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Changing Exchange Rate Pass-Through in Japan: Does It Indicate Changing Pricing Behavior?

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Abstract

This paper empirically explores recent changes in the exchange rate pass-through in Japan. We take a two-pronged approach. First, we estimate the exchange rate pass-through into domestic prices using time-varying parameter estimation. Second, we decompose the estimated exchange rate pass-through into the responsiveness of marginal costs to the exchange rate and the responsiveness of inflation to marginal costs. The estimation results show that the rates of exchange rate pass-through into the Producer Price Index and the Consumer Price Index have been increasing since the late 2000s. Evidence from international input-output tables suggests that the import-intensity of Japan's manufacturing sector has increased considerably over the last decade. We find that although the increasing dependence on imports in production (as well as in the retail sector) accounts for part of the rise in exchange rate pass-through, a larger part of the rise is due to greater responsiveness of inflation to marginal costs. This finding hints at a structural change in firms' pricing behavior since the late 2000s.

JEL Classification: C11, E31, F41;

Keywords: Exchange Rate Pass-Through; Phillips Curve; Time-Varying Parameter Estimation; Markov Chain Monte Carlo Estimation; International Input-Output Tables

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1 Introduction

In the light of price stability in a globalized economy, an issue of considerable importance is the extent to which changes in the exchange rate translate into changes in domestic prices, that is, exchange rate pass-through. For example, although the yen depreciated considerably in the mid-2000s, the Consumer Price Index (CPI) all items less fresh food did not rise significantly during the period. On the other hand, when the yen depreciated again over the last few years, domestic prices did in fact rise, suggesting that the rate of the exchange rate pass-through may have increased.

This means that exchange rate pass-through into domestic prices is a key issue to understand price dynamics in an open economy. Exchange rate fluctuations affect prices through their impact on production costs (for example, via prices of materials) and transport costs. This, in turn, implies that the extent of exchange rate pass-through affects price stability as well as firms' profitability and households' real incomes. Exchange rate pass-through therefore is of considerable interest not only to firms and consumers, but also to policymakers.

There is an extensive literature on the determinants of exchange rate pass-through into domestic prices. Broadly speaking, exchange rate pass-through depends on the responsiveness of marginal costs to exchange rate changes and on the responsiveness of prices to marginal costs. Each of these has attracted a considerable amount of research. Studies focusing on the responsiveness of marginal costs to exchange rate changes suggest that changes in the cost share of imported goods have a significant effect on a country's exchange rate pass-through. Campa and Goldberg (2005), for example, find that in around half of the OECD countries they examined, large shifts in the composition of countries' import bundles, in particular the downward trend in the share of materials in imports, have led to a substantial decrease in exchange rate pass-through.

On the other hand, studies examining the responsiveness of prices to marginal costs typically focus on firms' pricing behavior. Bergin and Feenstra (2009), for example, find that fierce competition between foreign and domestic producers tends to lower the degree of exchange rate pass-through. Meanwhile, Gopinath and Itskhoki (2010) focus on the relationship between price rigidities and exchange rate pass-through. They find a positive relationship between the frequency of price adjustment and the exchange rate pass-through. Finally, Devereux and Yetman (2010), considering the link with average inflation, show that countries with lower average inflation are likely to face lower exchange rate pass-through, suggesting that there is a link between exchange rate pass-through and firms' pricing behavior.

Given these two broad strands of explanations of the degree of exchange rate pass-through, a growing body of research seeks to investigate which of the two is more important — the responsiveness of inflation to marginal costs or the responsiveness of marginal costs to the exchange rate. Goldberg and Campa (2010), for instance, conduct a cross-country analysis to investigate the relationship between local distribution margins and exchange rate pass-through. They show that distribution margins decrease in response to a local currency depreciation. They conclude that larger local distribution margins tend to lower the degree of exchange rate pass-through into the CPI, since distributors attempt to keep their prices stable by adjusting their margins. Meanwhile, Auer and Schoenle (2013) investigate two channels of exchange rate pass-through into the prices a firm charges: a direct channel via changing production costs, and an indirect channel via changes in competitors' prices, which should eventually affect firms' prices. They provide empirical evidence that the two channels are equally important in determining the recent exchange rate pass-through in the United States.

Apart from the determinants of exchange rate pass-through, another issue that has been highlighted in recent studies is that exchange rate pass-through can be underestimated due to mis-measurement of import prices. Nakamura and Steinsson (2012) find that the size of import price changes may be underestimated if prices are rigid but products are replaced in price statistics before any price change is observed. If products in the price index are replaced more frequently than prices change, the resulting index may fail to capture price changes of the replaced product after the product is dropped from the index.[1] Consequently, measured import price changes will be smoother than actual import price changes. They conclude that the mis-measurement of import prices significantly reduces the observed exchange rate pass-through.[2]

Earlier studies on Japan's exchange rate pass-through suggest that both pass-through into marginal costs and pricing behavior played a significant role until the mid-2000s. For instance, Shioji and Uchino (2009) examine the role of the decline in the relative price of raw materials observed in the late 1990s. Their analysis is based on the reasoning that if the price elasticity of demand for raw materials is sufficiently low, a decrease in their price should lower the share of raw materials in total production costs. They empirically show that the decline in the relative price of raw materials indeed weakens exchange rate pass-through into domestic prices via this mechanism. There are also a considerable number of studies examining the relationship between the pricing behavior of Japanese firms and exchange rate pass-through. Otani et al. (2003) and Sekine (2006), for instance, find that the rate of exchange rate pass-through into import prices declined in the 1990s and show that this is linked to the increase in competition as a result of globalization. Otani et al. (2003) in addition argue

[1]Gagnon et al. (2014) point out that some of those replacements occur when firms change a product's characteristics and its price, since price statistics tend to regard the old and the new product as different and drop the former from the sample. Gagnon et al. (2014) also show that because of the way price statistics in the United States are constructed, products whose price recently changed are more likely to enter the index. If prices are rigid, it is likely to be a long time before the price of such a product will be changed again once it has entered the index.

[2]To date, there is no consensus in the literature regarding the quantitative importance of sample turnover. Gagnon et al. (2014), extending the analysis of Nakamura and Steinsson (2012), for example, report that the effect of sample turnover is limited.

that the sharp appreciation of yen after the Plaza Agreement likely encouraged firms to pass on less of changes in the exchange rate to prices in intra-firm transactions. Meanwhile, Ito et al. (2013) discuss exchange rate pass-through in Japan in recent years in the light of firms' choice of invoicing currency. Utilizing a unique survey of Japanese manufacturing firms conducted in 2009, they find that a firm's choice of invoicing currency depends on the type of trade concerned as well as the size of the firm. For example, the importer's currency is more likely to be used as the invoicing currency in intra-firm trade. In this sense, an expansion of intra-firm trade will lead to a decline in exchange rate pass-through into export prices. Their finding provides an insight into exchange rate pass-through into import prices. If foreign firms consider Japan as an increasingly important export market for their products, the yen is more likely to be employed as the invoicing currency when foreign firms export to Japan. In this case, the degree of pricing-to-market might change.

A few studies examine Japan's exchange rate pass-through since the Great Recession of 2008-2009. One of these is the study by Shioji (2014), who analyzes recent changes in the responsiveness of marginal costs to exchange rate changes in light of the cost share of imports in production. Estimating exchange rate pass-through over the period 1970 to 2013 using time-varying parameter vector autoregression (VAR) models, he finds that the rate of exchange rate pass-through into both import and domestic prices has been rising since the late 2000s. Based on additional analysis using domestic input-output tables, he suggests that the increasing share of imported intermediate goods has substantially contributed to the increase in exchange rate pass-through.

Against this background, the aim of the present study is to conduct empirical analyses on recent developments in the exchange rate pass-through in Japan, focusing in particular on developments since the Great Recession. We take a two-pronged approach. First, we estimate the exchange rate pass-through into the CPI using time-varying parameter estimation. Specifically, we estimate the Phillips curve relying on an open economy New Keynesian Phillips curve framework. The framework employed in this study is suggested by Gali and Lopez-Salido (2001), in which marginal costs reflect exchange rate dynamics via import prices. We use survey-based inflation expectations in estimating the Phillips curve to control for the impact of inflation expectations on actual inflation. To estimate the model, we adopt time-varying parameter estimation using the Bayesian Markov Chain Monte Carlo approach employed by Sekine (2006). Second, we investigate at which stage(s) of production (as well as in the retail sector) exchange rate pass-through into the CPI may have changed since the late 2000s. In particular, we decompose the estimated changes in exchange rate pass-through into two parts: changes in the responsiveness of marginal costs to the exchange rate, and the responsiveness of inflation to marginal costs, which may substantially reflect structural changes affecting firms' pricing behavior.

The estimation results show that the rates of exchange rate pass-through into the Producer

Price Index (PPI) and the CPI have been increasing since the late 2000s. Moreover, the analysis using international input-output tables suggests that the import-intensity of Japan's manufacturing sector in 2011 was twice as high as in the early 2000s. We also find that although the increasing dependence on imports in production accounts for part of the rise in pass-through rates, a larger part of the rise is not explained by this factor. This result indicates that changes in firms' pricing behavior likely have substantially contributed to the recent increase in the exchange rate pass-through into domestic prices.

The present study contributes to the literature on exchange rate pass-through in a number of ways. It is one of only a few studies providing estimations on Japan's exchange rate pass-through covering the post-Great Recession period. Furthermore, most existing studies covering the period only examine the impact of changes in production structure. By contrast, our analysis allows and evaluates changes in firms' pricing behavior in measuring the exchange rate pass-through. To our knowledge, this is the first study that documents the relative importance of changes in production structure and in pricing behavior in determining changes in Japan's exchange rate pass-through since the Great Recession. Specifically, our findings support Shioji's (2014) conclusion that the increasing share of imported intermediate goods has substantially contributed to the increase in exchange rate pass-through. Moreover, while he assumes that firms' pricing behavior has remained unchanged, our findings show that changes in pricing behavior also play an important role. In this regard, our findings are in line with those of Goldberg and Campa (2010) and Auer and Schoenle (2013) for the United States showing that changes in pricing behavior can be as important as those in production structure in explaining changes in exchange rate pass-through.

The rest of the paper is organized as follows. Section 2 provides an overview of recent developments in the exchange rate and prices in Japan, which we examine in this study. Section 3 presents the open economy Phillips curve framework that we employ for our analysis and measures the exchange rate pass-through into Japan's CPI by applying time-varying parameter estimation to the Phillips curve. Section 4 extends this framework by including foreign producers and domestic retailers, and investigates which factors contributed to changes in the estimated pass-through. Section 5 concludes.

2 Exchange Rate and Price Developments in Japan

Exchange rate pass-through measures the responsiveness of prices to changes in the exchange rate. In this study, as well as in the literature, it is defined as the percentage change in prices in response to a one percent change in the exchange rate. This section provides an overview of recent development in the relationship between prices and the exchange rate and other major determinants which influence price dynamics.

Figure 1 presents developments in prices and the nominal effective exchange rate from

1982Q1 to 2014Q4. Figures 1(a) and (b) plot year-on-year changes in the core CPI (the CPI for all items less fresh food) and the PPI, respectively, as well as changes in the nominal effective exchange rate. The two figures indicate that domestic prices show greater co-movement with the nominal effective exchange rate since the late 2000s, except for a few quarters around the time of the Great Recession. Meanwhile, Figure 1(c) depicts year-on-year changes in the Import Price Index (IPI) together with changes in the nominal effective exchange rate. The figure indicates that, unlike in the case of the CPI and PPI, there seems to have been little change in the relationship between the IPI and the exchange rate. Taken together, these figures suggest that the exchange rate pass-through into domestic prices seems to have increased since the late 2000s.

Next, Figure 2 shows the share of imports in producer and in consumer goods from 1995 to 2014. As can be seen, the import shares have risen quite steadily over the entire observation period. This trend potentially raises exchange rate pass-through into domestic prices, since firms' marginal costs are more responsive to exchange rate changes the higher the share of imports. On the other hand, the higher import-intensity could potentially also lead to lower exchange rate pass-through due to changes in firms' behavior. As already mentioned, Otani et al. (2003), for example, show that in the 1990s greater competition as a result of globalization reduced exchange rate pass-through into import prices. This means that whether an increase in the share of imports increases the exchange rate pass-through is an empirical matter. We examine this issue in Section 4.

However, the greater co-movement between domestic prices and the exchange rate since the late 2000s could also be due to other factors. That is, the recent increase in domestic inflation may be due to an improvement in the output gap and/or rising inflation expectations, while exchange rate pass-through has actually remained unchanged. Figure 3(a) depicts developments in the output gap and the year-on-year rate of change in the CPI. The two seem to show greater co-movement over the past few years. In addition, inflation expectations have also rise to some extent over the last few years. Figure 3(b) plots the one-year, two-year, and ten-year expected average of core CPI inflation of bond market participants. These series are taken from the Quick Monthly Market Survey (QUICK Survey) published by QUICK Corporation. The figure shows that inflation expectations have risen in recent years. It is therefore possible that the greater co-movement between domestic inflation and the nominal effective exchange rate may also be due to the improvement in the output gap and/or rising inflation expectations observed concurrently with the depreciation of the yen over the last few years. To examine whether Japan's exchange rate pass-through has actually increased, we take the effects of the output gap and inflation expectations on price dynamics into account when estimating the exchange rate pass-through.

3 Estimation of Exchange Rate Pass-Through

This section outlines our estimation of exchange rate pass-through in Japan over the past three decades. We start by presenting our analytical framework, then explain the model and data used for the estimation, and finally present our estimation results.

3.1 Analytical Framework

We start with an open-economy Phillips curve framework. In this setup, producers purchase materials from foreign firms. They use labor and imported materials to supply goods, and sell them to households. The production function is given by

$$Y_t = \left\{ \alpha_m M_t^{\frac{\sigma-1}{\sigma}} + (1-\alpha_m) L_t^{\frac{\sigma-1}{\sigma}} \right\}^{\frac{\sigma}{\sigma-1}\frac{1}{\Phi}} \bar{K}^{1-\frac{1}{\Phi}}, \tag{1}$$

where Y_t, M_t, L_t, and $\bar{K}$ denote output, imported goods, labor, and the capital stock at time t. The capital stock is assumed to be constant. α_m is a parameter governing the steady-state cost share of imported goods. σ represents the elasticity of substitution between imported goods and labor. $\left(1-\frac{1}{\Phi}\right)$ represents the share of fixed capital in production. We assume Φ to be larger than one.[3]

Equation (1) is the specification suggested by Rumler (2007), who extends the production function for an open economy provided by Gali and Lopez-Salido (2001). Gali and Lopez-Salido (2001) construct a production function in which producers use labor and imported materials. In their model, marginal costs reflect exchange rate dynamics via import prices. Rumler (2007) modifies their specification by introducing fixed capital into the production function. Cost minimization yields the (relative) labor demand function:

$$\frac{W_t}{P_t^m} = \frac{(1-\alpha_m)}{\alpha^m} \left(\frac{L_t}{M_t}\right)^{-\frac{1}{\sigma}}, \tag{2}$$

where P_t^m and W_t denote real import prices and real wages expressed in terms of domestic prices. Real marginal costs, mc_t, are given by the following equation:

$$\begin{aligned} \hat{mc}_t &= \phi \hat{p}_t^m + (1-\phi)\hat{w}_t + (\Phi-1)\hat{y}_t, \\ \text{where } \phi &= \frac{\alpha_m^\sigma (\bar{p}^m)^{1-\sigma}}{\alpha_m^\sigma (\bar{p}^m)^{1-\sigma} + (1-\alpha_m)^\sigma (\bar{w})^{1-\sigma}}. \end{aligned} \tag{3}$$

ϕ is the cost share of imports in production. Lower case letters p_t^m, w_t, and y_t denote the log of the original variables. Variables with bars and with hats represent the steady-state and

[3]This implies that to raise the level of output by one percent, firms need to increase the other two factors by more than one percent, because they cannot adjust the capital stock to achieve a higher level of output.

deviation from the steady-state, respectively.

Employing a Calvo pricing model, we obtain the following relationship between the inflation rate of domestically produced goods prices, π_t, and real marginal costs:

$$\hat{\pi}_t = \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \left[\hat{mc}_t + \hat{\mu}_t \right], \tag{4}$$

where $\hat{\mu}_t$ denotes a mark-up shock, which captures changes in the desired mark-up. The desired mark-up is what firms want to charge over the marginal costs if they face no frictions. It is defined as $\bar{\mu} = \frac{\eta}{(\eta-1)}$, where η is the price elasticity of demand. This means that the desired mark-up is higher when demand is less elastic. κ captures the responsiveness of inflation to real marginal costs. In the above setup,

$$\kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta \left[1 + (\Phi - 1)\,\eta \right]}. \tag{5}$$

θ reflects the degree of nominal price rigidity. A lower θ means that producers will more readily change the prices of their products. A decrease in η makes the Phillips curve steeper (raises κ) by encouraging firms to demand a higher margin from customers reflecting their lower price elasticity of demand. Substituting Equation (3) into Equation (4), we obtain the Phillips curve in terms of domestically produced goods prices:

$$\hat{\pi}_t = \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \left[\phi \hat{p}^m_t + (1-\phi)\hat{w}_t + (\Phi - 1)\hat{y}_t + \hat{\mu}_t \right]. \tag{6}$$

Real import prices can be broken down into the nominal exchange rate, e_t and foreign prices at-the-dock relative to domestic prices, p^f_t:

$$\hat{p}^m_t = \hat{e}_t + \hat{p}^f_t.$$

Consequently, the Phillips curve includes the exchange rate:

$$\begin{aligned} \hat{\pi}_t &= \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \left[\phi \left(\hat{e}_t + \hat{p}^f_t \right) + (1-\phi)\hat{w}_t + (\Phi - 1)\hat{y}_t + \hat{\mu}_t \right] \\ &= \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa\phi \hat{e}_t + \kappa \left[\phi \hat{p}^f_t + (1-\phi)\hat{w}_t + (\Phi - 1)\hat{y}_t + \hat{\mu}_t \right]. \end{aligned} \tag{7}$$

$\kappa\phi$, which is the parameter on the exchange rate, $\hat{e}_t$, represents the rate of exchange rate pass-through into consumption goods prices. In other words, exchange rate pass-through depends on (i) the response of marginal costs to a change in the exchange rate and (ii) the response of inflation to a change in marginal costs.

3.2 Model and Data for Estimation

We conduct time-varying parameter estimation of the exchange rate pass-through into retail prices using quarterly data. The Phillips curves to be estimated rely on the framework introduced in the previous section. Specifically, we estimate the following Phillips curve specification:

$$\pi_t^c = \lambda_{0,t} + \sum_{i=0}^{3} \lambda_{1,i,t} \Delta e_{t-i} + \sum_{i=0}^{1} \lambda_{2,i,t} \Delta p_{t-i}^{com} + \sum_{i=0}^{3} \lambda_{3,i,t} x_{t-i} + \lambda_{4,t} \pi_{t-1}^c + \lambda_{5,t} \tilde{\pi}_t + \varepsilon_t^c, \quad (8)$$

where π_t^c is the retail price inflation rate at time t. $\tilde{\pi}_t$ denotes long-run inflation expectations. e_t, p_t^{com}, and x_t denote the nominal effective exchange rate, real commodity prices, and the output gap, respectively. Real commodity prices are expressed as the ratio of nominal commodity prices to retail prices. Variables e_t and p_t^{com} are in logarithm and first differenced (shown by Δ). We include contemporaneous and one quarter lag values for Δp_t^{com}, and up to three quarter lags for Δe_t and x_t.[4] The terms $\sum_{i=0}^{3} \lambda_{1,i,t}$ and $\sum_{i=0}^{3} \lambda_{1,i,t}/(1-\lambda_{4,t})$ respectively capture the short-run and long-run exchange rate pass-through into retail prices.

We employ quarterly data for retail prices, the nominal effective exchange rate, international commodity prices, inflation expectations, and the output gap. For retail prices, we use the core CPI and the CPI for goods provided by the Ministry of Internal Affairs and Communications. We use two different CPI series because we want to estimate the pass-through into these series separately. For the nominal effective exchange rate, we use the series provided by the Bank for International Settlements. For international commodity prices, we construct a nominal commodity price index. This is the weighted average of the international market prices of eight major commodities expressed in U.S. dollars taken from the IMF Primary Commodity Prices website. The eight commodities are petroleum, coal, natural gas, iron, copper, nickel, zinc, and lead. They make up 90 percent of Japan's fuel- and mining-related commodity imports. As weights, we use the import shares of the commodities obtained from the Import Price Index statistics published by the Bank of Japan.[5] We then convert the nominal commodity price index into real terms by dividing by the retail price index that we focus on. For inflation expectations, we use the results of the QUICK Survey. We use the QUICK Survey data for the one-year, two-year, and ten-year expected average of core CPI inflation to estimate long-run inflation expectations. For the output gap, we use the output gap series estimated by the Bank of Japan.[6]

[4] The lag lengths of the explanatory variables are chosen based on the Schwarz information criterion (SIC) for the estimation results for the equation using ordinary least squares over the period 1982Q4 to 2014Q1.

[5] The Import Price Index statistics provide data for the import shares of the commodities for base years ending with 0 or 5.

[6] A detailed description of these output gap series can be found in Hara et al. (2006).

We use Δe_t and Δp_t^{com} rather than $\hat{e}_t$ and $\hat{p}_t^f$ in the estimation.[7] The output gap is used as a proxy for domestic labor costs.[8] Meanwhile, long-run inflation expectations, $\tilde{\pi}_t$, are used to capture changes in one-period ahead inflation expectations, which appear in Equation (7). We compute $\tilde{\pi}_t$ based on past inflation rates and survey-based inflation expectations.[9] The one-quarter lagged inflation rate captures sluggishness in retail price inflation which is not explained either by the long-run inflation expectations series we use or by the variables in Equation (8) comprising marginal costs. To take possible shifts in the exchange rate pass-through into account, we allow values of the parameters in the model to change over time. Specifically, we employ a time-varying Markov Chain Monte Carlo (MCMC) approach to Equation (8). The estimation methodology in this study is similar to the approach employed by Sekine (2006). Appendix A provides an overview of the estimation methodology used. We run the Gibbs sampler for 25,000 draws, which include 5,000 draws for burn-in, and carry out this exercise twenty times. Consequently, 400,000 draws are recorded. The observation period is from 1982Q4 to 2014Q4.

3.3 Estimation Results

In this section, we provide the estimation results of Equation (8) for the core CPI as well as for the CPI for goods. We then show which of the variables in the equation help to explain the recent rise in CPI inflation.

Figure 4 plots the estimated parameters of Equation (8). Figure 4(a) shows that the estimated exchange rate pass-through has been increasing over the last decade, particularly since the Great Recession. This result is in line with Shioji's (2014) finding of an increase in the exchange rate pass-through based on estimating a time-varying parameter VAR model for the period February 1970 to June 2013. Figures 4(b) and (c) depict the estimates of the parameters on commodity price inflation and the output gap. The two parameter values have risen since the mid-2000s.[10]

Figure 5 provides a decomposition of the fit of Equation (8) into the contribution of the different explanatory variables when using the core CPI. The figure indicates that since the Great Recession exchange rate changes have made a larger contribution to changes in the

[7] In practice, using $\hat{e}_t$ and $\hat{p}_t^f$ instead of Δe_t and Δp_t^f may give unstable estimation results, since the exchange rate and the commodity price series are found to be integrated of order one. To avoind using non-stationary series when estimating exchange rate pass-through, we follow earlier studies such as Sekine (2006) and Shioji (2014) using the log difference of the exchange rate.

[8] Muto (2009) finds that real marginal costs measured by the labor share are procyclical in Japan if labor adjustment costs and real wage rigidity are considered in estimating the New Keynesian Phillips curve. Taking this finding into account, we assume that domestic marginal costs are procyclical.

[9] A technical description of how the long-run inflation expectations series is constructed is provided in Appendix B.

[10] We obtain similar results when using the CPI all items less food (less alcoholic beverages) and energy instead of the core CPI or the CPI for goods.

core CPI than in the 1990s and early 2000s. This can be attributed to both an increase in the exchange rate pass-through into the CPI and the large fluctuations in the exchange rate during this period. This figure further shows that the recent rise in actual CPI inflation also reflects improvements in the output gap and rising inflation expectations.

4 Decomposition of Import-Intensity and Pricing Behavior

In practice, domestic producers are likely to use imported intermediate goods to supply consumer goods and to sell their products to households via retailers. Moreover, retailers may import consumer goods from foreign producers and sell them to households. This means that empirically examining exchange rate pass-through at the industry level will provide us with a better understanding of the increase in pass-through observed for recent years.

To this end, the present section presents a time-varying estimation of the exchange rate pass-through into import prices and domestic producer prices and investigates at which stage(s) of production (including retail) the exchange rate pass-through into retail prices may have changed since the late 2000s. As explained in Section 3, exchange rate pass-through is determined by the responsiveness of marginal costs to changes in the exchange rate and the responsiveness of inflation to marginal costs. Reflecting this, in the present section, we calculate industry-level import intensities using international input-output tables and other macroeconomic statistics and then decompose the estimated exchange rate pass-through into the part explained by changes in import-intensity in production and the remainder, which reflects structural changes affecting firms' pricing behavior.

4.1 Analytical Framework

Households purchase both domestically-produced and imported consumption goods. Retail price inflation, π_t^r, therefore is defined as

$$\pi_t^r = (1 - \phi_{m,c})\pi_t^{r,d} + \phi_{m,c}\pi_t^{r,cm}, \tag{9}$$

where $\pi_t^{r,d}$ and $\pi_t^{r,cm}$ denote retail price inflation of domestically-produced and imported consumption goods. $\phi_{m,c}$ is the import share of consumption goods.

The rate of retail price inflation for each type of goods is likely to differ from the rate of producer price inflation. Suppose retail price inflation for a good deviates from producer price inflation for the good by κ_r.[11] In this case, retail price inflation for each type of goods can be written as $\pi_t^{r,d} = \kappa_r\pi_t^d$ and $\pi_t^{r,cm} = \kappa_r\pi_t^{cm}$, where π_t^d and π_t^{cm} denote producer price inflation and import price inflation of consumption goods, respectively. Consequently, Equation (9)

[11] For simplicity, we assume that κ_r is the same for domestically-produced and imported goods.

becomes

$$\pi^r_t = \kappa_r \left[(1-\phi_{m,c})\pi^d_t + \phi_{m,c}\pi^{cm}_t\right]. \tag{10}$$

A rise in the parameter κ_r increases the exchange rate pass-through if producer prices and import prices respond to changes in the exchange rate. If the consumption goods purchased by retailers are the sole input in the retail sector, a rise in κ_r can be interpreted as an increase in retailers' mark-up. However, in reality, retailers use imported goods such as fuel for transport as well. This means that the parameter κ_r may reflect the cost share of imports in the retail sector as well, and part of the change in this parameter is likely to be incorporated in the exchange rate pass-through into marginal costs. We investigate whether and why κ_r has (or has not) changed in Section 4.3. An increase in $\phi_{m,c}$ may increase the pass-through as well, since the pass-through into import price of consumption goods may be higher than the pass-through into producer prices. We will examine the exchange rate pass-through into producer prices and import prices of consumer goods using Equation (10).

We begin with the exchange rate pass-through into producer prices. We assume that producers purchase materials from foreign firms and sell their products to retailers. This assumption is quite close to the setup employed in Section 3.1, in which producers sell their products to households. Hence, for producer price inflation, we use a specification similar to Equation (7). Replacing π_t in Equation (7) with π^d_t, we obtain

$$\hat{\pi}^d_t = \beta \mathbb{E}_t \hat{\pi}^d_{t+1} + \kappa_d \left[\phi_{m,i}\hat{p}^{m,i}_t + (1-\phi_{m,i})\hat{w}_t + (\Phi_d - 1)\hat{y}_t + \hat{\mu}_t\right], \tag{11}$$

$$\hat{p}^{m,i}_t = \hat{e}_t + \hat{p}^{f,i}_t, \tag{12}$$

where $p^{m,i}_t$ is the import price of intermediate goods in terms of the produce price of consumption goods, and $p^{f,i}_t$ is the foreign price of intermediate goods at-the-dock in terms of the producer price of consumption goods. Both variables are in logarithm. $\phi_{m,i}$ denotes the cost share of imports in production. In this model, the exchange rate pass-through into producer prices is defined as $\kappa_d\phi_{m,i}$. Note that Equation (12) does not explicitly model the pricing behavior of foreign producers.

Next, we introduce the pricing behavior of foreign producers into Equation (11) by modifying Equation (12) for $\hat{p}^{m,i}_t$. Campa and Goldberg (2005) assume that foreign producers change their mark-up in response to exchange rate changes. In their setup, nominal import prices in terms of importers' currency NP^m_t are given by

$$NP^m_t = E_t NP^f_t = E_t \mathcal{M}^f_t NMC^f_t, \tag{13}$$

where E_t, NP^f_t, $\mathcal{M}^f_t$ and NMC^f_t are the nominal exchange rate, nominal import prices, the mark-up, and foreign producers' nominal marginal costs, respectively. The exchange rate and marginal costs are expressed in terms of exporters' currency.

Since $\hat{p}_t^{m,i}$ is deflated by the producer price of consumption goods, we divide both sides of Equation (13) by the producer price and take the logarithm. The resulting equation is

$$p_t^{m,i} = e_t + \mu_t^f + mc_t^f, \tag{14}$$

where μ_t^f is the mark-up of foreign producers in logarithm and mc_t^f is the logarithm of foreign marginal costs relative to producer price.[12] Campa and Goldberg (2005) assume that foreign producers' mark-up is a linear function of the nominal exchange rate:

$$\mu_t^f = \gamma_0 + \gamma_1 e_t. \tag{15}$$

The parameter γ_1 reflects the degree of pricing-to-market. γ_1=0 signifies a complete pass-through of costs into import prices. If γ_1=-1, foreign producers fully offset the effect of exchange rate fluctuations on their prices in importing countries by adjusting their mark-up. From Equations (14) and (15), import price level is defined as

$$p_t^{m,i} = \kappa_{m,i} e_t + mc_t^f + \gamma_0, \tag{16}$$

where $\kappa_{m,i} = 1 + \gamma_1$. Equation (16) shows that the exchange rate pass-through into import prices of intermediate goods is $\kappa_{m,i}$.[13] This means that an increase in the degree of pricing-to-market (a lower $\kappa_{m,i}$) reduces the exchange rate pass-through. Using Equations (11) and (16), we obtain

$$\begin{aligned} \hat{\pi}_t^d &= \beta \mathbb{E}_t \hat{\pi}_{t+1}^d + \kappa_d \left[\phi_{m,i} \hat{p}_t^m + (1 - \phi_{m,i}) \hat{w}_t + (\Phi_d - 1) \hat{y}_t + \hat{\mu}_t \right] \\ &= \beta \mathbb{E}_t \hat{\pi}_{t+1}^d + \kappa_d \left[\phi_{m,i} \left(\kappa_{m,i} \hat{e}_t + \hat{mc}_t^f \right) + (1 - \phi_{m,i}) \hat{w}_t + (\Phi_d - 1) \hat{y}_t + \hat{\mu}_t \right]. \end{aligned} \tag{17}$$

Consequently, the exchange rate pass-through into producer prices becomes $\kappa_d \phi_{m,i} \kappa_{m,i}$.

The final step is to derive the exchange rate pass-through into the import price of consumption goods. We take the same approach as in the case of the import price of intermediate goods in Equation (16). Replacing $p_t^{m,i}$ in the equation with the import price of consumption goods, $p_t^{m,c}$, yields

$$p_t^{m,c} = \kappa_{m,c} e_t + mc_t^f + \gamma_0. \tag{18}$$

The exchange rate pass-through into import prices of consumption goods is $\kappa_{m,c}$.

In summary, the exchange rate pass-through into producer prices is a function of (a) the responsiveness of producer prices to marginal costs (κ_d), (b) the cost share of imports in the manufacturing sector ($\phi_{m,i}$), and (c) the exchange rate pass-through into import prices of

[12] For simplicity, in this setup, the mark-up and marginal costs are assumed to be the same for all foreign firms, even if they produce different types of goods. We will relax this assumption in Section 4.2.

[13] We obtain this by taking the first difference and adding producer price inflation to Equation (16).

intermediate goods ($\kappa_{m,i}$). The exchange rate pass-through into retail prices depends on (d) the difference between retail price inflation and producer price inflation (κ_r), (e) the import share of consumption goods ($\phi_{m,c}$), (f) the exchange rate pass-through into import prices of consumption goods ($\kappa_{m,c}$), and (g) the exchange rate pass-through into domestic producer prices.

4.2 Models and Data for Decomposition

Section 4.1 has shown that exchange rate pass-through into domestics prices can be decomposed into two parts, namely, the exchange rate pass-through into marginal costs and the responsiveness of domestic prices to marginal costs. In this section, we attempt to quantify the exchange rate pass-through into marginal costs. If this part does not sufficiently explain the exchange rate pass-through observed in recent years, this indicates that there must have been changes in the responsiveness of domestic prices to marginal costs, which in turn would imply that firms' pricing behavior may have come to play a more important role in the exchange rate pass-through.

To quantify the pass-through into marginal costs, we classify the seven parameters considered at the end of Section 4.1 as follows. Changes in (b) and (c) are classified as changes in exchange rate pass-through into producers' cost, while changes in (e) to (g) are classified as changes in exchange rate pass-through into retailers' cost. Changes in (a) and (d) are classified as changes in the responsiveness of inflation to marginal costs. Note that (c), (f), and (g) are rates of the exchange rate pass-through into import prices or producer prices. By quantifying each of the five parameters, (b), (c), (e), (f), and (g), we examine whether there has been any substantial change in cost-related parameters. In Section 4.2.1, we estimate three of the five cost-related parameters, (c), (f), and (g), using equations that we construct referring to the framework explained in Section 4.1. In Section 4.2.2, the remaining two of the five parameters, (b) and (e), are measured using a variety of economic statistics such as international input-output tables.

4.2.1 Exchange Rate Pass-Through into Import and Producer Prices

We start by constructing the equations for estimating the exchange rate pass-through into import prices. Equations (16) and (18) indicate that import price inflation depends on the nominal exchange rate, nominal commodity prices, and foreign labor costs. The equations to be estimated are

$$\pi_t^{m,c} = \delta_{0,t}^{m,c} + \sum_{i=0}^{3} \delta_{1,i,t}^{m,c} \Delta e_{t-i} + \sum_{i=0}^{1} \delta_{2,i,t}^{m,c} \Delta p_{t-i}^{x,comm} + \sum_{i=0}^{3} \delta_{3,i,t}^{m,c} \Delta w_{t-i}^{f} + \sum_{i=0}^{3} \delta_{4,i,t}^{m,c} x_{t-i} + \delta_{5,t}^{m,c} \pi_{t-1}^{m,c} + \epsilon_t^{m,c}, \quad (19)$$

$$\pi_t^{m,i} = \delta_{0,t}^{m,i} + \sum_{j=0}^{3} \delta_{1,j,t}^{m,i} \Delta e_{t-j} + \sum_{j=0}^{1} \delta_{2,j,t}^{m,i} \Delta p_{t-j}^{x,comm} + \sum_{j=0}^{3} \delta_{3,j,t}^{m,i} \Delta w_{t-j}^{f} + \sum_{j=0}^{3} \delta_{4,j,t}^{m,i} x_{t-j} + \delta_{5,t}^{m,i} \pi_{t-1}^{m,i} + \epsilon_t^{m,i}. \quad (20)$$

$\pi_t^{m,c}$ and $\pi_t^{m,i}$ denote the import price inflation rates of consumer goods and intermediate goods, respectively. $p_t^{x,comm}$ stands for nominal commodity prices, and w_t^f represents foreign unit labor costs. All variables except for the output gap are expressed in logarithm. In addition to the set of variables in Equations (16) and (18), we use lagged values of the output gap and those of import price inflation.

Similar to Equation (8), we include contemporaneous and one quarter lag values for $p_t^{x,comm}$, and up to three quarter lags for Δe_t, Δw_t^f and x_t.[14] All of the parameters in Equations (19) and (20) are assumed to be time-variant. $\sum_{i=0}^{3} \delta_{1,i,t}^{m,c}/(1-\delta_{5,t}^{m,c})$ is the long-run exchange rate pass-through into import prices of consumer goods. $\sum_{j=0}^{3} \delta_{1,j,t}^{m,i}/(1-\delta_{5,t}^{m,i})$ is the long-run exchange rate pass-through into import prices of intermediate goods. $\sum_{i=0}^{3} \delta_{1,i,t}^{m,c}/(1-\delta_{5,t}^{m,c})$ and $\sum_{j=0}^{3} \delta_{1,j,t}^{m,i}/(1-\delta_{5,t}^{m,i})$ can be interpreted as a proxy for $\kappa_{m,c}$ in Equation (18) and $\kappa_{m,i}$ in Equation (16), respectively.

The output gap is introduced in Equations (19) and (20) to control for the impact of demand conditions in Japan.[15] One quarter lagged import price inflation is included in Equations (19) and (20) to capture any sluggishness in the marginal costs of foreign producer not captured by any of the other variables in the equations.

Next, we formulate the equation to estimate the exchange rate pass-through into domestic producer prices. We slightly modify Equation (8), which we used to estimate the pass-through into the CPI:

$$\pi_t^d = \rho_{0,t} + \sum_{i=0}^{3} \rho_{1,i,t} \Delta e_{t-i} + \sum_{i=0}^{1} \rho_{2,i,t} \Delta p_{t-i}^{d,comm} + \sum_{i=0}^{3} \rho_{3,i,t} x_{t-i} + \rho_{4,t} \pi_{t-1}^d + \epsilon_t^d, \quad (21)$$

where π_t^d is the domestic producer price inflation rate. $p_t^{d,comm}$ is the log of real commodity prices in terms of domestic producer prices, that is, $\left(p_t^{x,comm} - p_t^d\right)$. $\sum_{i=0}^{3} \rho_{1,i,t}/(1-\rho_{4,t})$ is the long-run exchange rate pass-through into domestic producer prices and is related to $\kappa_d \phi_{m,i} \kappa_{m,i}$ in Equation (17). We assume that the time-varying constant captures developments in long-run inflation expectations for producer prices.[16]

[14]We use Δe_t and Δw_t^f instead of $\hat{e}_t$ and $\hat{w}_t^f$ since the data for e_t and w_t^f are found to be integrated of order one.

[15]Campa and Goldberg (2005) take demand conditions in the importing country into account when estimating the exchange rate pass-through into import prices.

[16]The reason for this assumption is that we cannot find suitable data for long-run inflation expectations for

Finally, we provide a description of the data for the variables introduced in this section. To construct import prices, we use data from the Import Price statistics provided by the Bank of Japan. We construct an import price index for intermediate goods by aggregating the import prices of raw materials, intermediate materials, and capital goods using the weights provided in the Import Price statistics. We will refer to this index as the IPI for intermediate goods. We compute an index of foreign unit labor costs using Japan's nominal and real effective exchange rates provided by the IMF. The IMF's real effective exchange rate series we use employs unit labor costs for developed countries as the deflator.[17] For domestic producer prices, we use the Domestic Corporate Goods Price Index by the Bank of Japan. To estimate the exchange rate pass-through into import and producer prices, we apply a time-varying MCMC approach to to Equations (19) to (21) using the same setup as in Section 3.2.

Figure 6 shows the long-run pass-through rates of exchange rate changes obtained estimating Equations (19) to (21). Figure 6(a) depicts the estimated pass-through into the IPI for intermediate goods and the IPI for consumer goods. The estimated pass-through rates since the late 2000s seem to be relatively stable compared to the exchange rate pass-through into the CPI during the same period. This result shows that the recent increase in the exchange rate pass-through into the CPI is unlikely to be explained only by the change in the exchange rate pass-through into the IPI. Figure 6(b) plots the estimated long-run exchange rate pass-through into the PPI for consumer goods and the CPI for goods. We find that the exchange rate pass-through into the PPI and the CPI has increased substantially since the late 2000s. The increased response of domestic prices to exchange rate changes suggests certain changes in the domestic market such as a change in import-intensity or in firms' pricing behavior.

4.2.2 Import-Intensity and Other Cost Shares

The remaining cost-related parameters are (b) the cost share of imports in the manufacturing sector and (e) the import share of consumption goods. Since we showed in Figure 2 that the import share of consumer goods calculated based on the Indices of Industrial Domestic Shipments and Imports statistics has been rising, let us focus on the measurement of parameter (b).

The cost share of imports in a particular industry depends on the share of imports in goods input and the share of goods input in total factor input within the industry. We compile industry-level cost shares of imports using international input-output tables and compute the cost share of imports in the manufacturing sector by aggregating the industry-level cost shares.

Suppose there are S industries in the manufacturing sector producing consumer goods, and the exchange rate pass-through into production costs in industry s at time t is represented

Japan's producer prices.

[17] We follow the method employed by Campa and Goldberg (2005) to construct foreign unit labor cost data.

by $c_{s,t}$. The vector of the rates of exchange rate pass-through into production costs, $c_t = [c_{1,t}, c_{2,t}, ..., c_{S,t}]'$, where the operator $'$ denotes the matrix (vector) transposition, is defined as

$$c_t = \left\{[I - (A_t - G_t)]^{-1}\right\}' G_t' z_t. \quad (22)$$

I is an $S \times S$ identity matrix. A_t is an input matrix for intermediate goods at time t which covers both domestically-produced and imported goods. G_t is an input matrix for imports which represents the share of imports in and industry's goods input. The term $[I - (A_t - G_t)]^{-1}$ describes the share of goods input in total factor input. $z_t = [z_{1,t}, z_{2,t}, ..., z_{S,t}]'$ is a vector of shocks to import prices. Every entry in z_t takes one in the case of a currency depreciation. We allow the matrices A_t and G_t to vary over time to express changes in production structure.

The aggregate exchange rate pass-through into the production costs for consumer goods producers, C_t, is given by

$$C_t = \varphi_t' c_t, \quad (23)$$

where $\varphi_t = [\varphi_{1,t}, \varphi_{2,t}, ..., \varphi_{S,t}]'$ is a vector of shares of the industries in total output of consumer goods at time t.

The values of entries in the matrices A_t and G_t are taken from the World Input-Output Tables (WIOT) from the World Input-Output Database (WIOD).[18] The WIOD provides a set of international input-output tables for major countries categorized by industry. The WIOT contain annual transactions of 35 industries in 40 major countries plus the rest of the world.[19] To construct $c_{s,t}$, we need to link every industry-level transaction in Japan with the related domestic producer price data. To do so, we choose 17 industries in the WIOT and link them to the corresponding industries in the PPI statistics. The 17 industries selected cover all the industries in the PPI statistics. Table 1 shows the correspondence between the industries in the WIOT and those in the PPI statistics. The vector of industry-level shares, φ_t, comes from the PPI statistics.

Figure 7 shows the computed exchange rate pass-through into domestic production costs for consumer goods producers, denoted by C_t in Equation (23).[20] The pass-through into domestic production costs for consumer goods producers in 2011 is twice as high as in the early 2000s. The computed pass-through shown in Figure 7 captures changes in the responsiveness of marginal costs to the exchange rate, which is $\phi_{m,i}$ in Equation (17). The figure indicates that the cost share of imports in production in the manufacturing sector has risen in recent years.

[18] A detailed description of the WIOD is provided by Timmer (2012).

[19] Since WIOT data after 2011 are not available, we extend the WIOT data to 2014 using the values for 2011.

[20] In Figure 7, complete pass-through of exchange rate changes into import prices is assumed. That is, we impose $z_{i,t} = 1$ for all i and t.

4.3 Decomposition

In our analytical framework, the exchange rate pass-through into retail prices consists of (d) the difference between retail price inflation and producer price inflation, (e) the import share of consumption goods, (f) the exchange rate pass-through into import prices of consumption goods, and (g) the exchange rate pass-through into domestic producer prices. Our findings in Section 4.2 suggest that the recent change in the estimated exchange rate pass-through into the CPI may have been caused by the increase in the import share of consumer goods, and by the increase in the exchange rate pass-through into domestic producer prices. The findings also indicate that the observed increase in the pass-through into the PPI may reflect greater import-intensity in the manufacturing sector, which would translate into greater responsiveness of marginal costs to exchange rate changes in the sector.

In this section, we evaluate to what extent the observed changes in the cost-related parameters can explain recent developments in the exchange rate pass-through. Specifically, we decompose the estimated change in the exchange rate pass-through into the CPI for goods into the part explained by changes in the cost-related parameters and the remaining part, which we assume reflects changes in firms' pricing behavior.

Before presenting the decomposition, we note that, as explained in Section 4.1, differences between retail price inflation and producer price inflation may reflect the cost share of imports in the retail sector as well as retailers' pricing behavior. Therefore, we first examine the cost share of imports in the retail sector and categorize changes therein as part of the change in the cost-related parameters.

Suitable data for the cost share of imports in the retail sector unfortunately are unavailable. As an alternative, we therefore use the cost share of labor in the sector, which shows changes in the overall cost shares in this sector. Figure 8 plots the ratio of total labor costs to sales in the retail sector from 1995 to 2013.[21] The data used come from the Financial Statements Statistics of Corporations by Industry published by the Ministry of Finance. The figure indicates that at least the cost share of labor has been stable in recent years. In the decomposition, we use changes in the cost share of labor as a proxy for changes in the cost share of imports in the retail sector.

Figure 9(a) provides a decomposition of cumulative changes in the exchange rate pass-through into the PPI for consumer goods. The black line represents the deviation of the exchange rate pass-through into the PPI from its level in 2000Q1. The gray bars show the contribution of changes in the response of marginal costs in the manufacturing sector. Changes in the response of marginal costs are due to changes in the exchange rate pass-through into the IPI for intermediate goods and changes in the import-intensity of production. The white bars capture the residual change, which represents the responsiveness of inflation to production costs and likely reflects changes in firms' pricing behavior. The figure shows

[21] Total labor costs consist of salaries for employees, bonuses for employees, and welfare expenses.

that changes in the response of marginal costs contributed to the rise in the exchange rate pass-through into the PPI. However, a large part of the increase in the pass-through is due to changes in the responsiveness of inflation to production costs, the contribution of which has grown faster since the Great Recession. This suggests that domestic producers are experiencing structural changes that affect their pricing behavior.

While we have considered the relationship between import-intensity and marginal costs, rising import-intensity can also lead to a decrease in the exchange rate pass-through due to fiercer competition as a result of globalization, as mentioned earlier. In this case, increasing import-intensity reduces the responsiveness of inflation to production costs. Looking at Figure 9(a), the rapid increase in the size of the white bars from 2006 suggests that this effect either was not very strong or was much smaller than structural factors affecting firms' pricing behavior working in the opposite direction.

Next, Figure 9(b) depicts the result of the decomposition in the case of the CPI for goods. The black line represents the deviation of the exchange rate pass-through into the CPI from its level in 2000Q1. The gray bars represent the exchange rate pass-through into retailers' costs —- that is, changes in the response of retailers' marginal costs. This is determined by the exchange rate pass-through into the IPI for consumer goods, the import-intensity of the retail sector, and the exchange rate pass-through into the PPI. The results are similar to the case of the PPI. A larger part of the change in the exchange rate pass-through is explained by changes in the response of inflation to marginal costs, represented by the white bars, which reflect changes in retailers' pricing behavior. Therefore, part of the recent increase in the exchange rate pass-through into domestic prices is due to an increase in the responsiveness of marginal costs to exchange rate changes. However, a larger part of the change in the pass-through is attributable to structural changes altering firms' pricing behavior.

Our findings are in line with Shioji's (2014) argument that the recent increase in the exchange rate pass-through is due to the rise in import dependence. Our analysis backs up this observation with industry-level and quantitative evidence on the responsiveness of marginal costs to exchange rate changes using industry-level information. Developments in Japan's economy suggest that the recent increase in the exchange rate pass-through may be due to changes in firms' pricing behavior. While we do not have sufficient evidence whether and why firms' pricing behavior has changed in recent years, changes in economic conditions in Japan may well have affected firms' conduct. For example, the large and sustained rise in commodity prices in the mid-2000s may have encouraged firms to change their prices more frequently to reflect rapid increases in production costs. If this is indeed the case, it could be interpreted as a decline in nominal price rigidity, which appears in Equation (5) and which would result in an increase in exchange rate pass-through. Pricing behavior may also have been affected by changes in lifestyles. For example, the rise in the labor participation rate of women may have affected shopping habits in that women that work have less time for bargain hunting and end up buying goods at a higher price. This, in turn, may have led to a decrease in the price elasticity of demand. Sudo et al. (2014), for example, show that there is a positive relationship between the time spent on shopping and the frequency of sales. This suggests that the rise in the female labor participation rate may also have made firms less reluctant to raise prices than in the past. However, it is beyond the scope of this study to further investigate to what extent and why firms' pricing behavior has changed in recent years.

5 Conclusion

Exchange rate pass-through into domestic prices is a key issue for understanding price dynamics in an open economy. Empirical studies suggest that exchange rate pass-through has declined in many countries over the last few decades. While this also appears to have been the case for Japan, the increased co-movement between the yen and domestic prices in recent years suggests that the exchange rate pass-through in Japan may have increased again.

Against this background, the present study empirically examined recent changes in the exchange rate pass-through in Japan. Exchange rate pass-through into domestic prices depends on the responsiveness of marginal costs to changes in the exchange rate and the responsiveness of inflation to marginal costs. In this study, we quantitatively analyzed the roles of these two factors in recent developments in the exchange rate pass-through.

Our results suggest that the rate of exchange rate pass-through into domestic prices indeed has been increasing since the late 2000s. Our analysis using international input-output tables and other macroeconomic statistics further showed that although the increasing dependence on imports is responsible for part of the rise in the pass-through rate, a large part of the rise is due to changes in firms' pricing behavior.

This implies that in order to gain an even better understanding of changes in exchange rate pass-through, it is necessary to examine whether and why firms' pricing behavior has changed. Possible reasons for such changes, as mentioned, include the large increase in commodity prices until the mid-2000s as well as changes in lifestyles. In addition, they may also reflect the increase in actual and expected inflation that Japan has recently experienced, given that the literature suggests the extent of exchange rate pass-through tends to be positively related to average inflation. These are issues that deserve further research in the future.

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Appendix

A Time-Varying Estimation: Bayesian MCMC Approach

This appendix presents an overview of the Markov Chain Monte Carlo (MCMC) algorithm we employ in the estimation of the exchange rate pass-through in Section 3.2 and 4.2. Specifically, we conduct time-varying parameter estimation of the Phillips curves for the core CPI, the CPI for goods, the PPI for consumer goods, the IPI for intermediate goods, and the IPI for consumer goods. Our approach is a modified version of the method used by Sekine (2006).

To estimate the time-variant parameters in these Phillips curves, we need to model how the parameters behave over time. We begin by transforming each of the Phillips curves into a state space form. Suppose all of the coefficients in Equation (8) are time-variant. We construct a state space model to be estimated in which the values of coefficients in the observation equation can change over time:

$$\pi_t = Z_t'\alpha_t + \sigma\varepsilon_t, \quad \text{for } t = 1, \ldots, T \tag{A.1}$$

$$\alpha_{t+1} = \alpha_t + Au_t, \quad \text{for } t = 1, \ldots, T-1. \tag{A.2}$$

$$\alpha_1 = \alpha_0 + A_0 u_0. \tag{A.3}$$

The observation equation (A.1) defines the behavior of the CPI inflation rate, π_t, based on Equation (8). Z_t is a p row vector of explanatory variables in Equation (8) observed at time t, where $Z_t = [1\ \Delta e_t, \ldots, \Delta e_{t-3}, \Delta p_t^{com}, \ldots, \pi_{t-1}^c, \tilde{\pi}_t]'$. α_t is a p row vector of time-varying coefficients in Equation (8), where $\alpha_t = [\lambda_{0,t}, \lambda_{1,0,t}, \ldots, \lambda_{1,3,t}, \lambda_{2,0,t}, \ldots, \lambda_{4,t}, \lambda_{5,t}]'$. The observation equation has an error term which consists of a constant volatility, σ, and an i.i.d. standard normal sequence, ε_t.

The state equation (A.2) describes movements of the coefficients in Equation (8). α_t follows a random walk process. The state equation has the error term Au_t, where u_t is an i.i.d. p-dimensional standard normal random sequence and A is a $p \times p$ matrix which controls the size of the error term. We can compute the matrix A using the following relationship: $H^{-1} = AA'$, where H^{-1} is a covariance matrix of the error term. We set H^{-1} using a Wishart prior of which the diagonal elements are set to 0.001 and the degree of freedom is one, as in Sekine (2006). For the initial values in the state equation, we set $\alpha_0 = 0$ and $H_0^{-1} = A_0A_0'$, where H_0^{-1} is a diagonal matrix. We use a Gamma prior to obtain diagonal elements in H_0^{-1}, instead of the Wishart prior used to set H^{-1}. u_0 follows a standard normal distribution. The same assumption is imposed on u_t for $t \geq 1$.

We extend this model to a state space model with stochastic volatility. Specifically, we re-define σ in Equation (A.1) as a time-variant variable in the following way:

$$\sigma_t \varepsilon_t = \gamma \exp(h_t/2)\varepsilon_t, \quad \text{for } t = 1, \ldots, T \tag{A.4}$$
$$h_{t+1} = h_t + \sigma_h \varepsilon_t^h, \qquad \text{for } t = 1, \ldots, T-1, \tag{A.5}$$
$$h_1 = h_0 + \sigma_{h0}\varepsilon_0^h. \tag{A.6}$$

h_t is the unobserved log volatility of the error term in Equation (A.1), and ε_t^h is an i.i.d. standard normal sequence. We simply assume that h_t follows a random walk process. As in the case of α, we set the initial value of h to $h_0 = 0$ and compute σ_{h0} using a Gamma prior which can be different from the Gamma prior used to compute H_0^{-1}. ε_0^h follows a standard normal distribution.

An additional condition enables us to estimate this state space model using the Bayesian MCMC algorithm. Taking the logarithm of the squared error term, we obtain

$$\epsilon_t = \log\left((\sigma_t \varepsilon_t)^2\right) = c + h_t + \zeta_t, \tag{A.7}$$

where $c = \log \gamma^2$ and $\zeta_t = \log \varepsilon_t^2$. $f(\zeta_t)$ denotes the density function of ζ_t. We approximate $f(\zeta_t)$ by a combination of normal density functions and apply the efficient Bayesian MCMC method offered by Kim et al. (1998) to estimate Equations (A.1) to (A.6). Kim et al. (1998) offer a method to approximate $f(\zeta_t)$ by a mixture of K normal density functions. Suppose $f_N\left(m_i, \nu_i^2\right)$ is a density function of a normal distribution with mean m_i and variance ν_i. Kim et al. (1998) approximate the density function $f(\zeta_t)$ by

$$f(\zeta_t) \approx g(\zeta_t) = \sum_{i=1}^{K} q_i f_N\left(\zeta_t | m_i, \nu_i^2\right), \tag{A.8}$$

where q_i denotes component probabilities. This density function can be rewritten as

$$(\zeta_t | s_t = i) \sim N(m_i, \nu_i^2), \text{ where } \Pr(s_t = i) = q_i. \tag{A.9}$$

$s_t \in \{1, 2, \ldots, K\}$ is a component indicator. Consequently, $f(\zeta_t)$ is expressed as a mixture of normal density functions and the standard MCMC method can be applied to estimate our state space model with stochastic volatility. Kim et al. (1998) conduct this exercise under $K = 7$, while Omori et al. (2007) extend their approach to the case of $K = 10$ to improve the precision of the approximation. In this paper, we set $K = 10$, and take values of m_i, ν_i^2, and q_i from Table 1 of Omori et al. (2007).

$p(\alpha_1, ..., \alpha_T, H, H_0, h_0, ..., h_T, \sigma_h^2, \sigma_{h0}^2, s_1, ..., s_T, c | \pi_1, ..., \pi_T)$ denotes the posterior density of the model which contains Equations (A.1) to (A.6). Further, we define $\pi = (\pi_1, ..., \pi_T), \alpha = (\alpha_1, ..., \alpha_T), h = (h_1, ..., h_T), s = (s_1, ..., s_T)$, and $\epsilon = (\epsilon_1, ..., \epsilon_T)$. The following algorithm generates the posterior density of the model:

- 1. Initialize $H, H_0, h, s, \sigma_h^2, \sigma_{h0}^2$ and c
- 2. Sample α from $\alpha|\pi, H, H_0, h$, s
- 3. Sample H and H_0 from $H|\alpha$ and $H_0|\alpha$, respectively
- 4. Sample s from $s|\epsilon, h, c$
- 5. Sample h from $h|\epsilon, s, \sigma_h^2, \sigma_{h0}^2, c$
- 6. Sample σ_h^2 and σ_{h0}^2 from $\sigma_h^2|h$ and $\sigma_{h0}^2|h$, respectively
- 7. Sample c from $c|\epsilon, s, h$
- Go to 2

Steps 2 and 3 correspond to the Gibbs sampling part of the time-varying parameter coefficients, while the steps 4 to 7 correspond to the Gibbs sampling part of the stochastic volatility model. We employ the simulation smoother proposed by de Jong and Shephard (1995) when sampling the series of α_t in Step 2 and h_t in Step 5. Further descriptions of each step are available in the appendix of Sekine (2006).

B Model for Inflation Expectations

We compute the series of long-run inflation expectations used in Equation (8) by modeling inflation expectations with survey data. As Figure 3(b) shows, survey-based short-run inflation expectations are correlated with current CPI inflation, while ten-year ahead inflation expectations are less volatile than short-run inflation expectations. Taking these features into account, we construct a model for long-run inflation expectations, $\tilde{\pi}_t$.

Specifically, we construct the following monthly model for s-month-ahead inflation expectations:

$$\mathbb{E}_m \pi_{m+s} = \psi \mathbb{E}_m \pi_{m+s-1} + (1-\psi)\tilde{\pi}_m, \tag{B.1}$$

$$\tilde{\pi}_m = \nu \pi_{m-1} + (1-\nu)\bar{\pi}. \tag{B.2}$$

where $\mathbb{E}_m \pi_{m+k}$ represents the model-based k-month ahead inflation expectations formed in month m. π_m is the year-on-year rate of change in the CPI in month m, and $\tilde{\pi}_m$ denotes the long-run expectations formed in month m. ψ controls how fast short-run expectations converge to long-run expectations, and ν governs the backward-lookingness of long-run inflation expectations.

We use the QUICK Survey results as a proxy of inflation expectations. This survey collects the forecasts of Japanese CPI inflation rates by bond market participants during the three business days ending on the final Thursday of a month.[22]

Survey respondents report their expectations of average annual inflation rates over the next one, two, and ten years. The survey usually receives respondents' CPI forecasts a few days before the release of the CPI for the previous month.

We attempt to find the set of parameters values in the model that replicate the QUICK Survey results. Since the QUICK Survey provides the average inflation expectations over a particular period, the survey expectations taken from the survey can be defined as follows:

$$\mathbb{F}_m \Pi_K = \frac{1}{K}\sum_{k=1}^{K} \mathbb{F}_m \pi_{m+k-2}, \; K \geq 1. \tag{B.3}$$

Π_K denotes the average inflation rate over the next K months. $\mathbb{F}_m \pi_{m+k}$ represents the survey-based k-month ahead inflation expectations formed in month m. Since the inflation rate in the previous month may not be available during each survey period, survey respondents are assumed to predict the most recent past inflation rate, as well as the current and future inflation rates.

[22] The QUICK Survey for December 2014 contains forecasts from 143 respondents. The number of respondents changes slightly over time.

Similarly, the model-based expectations over the next K months can be written as

$$\mathbb{E}_m\Pi_K = \frac{1}{K}\sum_{k=1}^{K}\mathbb{E}_m\pi_{m+k-2},\ K \geq 1. \tag{B.4}$$

In addition, survey-based inflation expectations gradually respond to actual inflation. Taking account of this, we replace inflation in the previous month in Equation (B.2) with the two-year average of past inflation:

$$\tilde{\pi}_m = \nu\left(\frac{1}{24}\sum_{i=1}^{24}\pi_{m-i-1}\right) + (1-\nu)\bar{\pi}. \tag{B.5}$$

Accordingly, we obtain the series $\mathbb{E}_m\Pi_K$ from Equations (B.1), (B.4) and (B.5) with a particular set of ν, ψ, and $\bar{\pi}$. Solving Equation (B.6) gives us the estimates of ν, ψ, and $\bar{\pi}$:

$$\min_{\nu,\psi,\bar{\pi}}\sum_{K}\sum_{m=1}^{M}\left[\mathbb{E}_m\Pi_K - \mathbb{F}_m\Pi_K\right]^2,\ K \in \{12, 24, 120\}. \tag{B.6}$$

The values of K correspond to the forecast spans of the QUICK Survey, which are one, two and ten years.

We estimate ν, ψ, and $\bar{\pi}$ for the observation period July 2004 to December 2014.[23, 24] The estimates of ν, ψ, and $\bar{\pi}$ are 0.39, 0.95, and 2.01, respectively. Using the estimated model, we extrapolate the values of the long-run inflation expectations before July 2004.

[23]In August 2012, the government announced an increase in the consumption tax rate from 5 to 8 percent in April 2014. The decision was finalized in September 2013. These announcements may have affected near-term forecasts, although the extent to which they did so may have varied across forecasters. To eliminate the impact of the tax rate rise on the near-term forecasts, we only use the ten-year inflation expectations from October 2013, which we assume to be less susceptible to the tax rate change. We also use the one-year and two-year inflation expectations until September 2013 and July 2012, respectively.

[24]In estimating the long-run inflation expectations, we assume that the CPI changed at a constant rate between September 2007 and January 2010. If we include the extremely volatile CPI data around the time of the collapse of Lehman Brothers, the estimated long-term inflation expectations fluctuate excessively as a result of this short-term volatility.

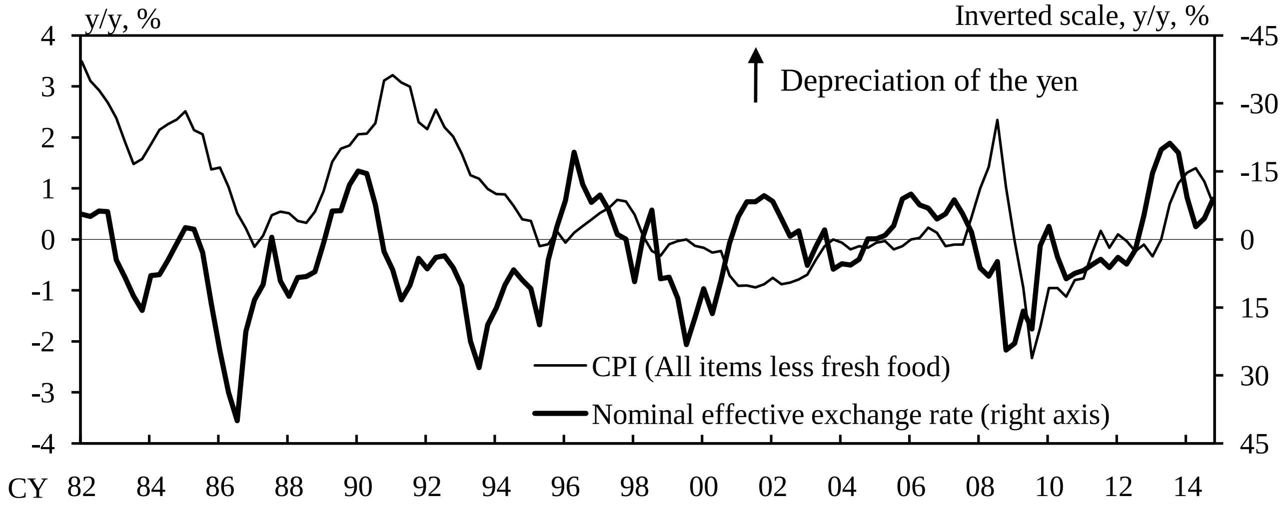
Table 1: Correspondence between WIOT industries and PPI (sub)groups

	WIOT industry name	Corresponding PPI (sub)groups and commodity classes
1	Agriculture, hunting, forestry and fishing	Agriculture, forestry & fishery products (G)
2	Mining and quarrying	Minerals (G)
3	Food, beverages and tobacco	Food, beverages, tobacco & feedstuffs (G)
4	Textiles and textile products	Textile products (G) (excl. Synthetic yarn (CC))
5	Leather, leather and footwear	Leather & related products (SG)
6	Wood and products of wood and cork	Lumber & wood products (G)
7	Pulp, paper, printing and publishing	Pulp, paper & related products (G), Printed matter & engravings (SG)
8	Coke, refined petroleum and nuclear fuel	Petroleum & coal products (G)
9	Chemicals and chemical products	Chemicals & related products (G), Synthetic yarn (CC)
10	Rubber and plastics	Plastic products (G), Rubber products (SG)
11	Other non-metallic mineral	Ceramic, stone & clay products (G)
12	Basic metals and fabricated metal	Iron & steel (G), Nonferrous metals (G), Metal products (G)
13	Machinery, nec	General purpose machinery (G), Production machinery (G), Household electric equipment (SG)
14	Electrical and optical equipment	Electric components & devices (G), Electric machinery & equipment (G) (excl. Household electric equipment (SG)), Information & communications equipment (G), Business oriented machinery (G)
15	Transport equipment	Transportation equipment(G)
16	Manufacturing, nec; recycling	Furniture & fixtures (SG), Musical instruments and recreational & sporting goods (SG), Other manufactured goods (SG), Scrap & waste (G)
17	Electricity, gas and water supply	Electric power, gas & water (G)

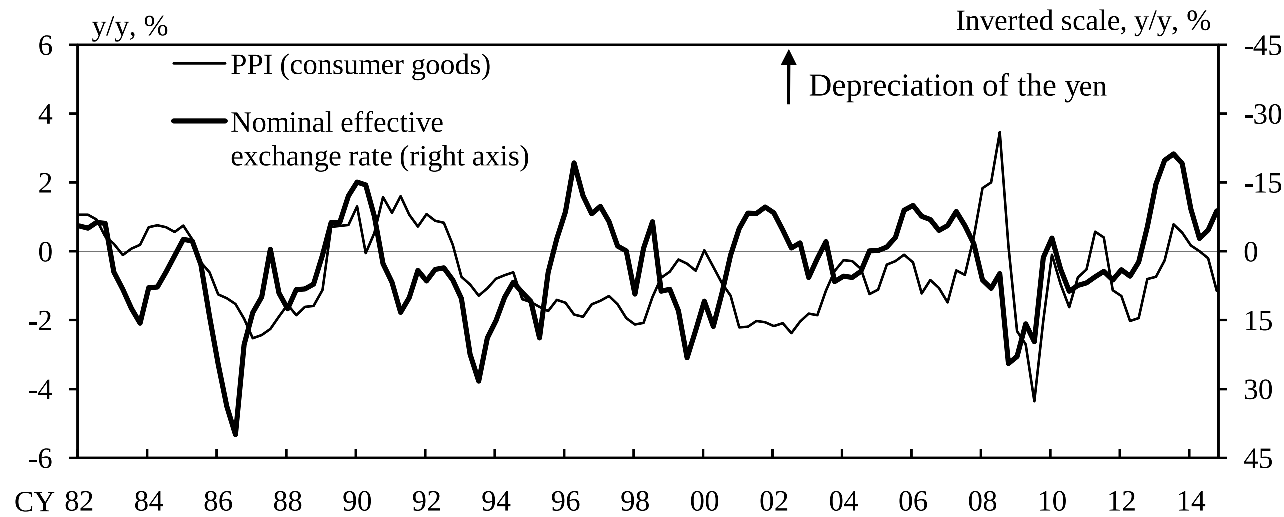
Note: The PPI statistics classify individual commodities in terms of the following hierarchical system: Group (G) - Subgroup (SG) - Commodity class (CC) - Commodity. Letters in parentheses correspond to this classification system.

Figure 1: Exchange rate and domestic prices

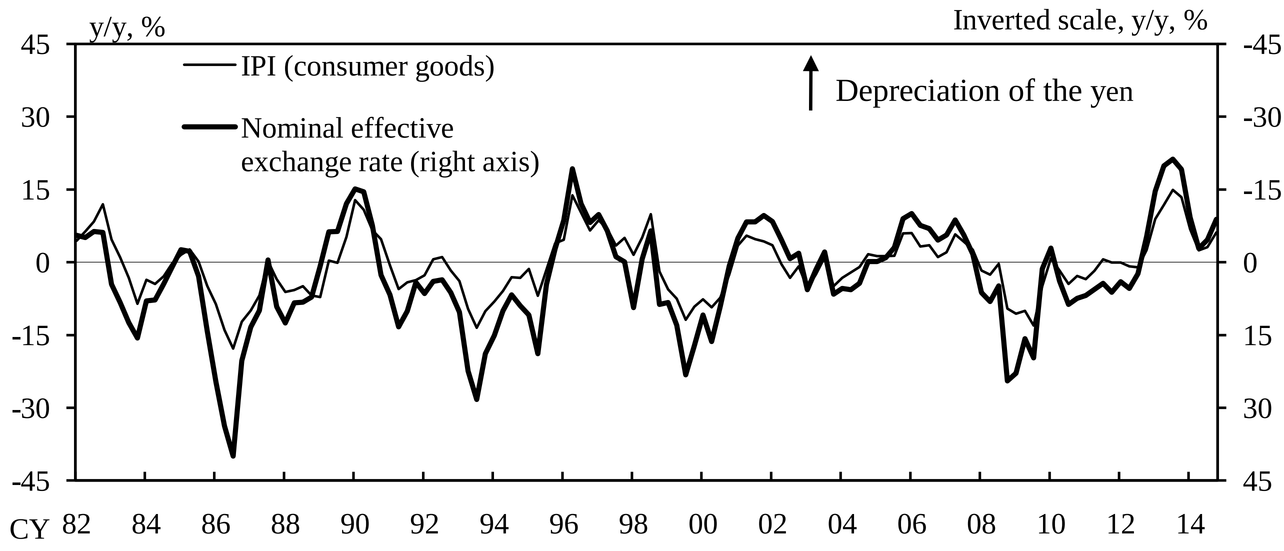
(a) Consumer Price Index (CPI)



(b) Producer Price Index (PPI)

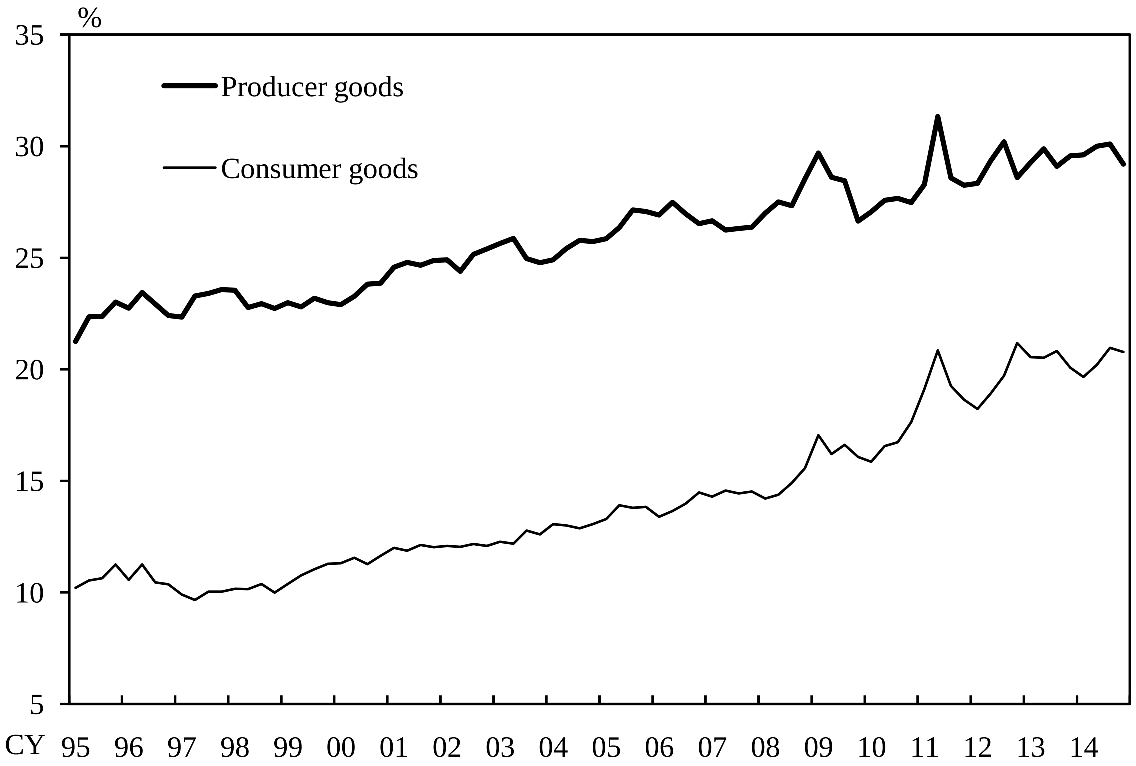


(c) Import Price Index (IPI)



Sources: BIS, Ministry of Internal Affairs and Communications, Bank of Japan.

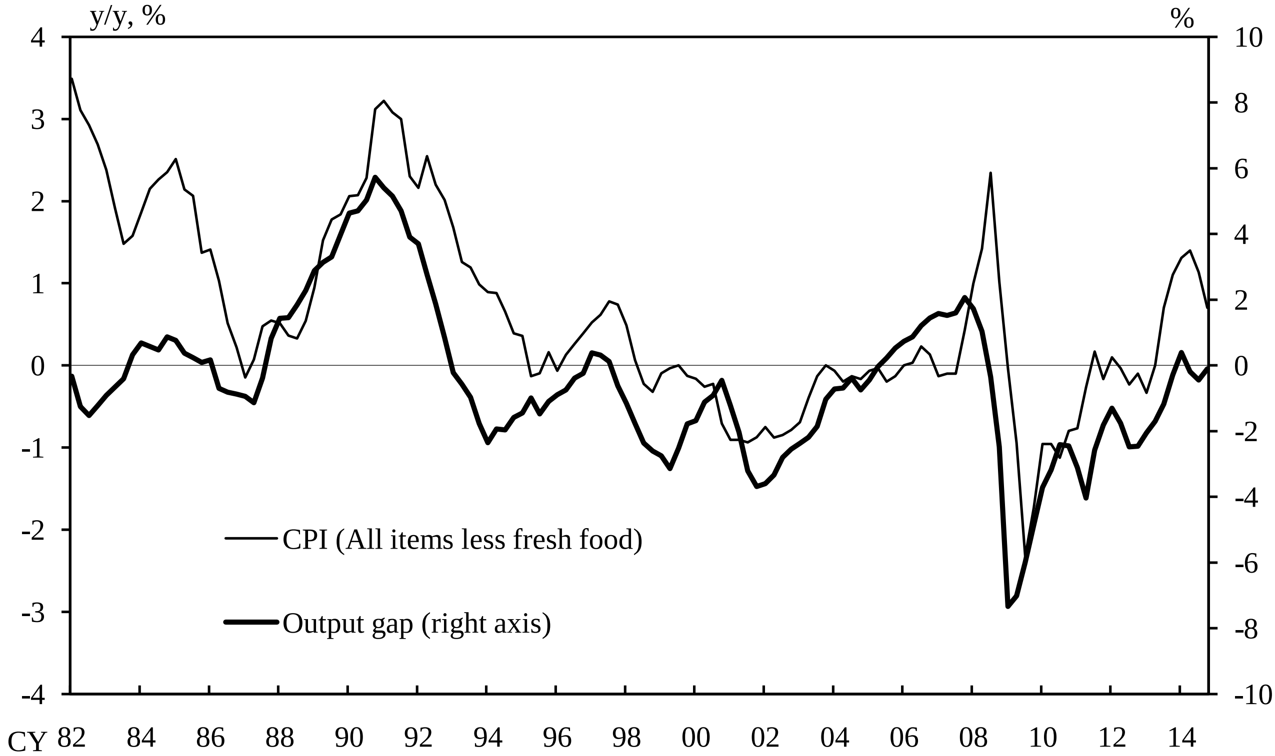
<u>Figure 2: Import penetration rates</u>



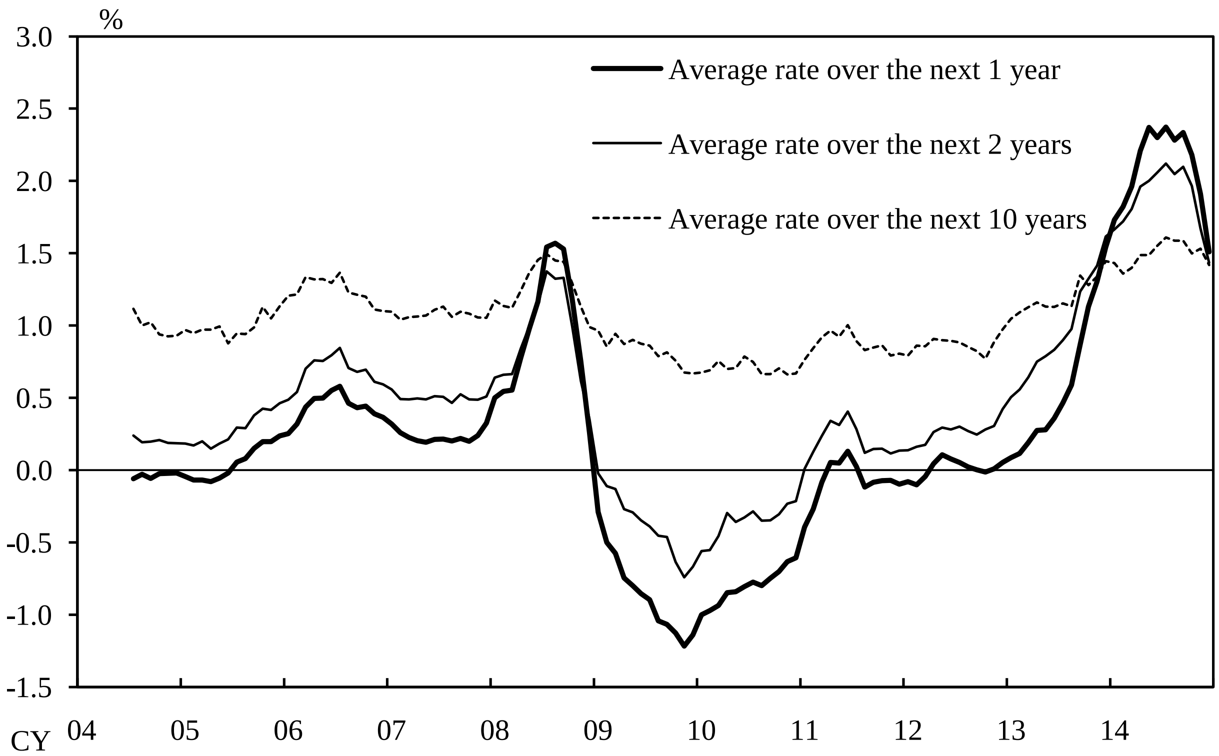
Source: Ministry of Economy, Trade and Industry, "Indices of Industrial Domestic Shipments and Imports."

Figure 3: Output gap and inflation expectations

(a) Output gap



(b) Inflation expectations



Sources: QUICK Corporation, Bank of Japan.

Figure 4: Estimated parameters of the Phillips curve

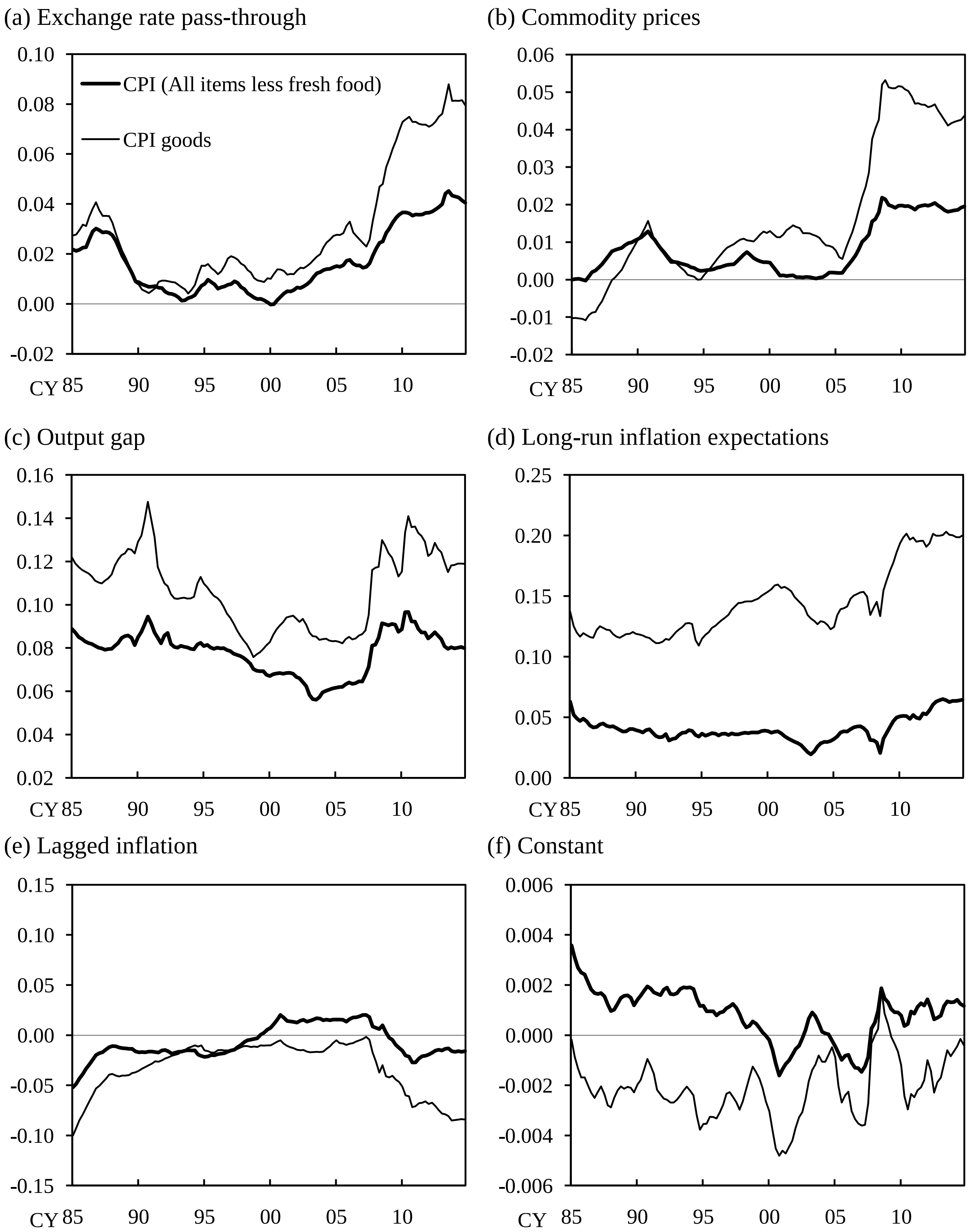
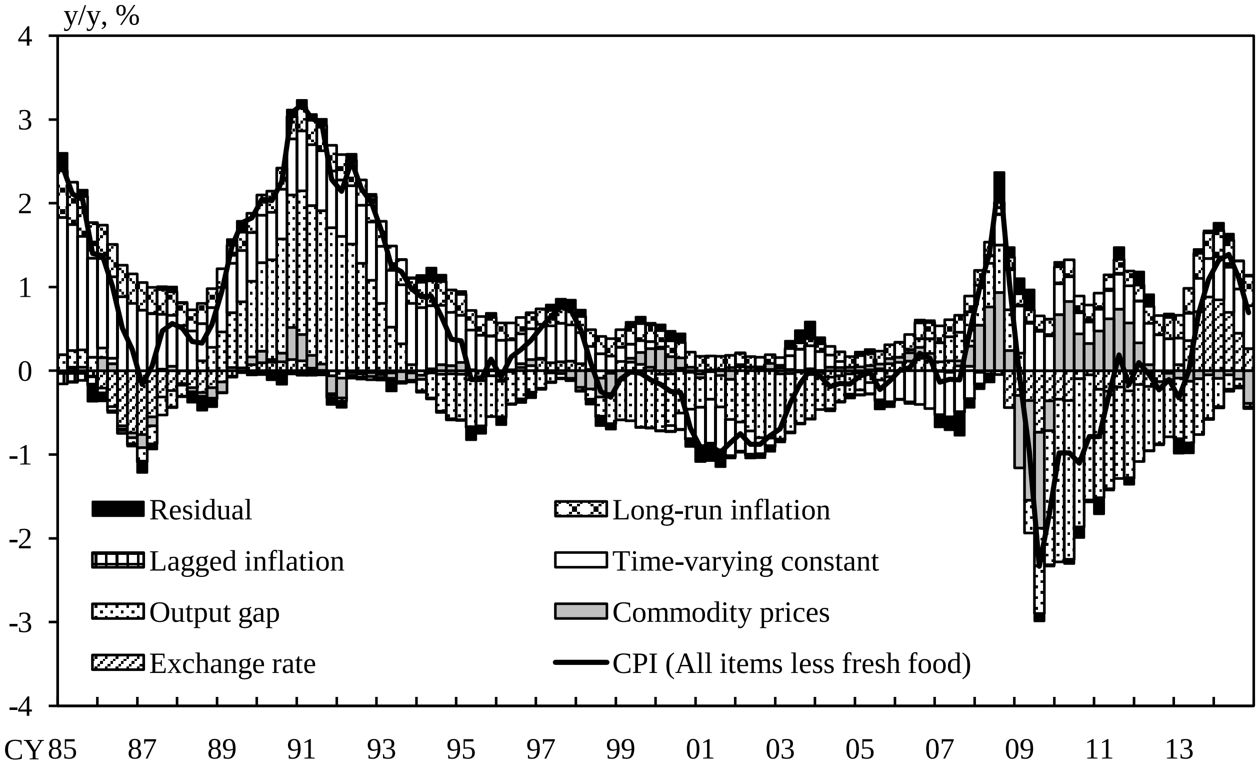
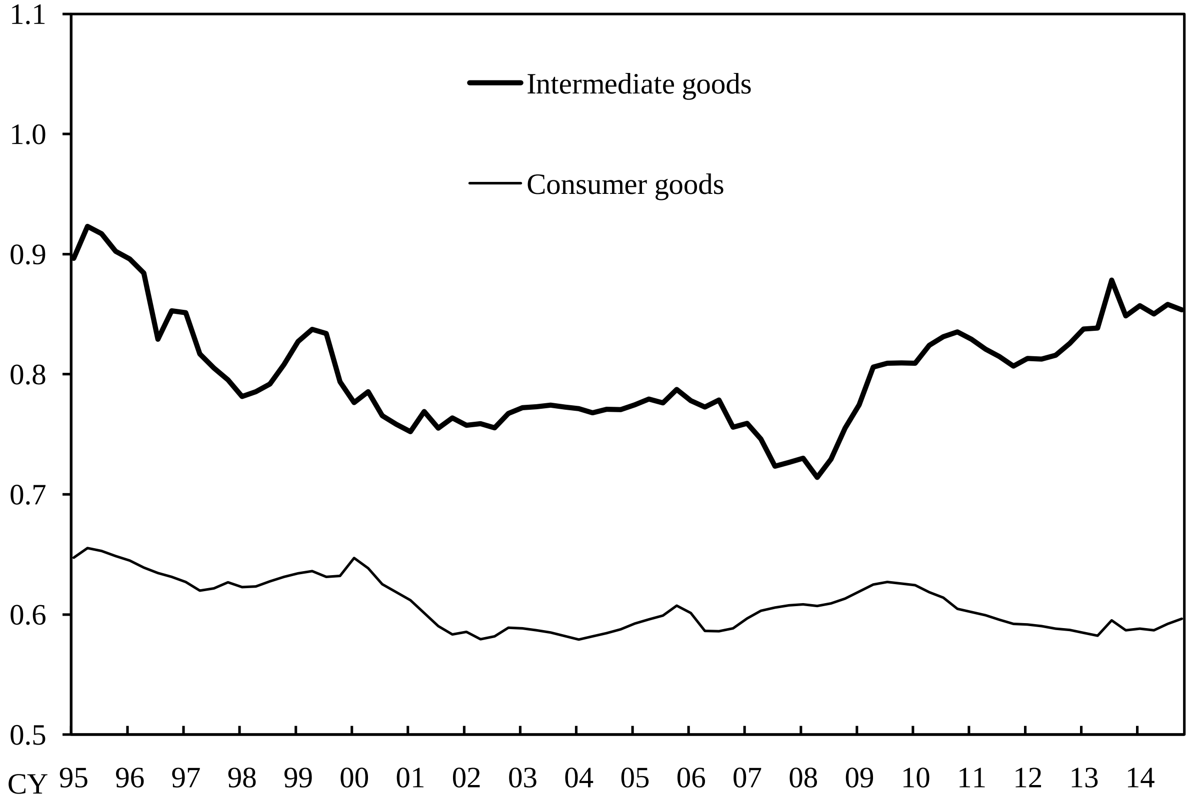


Figure 5: Decomposition of CPI inflation



<u>Figure 6: Estimated exchange rate pass-through by type of goods</u>

(a) IPI



(b) PPI and CPI

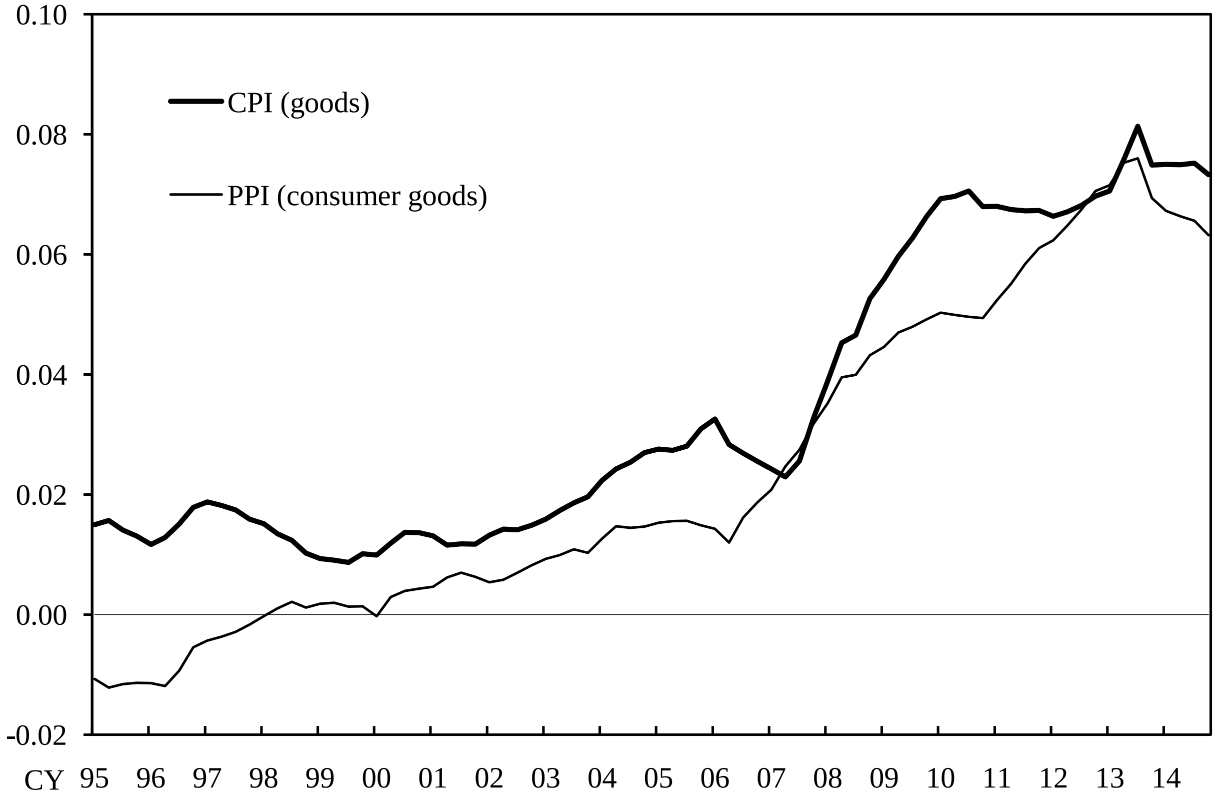
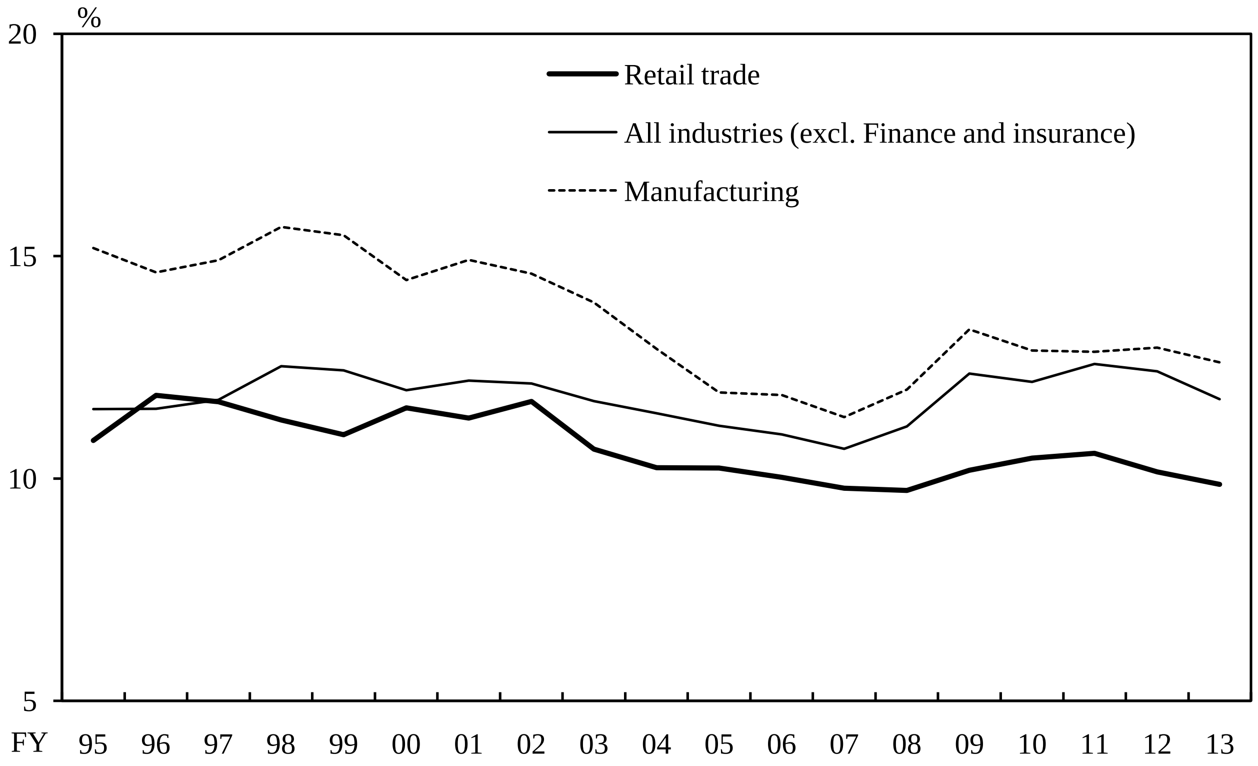


Figure 7: Exchange rate pass-through to production costs

Figure 8. Total labor costs to sales ratio

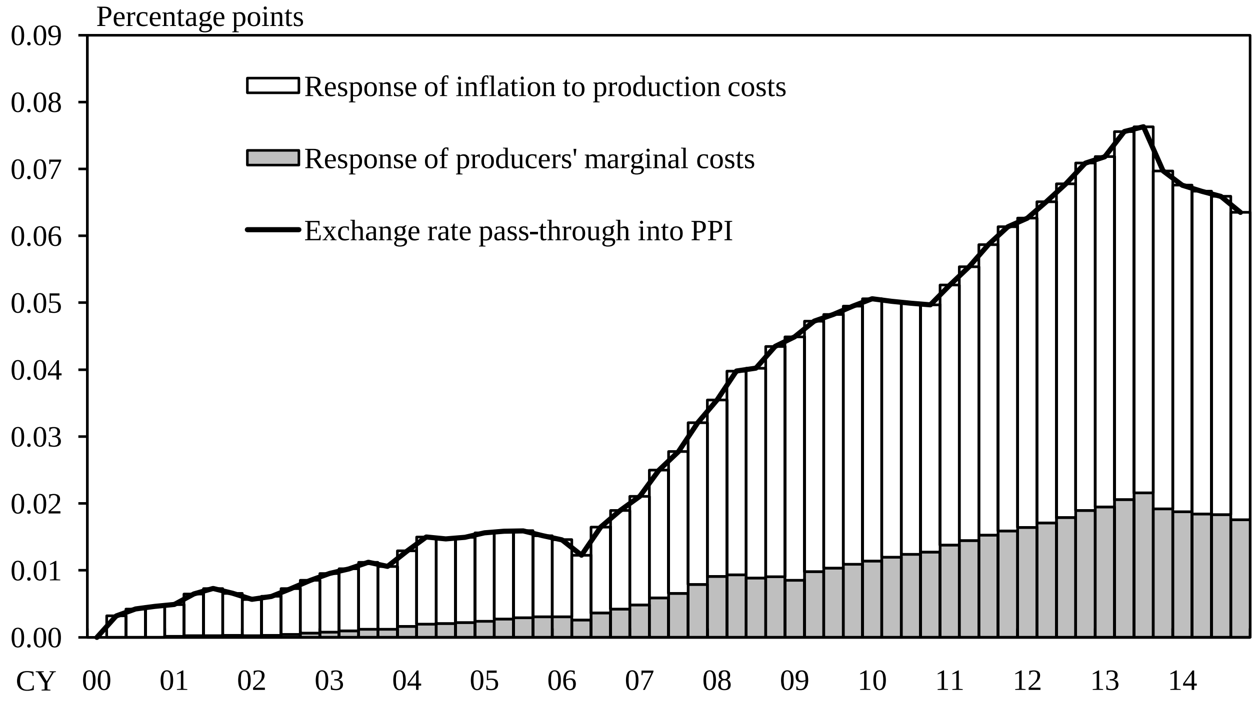


Note: The total labor costs to sales ratio is calculated as the sum of salaries for employees, bonuses for employees, and welfare expenses divided by sales.

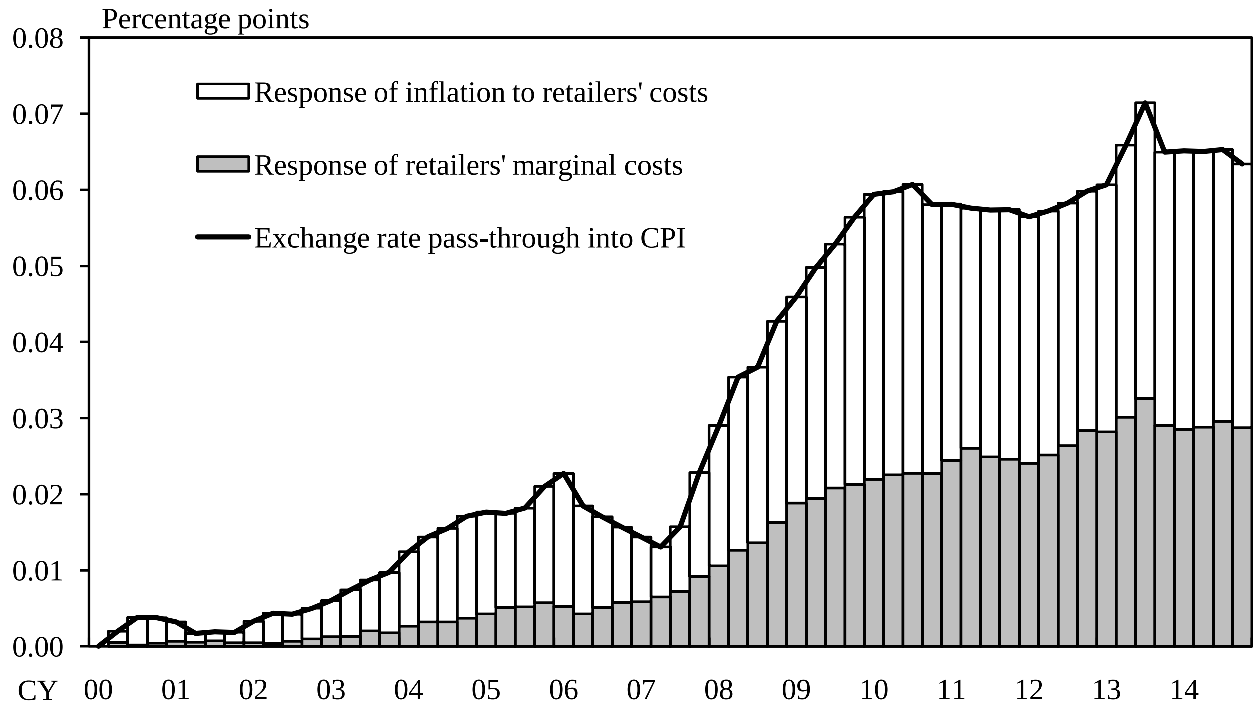
Source: Authors' calculation based on data from Ministry of Finance, "Financial Statements Statistics of Corporations by Industry."

Figure 9: Decomposition of the estimated exchange rate pass-through

(a) Cumulative change of exchange rate pass-through into PPI



(b) Cumulative change of exchange rate pass-through into CPI



Note: Panel (a) shows the cumulative changes in the exchange rate pass-through into producer prices from 2000Q1. The producer price series used is the PPI for consumer goods. Panel (b) shows the cumulative changes in the exchange rate pass-through into consumer prices from 2000Q1. The consumer price series used in this figure is the CPI for goods excluding fresh food, electricity, gas and water charges, and publications. The exchange rate pass-through into retailers' costs in Panel (b) refers to the pass-through into the prices of goods purchased from domestic and foreign producers.