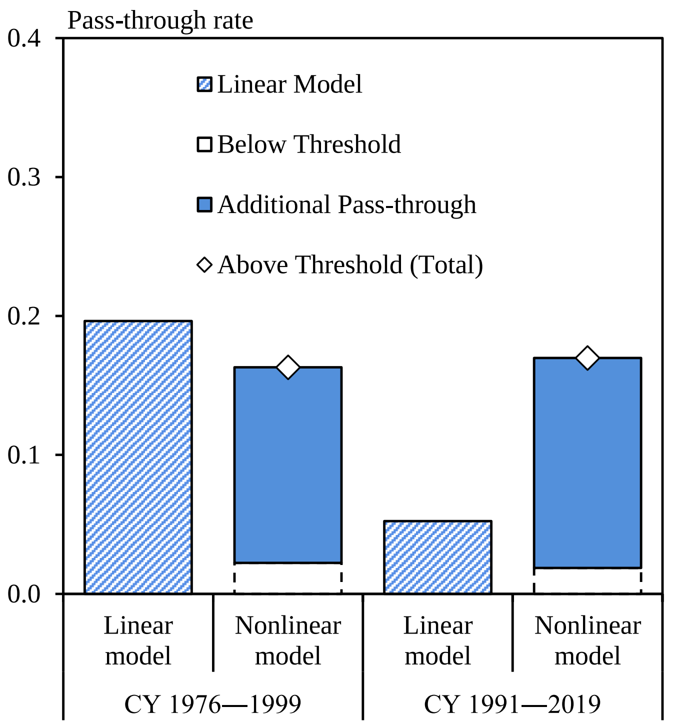
(3) Wages



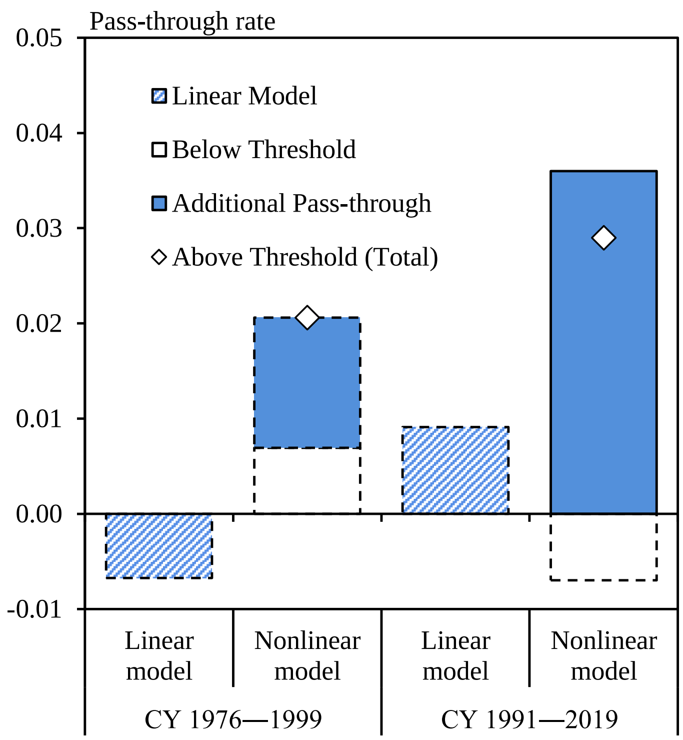
Note: The estimation period is from 1991 to 2019. The gray lines in the figures show the end of the estimation period.
Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 10: Estimated Coefficients (with Slack Variable) for CPI Inflation (less fresh food, energy)

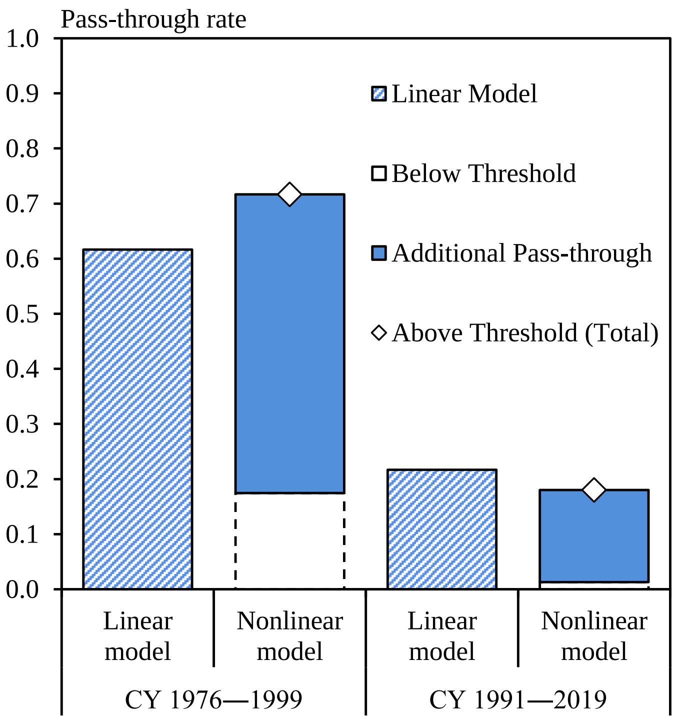
(1) Producer prices



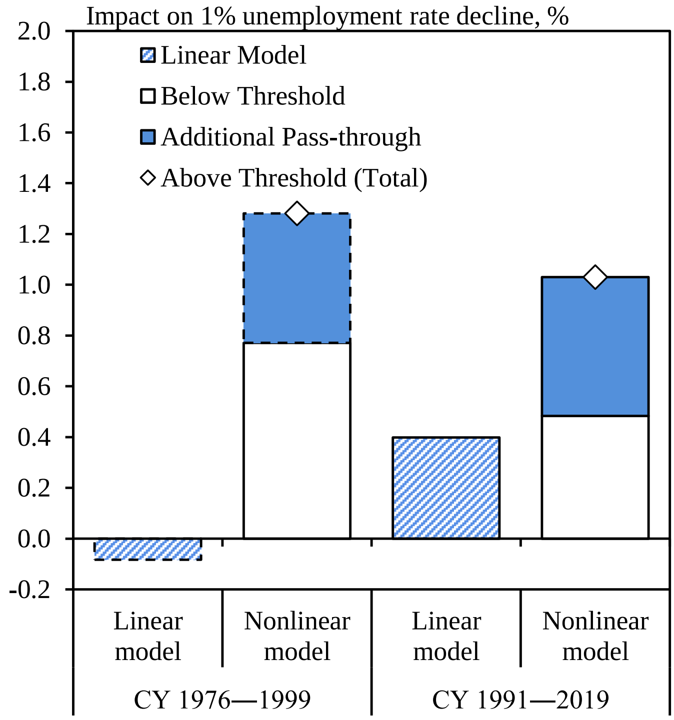
(2) Exchange rates



(3) Wages



(4) Slack (unemployment rate, sign inverted)

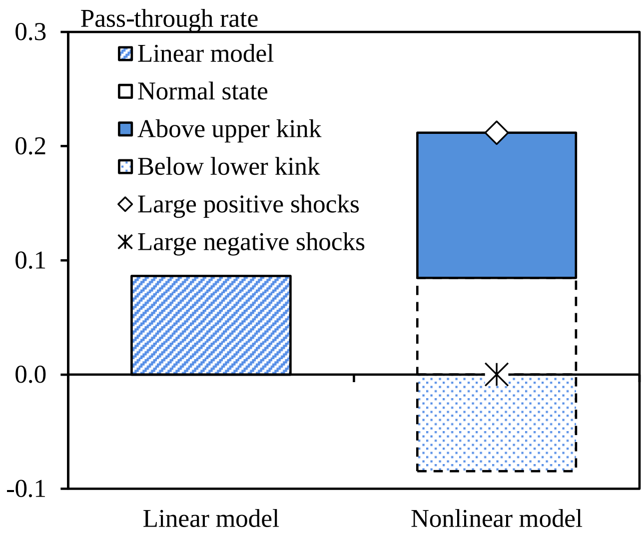


Notes: 1. The solid line indicates that the results are statistically significant at the 5% level based on Newey-West standard errors, while the broken line indicates that the result is not statistically significant.
2. "Above Threshold (Total)" indicates the sum of the pass-through "below" and "above" thresholds.

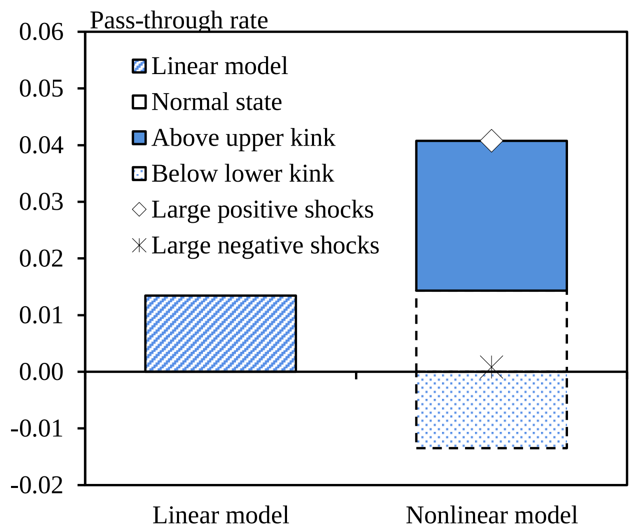
Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 11: Estimated Coefficients (with Lower Bounds) for CPI Inflation (less fresh food, energy)

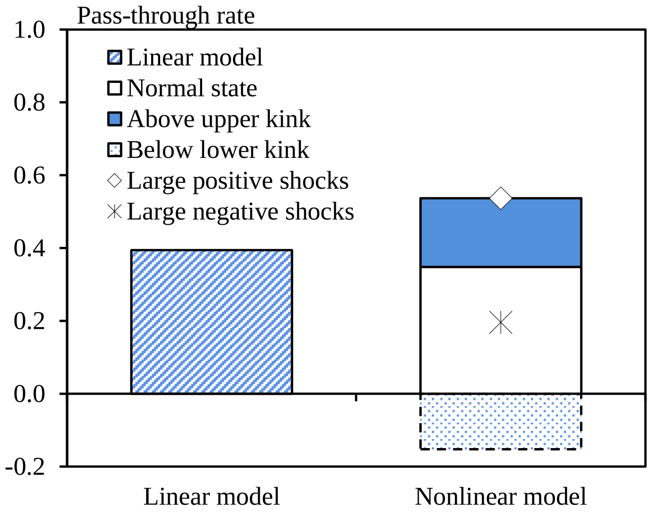
(1) Producer prices (coefficients)



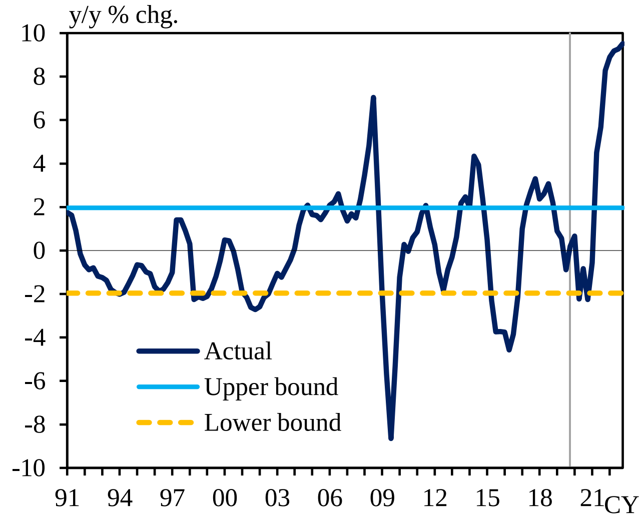
(2) Exchange rates (coefficients)



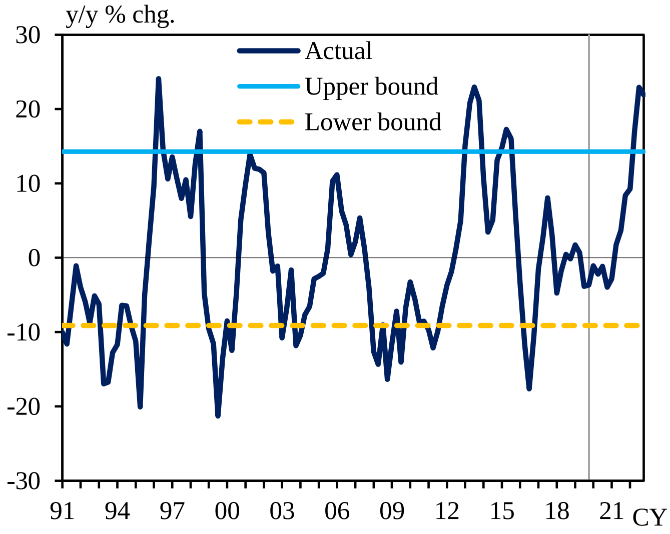
(3) Wages (coefficients)



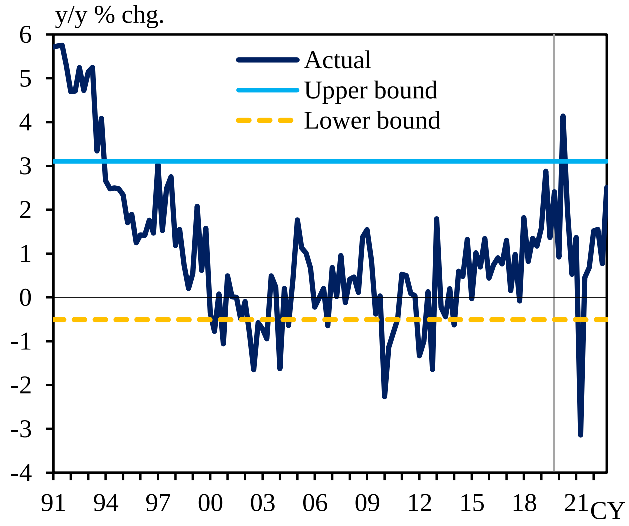
(4) Producer prices (thresholds)



(5) Exchange rates (thresholds)



(6) Wages (thresholds)



Notes: 1. The solid line indicates that the results are statistically significant at the 5% level based on Newey-West standard errors, while the broken line indicates that the result is not statistically significant.

2. "Above Threshold (Total)" indicates the sum of the pass-through "below" and "above" thresholds.

Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

Panel 12: Nonlinear Pass-through for Disaggregated Series

	Items	Explanatory variables		
		Producer prices	**Exchange rates**	**Wages**
Goods	Fresh food		✓	
	Other agricultural products			✓
	Food products	✓	✓	
	Textiles			
	Petroleum products			
	Other industrial products	✓		
	Electricity, gas, water charges			
	Publications			✓
General Services	Domestic duties	✓		✓
	Medical care and welfare			
	Education			✓
	Communication, culture, recreation		✓	✓
	Eating out	✓		✓
Public Services	Domestic duties			
	Medical care and welfare			
	Forwarding and communication			
	Education			
	Culture and recreation		✓	
	School lunch	✓	✓	

Notes 1. "✓" denotes items whose coefficients for nonlinear pass-through are positive and statistically significant at the 1% level.
2. For each individual item, we select the optimal lag length of explanatory variables based on AIC.
Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

(Appendix Panel 1)

Panels 4&5: Estimated Result for CPI Inflation (less fresh food and energy)

Model		Linear model		Nonlinear model	
Estimation period		**CY 1976-1999**	**CY 1991-2019**	**CY 1976-1999**	**CY 1991-2019**
Producer prices	(Linear)	0.194 **	0.086 **		
		(0.026)	(0.026)		
	(Below threshold)			0.122 **	0.026
				(0.046)	(0.035)
	(Additional pass-through)			0.087	0.159 **
				(0.044)	(0.048)
Exchange rates	(Linear)	-0.006	0.013 *		
		(0.006)	(0.006)		
	(Below threshold)			-0.008	0.008
				(0.005)	(0.006)
	(Additional pass-through)			0.029 *	0.028 **
				(0.013)	(0.010)
Wages	(Linear)	0.602 **	0.394 **		
		(0.054)	(0.035)		
	(Below threshold)			0.489 **	0.277 **
				(0.059)	(0.042)
	(Additional pass-through)			0.323 **	0.234 **
				(0.050)	(0.064)
Constant term		2.235 **	0.166 **	2.003 **	-0.088
		(0.093)	(0.058)	(0.104)	(0.057)
Thresholds (d_i)					
Producer prices				1.1	0.8
Exchange rates				1.6	1.5
Wages				1.7	1.2

Note: ** and * indicate statistical significance at the 1% and 5% level, respectively. Figures in parentheses are Newey-West standard errors.

Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

(Appendix Panel 2)

Panels 8&9: Estimated Result for CPI Inflation (less fresh food)

Model		Linear model		Nonlinear model	
Estimation period		CY 1976-1999	CY 1991-2019	CY 1976-1999	CY 1991-2019
Producer prices	(Linear)	0.285 **	0.198 **		
		(0.016)	(0.024)		
	(Below threshold)			0.156 **	0.150 **
				(0.044)	(0.028)
	(Additional pass-through)			0.170 **	0.138 **
				(0.043)	(0.050)
Exchange rates	(Linear)	-0.006	0.004		
		(0.005)	(0.006)		
	(Below threshold)			0.011	-0.000
				(0.009)	(0.005)
	(Additional pass-through)			-0.022	0.024 **
				(0.015)	(0.006)
Wages	(Linear)	0.610 **	0.358 **		
		(0.042)	(0.032)		
	(Below threshold)			0.489 **	0.162 **
				(0.059)	(0.044)
	(Additional pass-through)			0.309 **	0.334 **
				(0.063)	(0.065)
Constant term		2.223 **	0.232 **	2.003 **	-0.070
		(0.087)	(0.053)	(0.135)	(0.055)
Thresholds (d_i)					
Producer prices				1.1	0.9
Exchange rates				0.7	1.5
Wages				1.0	0.8

Note: ** indicates statistical significance at the 1% level. Figures in parentheses are Newey-West standard errors.

Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

(Appendix Panel 3)

Panel 10: Estimated Result (with Slack Variable) for CPI Inflation (less fresh food, energy)

Model		Linear model		Nonlinear model	
Estimation period		CY 1976-1999	CY 1991-2019	CY 1976-1999	CY 1991-2019
Producer prices	(Linear)	0.196 **	0.052 *		
		(0.027)	(0.023)		
	(Below threshold)			0.022	0.019
				(0.040)	(0.017)
	(Additional pass-through)			0.141 **	0.151 **
				(0.044)	(0.036)
Exchange rates	(Linear)	-0.007	0.009		
		(0.006)	(0.005)		
	(Below threshold)			0.007	-0.007
				(0.006)	(0.005)
	(Additional pass-through)			0.014	0.036 **
				(0.013)	(0.009)
Wages	(Linear)	0.617 **	0.217 **		
		(0.076)	(0.053)		
	(Below threshold)			0.175	0.013
				(0.103)	(0.045)
	(Additional pass-through)			0.542 **	0.167 **
				(0.099)	(0.048)
Slack (unemployment rate, sign inverted)	(Linear)	-0.083	0.398 **		
		(0.222)	(0.084)		
	(Below threshold)			0.771 **	0.484 **
				(0.228)	(0.062)
	(Additional pass-through)			0.510	0.547 **
				(0.338)	(0.078)
Constant term		2.238 **	0.174 **	1.574 **	-0.111 *
		(0.092)	(0.053)	(0.108)	(0.050)
Thresholds (d_i)					
Producer prices				0.6	1.5
Exchange rates				1.4	0.6
Wages				0.5	1.2
Slack				0.8	1.7

Note: ** and * indicate statistical significance at the 1% and 5% level, respectively. Figures in parentheses are Newey-West standard errors.

Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED

(Appendix Panel 4)

Panel 11: Estimated Result (with Lower Bounds) for CPI Inflation (less fresh food, energy)

Model		Linear model	Nonlinear model
Estimation period		CY 1991-2019	
Producer prices	(Linear)	0.086 **	
		(0.026)	
	(Normal state)		0.085
			(0.043)
	(Above upper kink)		0.127 *
			(0.051)
	(Below lower kink)		-0.085
			(0.060)
Exchange rates	(Linear)	0.013 *	
		(0.006)	
	(Normal state)		0.014
			(0.008)
	(Above upper kink)		0.026 *
			(0.011)
	(Below lower kink)		-0.013
			(0.011)
Wages	(Linear)	0.394 **	
		(0.035)	
	(Normal state)		0.348 **
			(0.053)
	(Above upper kink)		0.189 **
			(0.070)
	(Below lower kink)		-0.152
			(0.078)
Constant term		0.166 **	-0.171 *
		(0.058)	(0.069)
Upper bound (dU)			
Producer prices			0.9
Exchange rates			1.5
Wages			1.2
Lower bound (dL)			
Producer prices			-0.8
Exchange rates			-0.8
Wages			-0.9

Note: ** and * indicate statistical significance at the 1% and 5% level, respectively. Figures in parentheses are Newey-West standard errors.

Sources: Ministry of Internal Affairs and Communications; Ministry of Health, Labour and Welfare; Bank of Japan; FRED