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Exchange rate pass-through under the unconventional monetary policy regime*

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Abstract

We apply the structural VAR model to Japan under the unconventional monetary policy regime, 2000Q1 and 2019Q4. In addition to the traditional sign restrictions, we impose narrative sign restrictions based on five phenomenal economic episodes. Estimated exchange rate pass-through induced by monetary policy shock or exogenous exchange rate shock is consistent with the conventional view, i.e., a Japanese yen depreciation induces inflation at the consumer level. On the other hand, we found evidence of perverse exchange rate pass-through induced by demand shock. A ten percent exchange rate depreciation driven by weak domestic demand is associated with a one percent deflation at the consumer level. The magnitude of the latter effect is greater than the former. This demand-shock-induced exchange rate pass-through effect may have undermined the continuous efforts of the Bank of Japan to achieve the target of a two percent inflation rate.

Keywords: Exchange rate pass-through; Structural VAR; Unconventional monetary policy
JEL Classification: E31 (foreign exchange); F31 (price level); F41 (open economy macroeconomics)

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1. Introduction

The level of inflation rate has become one of the essential targets of monetary policy in many countries; one or two percent annual growth rate of consumer price index are considered sound as maintaining price stability and keeping pace with a moderately growing economy. Nevertheless, successfully adjusting an inflation rate in concert with the inflation target has been challenging for some countries. The Bank of Japan (BOJ) officially adopted in 2013 the inflation targeting of a two percent annual growth rate of the consumer price index. Since then, the BOJ has never achieved its target even once under Governor Kuroda for more than eight years; see Figure 1 for the inflation rate in Japan. Figure 2 also shows that the interest rate had been kept at the effective lower bound even before the adoption of inflation targeting policy, and the BOJ has kept increasing the base money substantially.

Controlling inflation is not a simple task because domestic inflation is not insulated from external shocks. For example, as observed in many countries during the global financial crisis, an external shock of great magnitude diminished the world demand, caused a lower expected future inflation rate, and thus led to a sudden decline in the current price level. During such a challenging period, an unconventional monetary policy, e.g., zero lower bound interest rate and asset-purchasing program, as a countermeasure may only mitigate the situation by slowing down the speed of declining price level.

The domestic price level is also constantly susceptible to other external shocks, i.e., exchange rate fluctuations. Since adopting inflation targeting in 2013, Japan experienced favorable conditions in exchange rate movements to raise inflation. The conventional view supports that the depreciation of home currency induces a rise in the consumer price level by increasing the prices of imported products. The expected range of ERPT falls between zero percent (zero pass-through) and 100 percent (complete pass-through)[1]. From the historical high (since the begging of the Bretton Woods system) of 75.55 yen per US dollar in October 2011, the Japanese yen experienced a significant swing in the direction of depreciation to approximately 100 yen per US dollar in 2013 and then further to approximately 120 yen per US dollar in 2014, see Figure 1. Nevertheless, the inflation rate had never exceeded the target level of two percent annually during these periods.

The literature on exchange rate pass-through has flourished on evidence of how much and what environments a change in the exchange rate may affect the consumer price level. Some studies also focus on the effect of exchange rate movements on import prices. Ito and Sato (2008) find among Asian countries that exchange rate pass-through on consumer price is generally low, whereas exchange rate pass-through on import prices are high, especially for those countries severely hit by the Asian crisis. For the sample of 23 OECD countries between 1975 and 2003, Campa and Goldberg (2005)

[1] Due to anomalies, measurement errors, and other factors, empirical evidence sometimes finds ERPT estimates falling below zero percent. In this case, a depreciation of home currency lowers the consumer price. This downward effect of depreciation on the consumer price is called as ‘perverse’ by Froot and Klemperer (1989).

report that partial exchange rate pass-through on import prices are pervasive in the short run. There is ample evidence that the exchange rate pass-through at the consumer price level is a little even when the exchange rate pass-through at the import price level is substantial, see Sassaki, Yoshida, and Otsubo (2019, 2022), among other studies.

Shambaugh (2008) points out that an exchange rate movement is not entirely exogenous. Various theoretical models suggest that money supplies, interest rates, long-run price levels, and real economic growths, among many other possible sources, affect the exchange rate[2]. Different shocks possibly drive a change in the exchange rate and consumer price, and therefore, exchange rate pass-through may behave differently according to the source of shocks. The study of Forbes, Hjortsoe, and Nenova (2018) focuses on this issue; they examine the exchange rate pass-through of the UK by different structural shocks estimated by the Bayesian vector autoregressive (BVAR) model. They find that the exchange rate pass-through driven by a demand shock works just opposite for UK inflation[3].

In this paper, we estimate the exchange rate pass-through of Japan by adopting the BVAR model of Forbes et al. (2018). In this way, we can examine when and how much each exchange rate depreciation episode contributed to raising the consumer price index in Japan. Our model consists of six variables: gross domestic products of Japan, consumer price index of Japan, policy interest rate of Japan, nominal effective exchange rate of the Japanese yen, import price index of Japan, and the world export price. All variables enter the model in log-difference form except policy interest rate. Following Forbes et al. (2018), twelve zero restrictions and fifteen sign restrictions are imposed on a structural VAR model for the sample of the first quarter in 2000 to the fourth quarter in 2019, just before the COVID-19 pandemic.

For the monetary policy rate, we implement a shadow rate, in which a yield curve at the zero period maturity is considered under the condition that a short interest rate is allowed to fall below the effective lower bound. The observed interest rate is at the effective lower bound only because the interest rate works as an option at that rate, Black (1995). We implement quarterly shadow rates by quarterly-averaging daily shadow rates provided by Krippner (2013); see Figure 2. By replacing the monetary policy rate with shadow rate, we can correctly measure the impact of unconventional monetary policy on other macroeconomic variables even when the rate is observationally fixed at the lower bound.

In addition to the standard restrictions of zero and sign restrictions on impulse response at the impact, we also impose restrictions on contributions of a specific shock on some episodes, the methodology introduced as narrative sign restrictions by Antolín-Díaz and Rubio-Ramírez (2018).

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[2] Monetary models of exchange rate are not well supported by empirical evidence (Cheung, Chin, and Pascual, 2005).

[3] It is no surprise to find downward effect of depreciation on consumer price at the impact because they impose sign restrictions of demand shock on exchange rate and consumer price in a such way. However, these restrictions do not gurantee that ERPT estimates are statistically significant nor 'perverse' at the consequent periods after the impact. Forbes et al. (2018) find that ERPT induced by demand shock is 'perverse' with statistical significance even in the long-run.

These additional narrative sign restrictions improve the precision of Bayesian estimates. The five episodes are the followings: (i) 2001:Q1 (the introduction of quantitative easing policy), (ii) 2006:Q3 (temporally lift of zero interest rate policy), (iii) 2008:Q4 (the outset of the Global Financial Crisis), (iv) 2011:Q1 (the Great East Japan Earthquake and Tsunami), and (v) 2013:Q1 (the beginning of the Abe administration). These episodes are shown as vertical lines in Figure 1.

As a result, we confirmed the following for Japan. Not all exchange rate pass-though is alike; they differ when different structural shocks are in play. More specifically, the most important empirical findings of this paper are the following three points. First, not surprisingly, not all the structural shocks affect consumer prices with statistical significance. Exchange rate pass-through induced by demand shocks, monetary policy shocks, and exogenous exchange rate shocks are statistically different from zero, but not statistically significant for other shocks. Second, an exchange rate depreciation induced by monetary policy shocks or exogenous exchange rate shocks raises consumer price as in the conventional view. However, the median estimates indicate that ERPT is approximately only ten percent. Third, however, an exchange rate depreciation induced by demand shocks lowers consumer price. The median estimate of ERPT induced by demand shock is about twenty percent, roughly two-folds of ERPT induced by either monetary policy or exogenous exchange rate shocks.

Among many other possible causes for the non-responsiveness of consumer prices to rise despite the unconventional monetary policy pursued by the BOJ, we provide one additional explanation to this puzzle in the literature. If an exchange rate depreciation is partly induced by weak domestic demand, the power of other driving forces that push consumer price up will be diminished. In the first quarter of 2013, Japan's nominal effective exchange rate depreciated more than 13 percent. The historical decomposition reveals that monetary policy shock, exchange rate shock, and demand shock contribute 4.7, 3.5, and 1.5 percent to this sharp depreciation, respectively. The median estimates of ERPT induced by monetary policy and exchange rate shocks are less than ten percent, whereas the median of demand-induced ERPT is approximately twenty percent. The back-of-the-envelope calculation indicates that inflationary pressure from this depreciation would have been 0.82 percent instead of 0.52 percent if demand shock were absent.

The rest of the paper is structured as follows. The following section discusses how the exchange rate pass-through approach in Forbes et al. (2018) differs from the standard approach in the literature and briefly reviews the Bayesian approach to the structural VAR model. Section 3 describes the dataset, and section 4 provides how we impose zero, traditional sign, and narrative sign restrictions to identify the structural VAR. Section 5 discusses the results of exchange rate pass-through by structural shocks. The last section concludes.

2. Econometric Approaches for Estimating Exchange Rate Pass-through

This section is not meant to provide a complete perspective of the existing studies in the exchange rate pass-through literature; however, we aim to emphasize how the empirical methodology of SVAR employed in this study complements the mainstream empirical approach in the exchange rate pass-through literature and make a contribution to the accumulated evidence. We also provide brief descriptions of the traditional signs and narrative signs restrictions in the unified framework and define our measure of time-varying ERPT.

2.1. Single-equation reduced form approach

Controlling for possible exogenous variables which might affect the relationship between price and exchange rate, the base regression model in most empirical studies of exchange rate pass-through can be generalized in the following single-equation reduced form.

$$p_{ijt} = \alpha_i + \theta_j + \lambda_t + \beta ex_{ijt} + \sum_{k \in K} \gamma_k X_{ijt}^k + \varepsilon_{ijt}, \tag{1}$$

where ε_{ijt} is disturbance term. The log of price variable as the endogenous variable is denoted as p_{ijt} and they may be import, export, or consumer price with *i, j, t*, denoting exporting country (or firm), importing country (or firm), and time, respectively. The key parameter in the exchange rate pass-through is β with ex_{ijt} denoting the log of bilateral exchange rate between country *i and j*. Heterogeneity among exporters, importers, and trend/seasonality are controlled by individual dummies, α_i and θ_j, and time dummies, λ_t. Panel data analysis with two-way fixed effects is first introduced by Knetter (1989) to the literature and is also adapted in Takagi and Yoshida (2001) among many other studies. Contributions of many new studies can be attributed to the introduction of a new control variable in X_{ijt}^k.

Equation (1), based on microeconomic or industry organizational perspectives, overlooks the potential problem of endogeneity of some of the explanatory variables. Instead of relying on instrumental variable estimation to address the endogeneity problem, Ito and Sato (2008) applied a five-variable VAR model to allow an interacting relationship between exchange rate and prices. Five variables are oil prices, output gap, money supply, exchange rate, and price index. For the place of price index, import price, producer price, and consumer price index are used alternatively. Borensztein and von Heideken (2016) apply a variant of VAR model to six South American countries. On the other hand, Shioji (2012) and Sasaki, Yoshida, and Otsubo (2019, 2022) exclusively focus on the interaction among exchange rate and import price, producer price, and consumer price in Japan and apply time-varying parameter (TVP) VAR. Similarly, Donayre and Panovska (2016) apply a Bayesian threshold VAR, a variant of TVP-VAR in which parameters alter between two regimes, to Canada and Mexico.

2.2. Structural VAR with traditional sign restrictions and narrative sign restrictions

Critical implications arise when exchange rate pass-through is seen as simultaneous responses of prices and exchange rate to structural shocks: Different underlying shocks affect exchange rate and price differently. For example, if the underlying mechanism in equation (1) is based on the foreign exporting firm's pricing behavior, a depreciation of home currency will be only partly reflected as an increase in import price. In this framework, what kind of underlying shocks originally caused a move in the exchange rate is not adequately addressed. The first study to bring this concept to attention is the work by Shambaugh (2008). Consequently, Forbes, Hjortsoe, and Nenova (2018) applied it to the UK; Comunale and Kunovac (2017) to Germany, France, Italy, and Spain; Corbo and Di Casola (2018) to Sweden; An, Wynne, and Zhang (2021) to Japan; and Forbes, Hjortsoe, and Nenova (2020) to 26 small open economies with flexible exchange rate regime.

We follow Rubio-Ramírez, Waggoner, and Zha (2010) and Arias, Rubio-Ramírez, and Waggoner (2018) for a general SVAR model with traditional sign restrictions and zero restrictions, and Antolín-Díaz and Rubio-Ramírez (2018) for implementing narrative sign restrictions[4]. A structural VAR(p) model is represented as Equation (2).

$$y_t^{'} A_0 = \sum_{i=1}^{p} y_{t-i}^{'} A_i + c + \varepsilon_t^{'} \tag{2}$$

where y_t is an $n \times 1$ vector of variables including exchange rate, price, and other macroeconomic variables. Autoregressive parameters in an $n \times n$ matrix are denoted as A_i for $1 \le i \le p$. The impact parameters are denoted as A_0 in an invertible $n \times n$ matrix. Structural shocks in an $n \times 1$ vector form denoted as ε_t is Gaussian with mean zero and convarince matrix I_n, the $n \times n$ identity matrix.

The model can be expressed in reduced form as

$$y_t^{'} = \sum_{i=1}^{p} y_{t-i}^{'} A_i A_0^{-1} + \varepsilon_t^{'} A_0^{-1}$$

$$y_t^{'} = \sum_{i=1}^{p} y_{t-i}^{'} B_i + u_t^{'} \tag{3}$$

where $B_i = A_i A_0^{-1}$ and $u_t^{'} = \varepsilon_t^{'} A_0^{-1}$ and $E[u_t u_t^{'}] = E[A_0^{-1'} \varepsilon_t \varepsilon_t^{'} A_0^{-1}] = E[A_0^{-1'} A_0^{-1}] = \Sigma$. By denoting $\mathbf{A} = [A_1 \cdots A_p]$ and $\mathbf{B} = [B_1 \cdots B_p]$, the matrices $(\mathbf{B}, \Sigma)$ are the reduced-form parameters and $(A_0, \mathbf{A})$ are the structural parameters. Given structural parameters, the structural shocks at time t are $\boldsymbol{\varepsilon}_t^{'}(A_0, \mathbf{A})$.

Following Antolín-Díaz and Rubio-Ramírez (2018), we define impulse response functions and historical decompositions as functions of structural parameters and structural shocks. Narrative sign restrictions use historical decomposition, whereas traditional sign restrictions use impulse

[4] See Kilian and Lütkepohl (2017) for succinct summary of structural VAR model and the methodology associated with identifications.

response functions. Impulse response functions in matrix form are defined recursively by

$$\mathbf{L_0}(A_0,\mathbf{A})=(A_0^{-1})', \quad \mathbf{L}_k(A_0,\mathbf{A})=\sum_{i=1}^{k}(A_iA_0^{-1})'\mathbf{L}_{k-i}(A_0,\mathbf{A}) \ \text{ for } \ 1\le k\le p,$$

and $\mathbf{L}_k(A_0,\mathbf{A})=\sum_{i=1}^{p}(A_iA_0^{-1})'\mathbf{L}_{k-i}(A_0,\mathbf{A})$ for $p<k<\infty$.

The historical decomposition, i.e., the contribution of the *j*th shock to the observed unexpected change in the *h*th variable between period *t* and $t+\tau$ is

$$\mathbf{H}_{h,j,t,t+\tau}(A_0,\mathbf{A},\boldsymbol{\varepsilon}_t,\cdots\boldsymbol{\varepsilon}_{t+\tau})=\sum_{k=0}^{\tau}e_{h,n}^{'}\mathbf{L}_k(A_0,\mathbf{A})e_{j,n}e_{j,n}^{'}\boldsymbol{\varepsilon}_{t+\tau-k},$$

where $e_{j,n}$ is the *j*the conlumn of I_n, for $1\le h,j\le n$ and for $\tau\ge 0$.

Traditional sign restrictions can be characterized by the following function, Arias, Rubio-Ramírez, and Waggoner (2018).

$$\boldsymbol{\Gamma}(A_0,\mathbf{A})=(e_{1,n}^{'}\mathbf{F}(A_0,\mathbf{A})'\mathbf{S}_1^{'},\ldots,e_{n,n}^{'}\mathbf{F}(A_0,\mathbf{A})'\mathbf{S}_n^{'})'>0 \tag{4}$$

Narrarive sign restrictions can be characterized by the three classes, Antolín-Díaz and Rubio-Ramírez (2018). The first class imposes the sign on the *j*th shock at the particular date, $\tilde{t}$. For example, for a positive shock restriction,

$$e_{j,n}^{'}\boldsymbol{\varepsilon}_{\tilde{t}}>0 \tag{5}$$

The second class imposes that a contribution of *j*th shock in the *h*th variable at the particular date, $\tilde{t}$, is larger in absolute terms than contributions of any other shocks. This shock is called the *most important* driver or Type A restriction on the historical decomposition in Antolín-Díaz and Rubio-Ramírez (2018).

$$\left|\mathbf{H}_{h,j,t,t+\tilde{t}}(A_0,\mathbf{A},\boldsymbol{\varepsilon}_t,\cdots,\boldsymbol{\varepsilon}_{t+\tilde{t}})\right|>\max_{j^{'}\ne j}\left\{\left|\mathbf{H}_{h,j^{'},t,t+\tilde{t}}(A_0,\mathbf{A},\boldsymbol{\varepsilon}_t,\cdots,\boldsymbol{\varepsilon}_{t+\tilde{t}})\right|\right\} \tag{6}$$

The third class imposes that a contribution of *j*th shock in the *h*th variable at the particular date, $\tilde{t}$, is larger in absolute terms than the sum of contributions of all other shocks. This shock is called the *overwhelming* driver or Type B restriction on the historical decomposition in Antolín-Díaz and Rubio-Ramírez (2018).

$$\left|\mathbf{H}_{h,j,t,t+\tilde{t}}(A_0,\mathbf{A},\boldsymbol{\varepsilon}_t,\cdots,\boldsymbol{\varepsilon}_{t+\tilde{t}})\right|>\sum_{j^{'}\ne j}\left\{\left|\mathbf{H}_{h,j^{'},t,t+\tilde{t}}(A_0,\mathbf{A},\boldsymbol{\varepsilon}_t,\cdots,\boldsymbol{\varepsilon}_{t+\tilde{t}})\right|\right\} \tag{7}$$

The structural parameters of SVAR model are set-identified by drawing a set of reduced parameters from the posterior distribution, drawing orthonormal matrix, recovering structural parameters, and checking whether structural parameters satisfy the identification restrictions of zero, traditional signs, and narrative signs.

2.3. Exchange rate pass-through induced by structural shocks

After obtaining impulse responses of exchange rate and consumer price index from individual structural shocks, we can define shock-specific exchange rate pass-through as the ratio of the cumulated changes in consumer price index to the cumulated changes in exchange rate to the corresponding structural shock. More specifically, $ir^h(t;j) \equiv e_{h,n}^{'} L_t(A_0, \mathbf{A}) e_{j,n}$ is the impulse response of variable *h*, either price or exchange rate, at *t*-th quarter after the *j*-th structural shock. Exchange rate pass-through evaluated at the τ -th quarter after the *j*-th structural shock is defined as the following.

$$ERPT(\tau;j) = \frac{\sum_{t=0}^{\tau} ir^p(t;j)}{\sum_{t=0}^{\tau} ir^{er}(t;j)} \tag{8}$$

Therefore, exchange rate pass-through measured in this approach are time-varying and shock-dependent. The TVP-VAR approach adopted in Shioji (2012) and Sasaki et al. (2019, 2022) can provide evidence of time-varying exchange rate pass-through; however, their methodology cannot explain why. This approach complements these studies and explains why exchange-rate pass-through is time-varying: The exchange rate pass-through is time-varying because underlying structural shocks are different at different points of time.

3. Data

Real gross domestic product is a seasonally adjusted quarterly series provided by the Cabinet Office of Japan. The consumer price index is consumption-tax adjusted series calculated by the Ministry of Internal Affairs and Communications. The quarterly CPI is constructed by averaging the monthly series. Monetary policy rates are constructed by combining the following two sources. Quarterly policy rates between 1990Q1 and 1994Q4 are calculated by averaging the monthly average of overnight call rates[5]. Quarterly shadow rates between 1995Q1 and 2019Q4 are constructed by averaging the daily shadow rate series of Krippner (2013), updated on his website. Nominal effective exchange rate in quarterly series is taken from the IFS, IMF. Import price is the import price index, with the year 2015 as the base, in the Corporate Goods Price Index by the Bank of Japan.

Under the conventional monetary policy regime, short-term policy rates such as the federal fund rates in the US and overnight call rates in Japan correctly represent the monetary policy stance. However, an unconventional monetary policy such as large asset purchase by the central banks will not be reflected on the policy rates when the policy rates are at the zero lower bound or effective lower bound. If possible, the policy rate would have been in the negative range under the unconventional

[5] In the following empirical sections, we choose the sample period of the base model to be between 2000Q1 and 2019Q4 for the sake of computation time as described in footnote 10. Therefore, call rates are not used in the main empirical estimations. However, we also estimated the SVAR model between 1990Q3 and 2019Q4 for robustness check.

monetary policy regime. Black (1995) suggests the idea that the holders of bonds have an option to convert them to cash when interest rates hit zero or a negative rate. Therefore, a shadow rate can be in the negative range even when an observable nominal rate is at the effective lower bound. Krippner (2013) and Ichiue and Ueno (2007) provide a shadow rate for Japan by calculating the shadow term structure[6]. We construct quarterly series for the Japanese monetary policy rate by averaging the daily shadow rate updated on Krippner's website.

The world export price index is constructed in the following procedure. The selection of the top 20 exporters to Japan is based on the total export values, which aggregate exporting country's annual export to Japan over the sample between 1990 and 2019. Each year, the country weight is recalculated by an exporter's share among the top 20 exporters in exports to Japan. The export price of each country is taken from three sources: quarterly 'export price index' in IFS; the combination of annual 'price level of exports' in Penn World Table, and quarterly 'producer price index' in IFS. For the US, Australia, Korea, Germany, France, Singapore, UK, quarterly 'export price index' in the IFS are directly used. For China, Malaysia, Thailand, Canada, and Italy, 'export price index' is not available; therefore, the annual value of 'price level of export' in the corresponding year is adjusted by the percentage difference in the corresponding quarter from the annual average of quarterly 'producer price index.'

Some caveats should be mentioned here. First, reliable data are only available for 12 countries among the top 20 countries. The most reliable source is the quarterly series of 'export price index.' The PWT's 'price level of export' is also reliable, but it is only available in the annual frequency. We implemented interpolation methodology by reflecting a quarterly change in other related series, namely, 'producer price index' and 'wholesale price index,' to modify the frequency from annual to quarterly. We have compared the correlations with 'export price index' of 'producer price index' and 'wholesale price index.' We decided to use 'producer price index' because we found higher correlations for 'producer price index' for more countries when both 'producer price index' and one of these two alternative indexes is available. Second, not all 12 countries have the maximum number of observations. We rescaled the individual weights by dividing the exporter's share by the total share of all top 20 exporters available in the corresponding year. The total share of available top 20 exporters varies by year, but it is consistently above 50 percent throughout the sample years. All series are log-differenced and multiplied by 100 except for the monetary policy rate.

4. The Specifications and Restrictions of the SVAR Model

4-1. The SVAR model

Closely following the SVAR model of Forbes et al. (2018) for UK, Equation (2) or (3)

[6] Wu and Xia (2016) propose multi-factor shadow rate term structure model and the updates for the US shadow rates are available on the Atlanta Fed's website.

applied to the Japanese economy between 2000Q1 and 2019Q4[7] can be expressed as the following.

$$\begin{aligned}&[\Delta \ln GDP_t \quad \Delta \ln CPI_t \quad sr_t \quad \Delta \ln neer_t \quad \Delta \ln mp_t \quad \Delta \ln wep_t] A_0 = \\ &\sum_{i=1}^{2} [\Delta \ln GDP_{t-i} \quad \Delta \ln CPI_{t-i} \quad sr_{t-i} \quad \Delta \ln neer_{t-i} \quad \Delta \ln mp_{t-i} \quad \Delta \ln wep_{t-i}] A_i + \varepsilon_t\end{aligned} \tag{9}$$

where *GDP* is a seasonally adjusted real gross domestic product, *CPI* is the consumer price index, *sr* is a shadow rate, *neer* is a nominal effective exchange rate, *mp* is the import price index, and *wep* is the world export price index.

To identify the structural shocks, we need to put the number of sign and zero restrictions on the impulse responses of endogenous variables to the corresponding structural shocks. The identification algorithm implemented in this study adopts Binning's (2013) under-identified model, which extended the algorithm suggested by Rubio-Ramirez et al. (2010). The short and long-run zero restrictions and sign restrictions are presented in Table 1, and the DSGE model in Forbes et al. (2018) is briefly described in the following subsection.

4-2. Zero and sign restrictions based on the DSGE model

Short- and long-run zero restrictions and sign restrictions are based on the open-economy DSGE model of Forbes et al. (2018). Their model is a standard model in the DSGE literature in which both price rigidities and local-currency pricing generate incomplete exchange rate pass-through. Some exporters set their prices in their own currency (i.e., producer-currency pricing), and others set their prices in the currency of destinations (i.e., local-currency pricing). Prices are set in a staggered Calvo fashion. These features play the same role in exchange rate pass-through to all shocks. However, exporter's pricing decisions also involve their expected marginal costs and expected demand conditions in a forward-looking manner, and they respond differently to different shocks. Therefore, we observe different patterns of exchanger rate pass-through with corresponding structural shocks.

4-3. Narrative sign restrictions based on the five episodes

We have selected five pivotal episodes, in which the effect of specific structural shock clearly constitutes the overwhelming contribution to a change in one of the endogenous variables, from both international and domestic perspectives during the sample period. These five episodes are shown as vertical lines in Figure 1. (i) The first episode is the introduction of quantitative easing policy in the first quarter of 2001, in which the policy target for money market operation is changed from the call rate to the outstanding current account balances at the BOJ. In this episode, we impose a restriction that monetary policy rate shock on the exchange rate is negative and the contribution is overwhelming. (ii) The second episode is the temporally lifting of zero lower bound monetary policy in the third quarter of 2006. The narrative restriction for this episode is the following: the monetary policy shock

[7] To make the empirical results of Japan in this study comparable to the results of UK in Forbes et al. (2018), we chose the number of lags to be two. Therefore, the beginning of the sample starts from the third quarter of 2000 in the regression.

appreciates exchange rate, and its contribution is overwhelming. We alternatively impose a modified restriction in this episode that the demand shock pushed the policy rate up, and its contribution is overwhelming. (iii) The third episode is the global turmoil after the collapse of the Lehman Brothers in September 2008; we choose the fourth quarter of 2008 for a narrative sign restriction. The policy rates in the US as well as in Europe are lowered abruptly during this quarter period, raising the relative position of the Japanese policy rate against those overseas. In this episode, we impose a restriction that a monetary policy shock appreciated the Japanese yen, and its contribution is overwhelming. (iv) The fourth episode is the Great East Japan earthquake in the first quarter of 2011. The production facility was devastated in the northeastern region of Japan due to the tsunami, and the supply system in the broader area of Japan was severely affected because of disruption in the domestic supply chain. The narrative restriction for this episode is the following: the supply shock deteriorated the GDP of Japan, and its contribution is overwhelming. (v) The fifth episode is the political power transition to the Abe administration of the Liberal Democratic Party in the first quarter of 2013. The general election in December of 2012 defeated the ruling party, the Democratic Party, and we observed the Japanese yen start a sharp depreciation. At that time, the former governor of the Bank of Japan was still Mr. Shirokawa, and the large-size purchase of the Japanese government bonds by Mr. Kuroda was yet to come. We impose a narrative restriction that the exogenous exchange rate shock depreciated the Japanese yen, and its contribution is overwhelming.

4-4. Two-step algorithm to impose narrative sign restrictions

The narrative sign restriction SVAR algorithm suggested by Antolín-Díaz and Rubio-Ramírez (2018) impose all zero, traditional sign, and narrative sign restriction on each draw. The Bayesian set estimate of structural parameters consists of these draws, which passed all restrictions. This algorithm is efficient if a study either has only one episode or simultaneously estimate for multiple episodes[8]. However, it is more efficient to (i) impose only zero and traditional sign restrictions on draws to obtain the first-pass set and (ii) then impose narrative sign restrictions on draws from the first-pass set, if one aims to compare the effect of imposing different episodes on the final set of structural parameters, impulse responses, or historical decompositions as in this study. We use this two-step algorithm in this study[9].

5. Empirical Results

5-1. Exchange rate pass-through by shocks with only traditional sign restrictions

[8] Antolín-Díaz and Rubio-Ramírez (2018) are well aware of exponential increase of calculation burden for multiple episodes or events. The authors' caveats are noted in the footnote 4 and the appendix D of their study.

[9] The matlab codes will be made publicly available once this study is published. In the first step, we use matlab codes for Bayesian SVAR estimates provided by other authors. In the second step, we originally coded the part which impose narrative sign restriction on the first-pass set.

The sample period is from the first quarter in 2000 to the fourth quarter in 2019[10]. The standard set of output results, such as impulse responses of each variable, is available in the appendix figures A1 through A6 in the supplementary material. In this section, we immediately turn to the estimates of exchange rate pass-through. It should be noted that an increase in the nominal effective exchange rate represents an appreciation. Figure 3 provides the (median) exchange rate pass-through calculated as the ratio of the accumulated impulse response of consumer price index to the accumulated impulse response of exchange rate, with respect to corresponding shocks as defined by equation (8) in section 2.3. Zero exchange rate pass-through cannot be rejected for supply shocks, persistent global shocks, and transitory global shocks.

However, we can find an appreciation of exchange rate is associated with a decrease in the consumer price index for monetary policy shock and exogenous exchange rate shock and their confidence intervals are significantly below zero. In other words, a depreciation of the Japanese yen associated with these two structural shocks should be associated with positive inflation, which will help the BOJ to achieve its inflation targeting goal. Figure 4 shows that even the 97.5-th percentile of exchange rate pass-through is below zero throughout 20 quarters after the monetary policy shock. The median exchange rate pass-through is approximately - 0.08. This implies that the consumer price index increases by 0.8 percent, achieving 40 percent of inflation targeting goal if the Japanese yen depreciates by ten percent solely due to the monetary shock. Similarly, for an exogenous exchange rare shock, exchange rate pass-through is well below zero for the 68-th percentile throughout 20 quarters but only up to five quarters for the 97.5-th percentile, as shown in Figure 5. The median draw of exchange rate pass-through induced by exogenous exchange rate shock is approximately minus nine percent.

On the other hand, the exchange rate pass-through associated with domestic demand shock is positive and its credible interval is well above zero. Figure 6 presents the upper and lower percentiles for 68 and 95 percent bands and median exchange rate pass-through for demand shock. The exchange rate pass-through induced by demand shock goes against the conventional wisdom of how prices respond to an appreciation of the home currency. An increase in the consumer price index is associated with an appreciation of exchange rate when Japan is affected by a positive demand shock. More appropriately put for the long-lasting period of the slow growth of Japan, weak demand shock simultaneously depreciates the Japanese yen and puts deflationary pressure on the consumer price. This is, in general, consistent with many macroeconomic models; however, in the literature of

[10] The estimation execution time heavily depends on the sample period. Before determining the sample period for this study, we attempted various sets of sample period. By fixing the last quarter to the 2019Q4 and setting the first quarter to various periods, we decided to disregard those sample periods which cannot find a single draw satisfying zero and sign restrictions within an hour. The workstation used for computation is Dell Precision 5750 with Intel(R) Xeon(R) W-10855M CPU @2.80GHz. 1,000 draws for this study took the total computation time of 165 hours (6.9 days) for the sample period used in this study. Alternatively, merely 100 draws take 187 hours for the sample starting from 1990Q3. Although only with one tenth of draws, the qualitative shapes of exchange rate pass-through by shocks resemble those in Figure 3.

exchange rate pass-through, the phenomenon is called as perverse[11]. This demand effect on exchange rate pass-through in Japan is consistent with the UK results in Forbes et al. (2018).

We also calculated the exchange rate pass-through on import price by structural shocks, see Figure 7. All series, except the one corresponding to transitory global shock, demonstrate similar responses to exchange rate pass-through on consumer price index as shown in Figure 3. More importantly, the median estimates for the import price are less precise and vary more widely than those for the consumer price. With 95 percent credible intervals, none of the exchange rate pass-throughs by shocks are different from zero[12].

The study closely related to our study focusing on exchange rate pass-through on Japanese consumer price is Sasaki, Yoshida, and Otsubo (2019, 2022), which estimates the time-varying coefficient VAR model of four variables, i.e., namely, nominal effective exchange rate, corporate import price, corporate domestic price, and consumer price index. During the sample period between 1988 and 2017, they find exchange rate pass-through on the consumer price index increases and becomes statistically significant in the recent period; however, it is at most two percent. Our study complements Sasaki et al. (2019, 2022) and explains why exchange rate pass-through is relatively small in comparison with other studies with empirical evidence at the firm or product level. The most important findings of this study are that not all exchange rate movements are associated with the same corresponding movements in the consumer price index. Each structural shock, especially demand shock, induces different signs of exchange rate pass-through. An exchange rate pass-through estimated with all shocks combined will be small due to the canceling effects among structural shocks.

5-2. *Exchange rate pass-through by shocks with traditional and narrative sign restrictions*

We implement the two-step algorithm described in section 4-4. The first-pass set consists of 1,000 draws and is fully described in the previous section. The five episodes are the followings: (i) 2001:Q1 (the introduction of quantitative easing policy), (ii) 2006:Q3 (temporally lift of zero interest rate policy), (iii) 2008:Q4 (the outset of the Global Financial Crisis), (iv) 2011:Q1 (the Great East Japan Earthquake and Tsunami), and (v) 2013:Q1 (the beginning of the Abe administration). Table 2 represents the number of draws satisfying narrative restrictions of two classes out of 1,000: The sign of shock in Equation (5) and the overwhelming shock restriction in Equation (7). First, all episodes except for the episode in the third quarter of 2006 are consistent in terms of the sign of structural shocks with the first-pass set. For four episodes, more than 85 percent of the draws in the first-pass set are consistent with sign restrictions imposed on the structural shock. The overwhelming or Type B narrative sign restriction in Equation (7) is more restrictive in general; however, more than 20 percent of the first set draws satisfy the restriction, except for the third quarter of 2006Q3. Therefore, we are

[11] A microeconomic model can also induce a perverse exchange rate pass-through when market share enters the objective function of exporting firm in a two-period model, Froot and Klemperer (1989).

[12] With 68 percent intervals, exchange rate pass-through by monetary policy shocks are significantly different from zero for the first three periods and exchange rate pass-through by persistent global shock for only the first period.

left with four narrative sign episodes to proceed.

In order to increase accuracy and make results comparable with the previous section, we combined the 1,000 draws in the first-pass set with another 3,000 draws, which satisfy both zero and traditional sign restrictions. The numbers of the set for structural parameters, impulse responses, and historical decompositions are approximately four folds of the figures in the rightmost column in Table 2. In order to calculate importance weight, we simulate 10,000 independent draws of structural shocks from the standard normal distribution[13]. The importance-weighted results are summarized in Figures 8 through 10[14]. Figure 8 compares the dynamics of exchange rate pass-through induced by monetary policy shock of narrative sign restrictions for episodes (i), (iii), (v), and that of without narrative sign restrictions. There is almost no conceivable difference between no-episode result and episode (v). However, additional narrative sign restrictions for episodes (i) and (iii) significantly increase the accuracy of credible intervals. The estimate of exchange rate pass-through induced by monetary policy shock ranges between -0.01 and -0.14 with 95 percent credibility when we impose the restriction that monetary policy shock overwhelms other structural shocks in the exchange rate movement in the first quarter of 2000.

Similarly, Figure 9 compares the dynamics of exchange rate pass-through induced by exogenous exchange rate shock. For exchange rate shock, neither episode (i) nor episode (iii) makes any discernable difference to the exchange rate pass-through dynamics of estimates without narrative sign restrictions. However, imposing narrative sign restriction on the first quarter of 2013 in episode (v) reduces the credible interval to approximately one-tenth. Moreover, it almost wipes out the possibility of positive exchange rate pass-through after 12 quarters, as observed in Panel (a) through (c). Nevertheless, imposing additional narrative sign restrictions on monetary policy shock or exchange rate shock does not improve the preciseness in the exchange rate pass-through induced by demand shocks. Four panels in Figure 10 are almost equivalent.

To summarize the findings with additional narrative sign restrictions imposed on the set of structural parameters obtained in the previous subsection, we have the following points. First, 'the introduction of zero interest rate as unconventional monetary policy overwhelmingly affected the Japanese yen to depreciate' is consistent with the set of structural parameters obtained for zero and traditional sign restrictions whereas 'temporally lifting of zero interest rate overwhelmingly affected the Japanese yen to appreciate' is inconsistent. Second, imposing narrative sign restrictions on the structural shock significantly improves the preciseness of exchange rate pass-through estimates induced by the same shock. Therefore, finding an episode with correctly specified narrative sign

[13] For the algorithm to calculate the importance weight of parameters, see Algorithm 1 in Antolín-Díaz and Rubio-Ramírez (2018). For the step (v) in the Algorithm 1, we simply find the median and credible region by using the importance-weighted draws that satisfy zero, traditional sign, and narrative sign restrictions.

[14] Episode (iv), which relies on the information of supply shock, does not make any discernable changes to the exchange rate pass-through dynamics. In the following, therefore, we omit the results of using episode (iv) as narrative sign restrictions as well as episode (ii).

restrictions is essential for modeling a structural VAR model.

5-3. Discussions

So far, we have shown that exchange rate pass-through is shock-dependent and the degree of which varies widely to the extent that the signs of effects can be opposite. However, how important is each structural shock as a determinant of ERPT? A structural shock may associate with (in terms of absolute value) a high degree of exchange rate pass-through, but it does not affect the overall exchange rate pass-through if its contribution to affecting the exchange rate is negligent. Table 3 provides forecast error variance decomposition of exchange rate changes at one, four, and twenty quarters ahead of forecast horizons. The two largest contributions for exchange rate fluctuations are monetary policy and exogenous exchange rate shocks, and each approximately contributes to one-third of exchange rate changes. On the other hand, the proportion of exchange rate changes due to domestic demand shocks is only six percent after one year. So, demand shock may lower consumer price even when it drives the Japanese yen to depreciate, but that phenomenon is not observed as often as exchange rate movement driven by either a monetary policy or exogenous exchange rate shock.

The historical decomposition of the exchange rate, an alternative way to measure the relative importance of each structural shock in exchange rate movements, is shown in Figure 11. A few points are noteworthy. First, the contribution of structural demand shocks is, in general, not large. However, there are some periods in which demand shock makes the largest contribution to exchange rate movement. These quarters are 2006Q2, 2007Q4, 2017Q2, and 2018Q3. Second, the largest depreciation of the Japanese yen, over 13 percent change, occurred in the first quarter of 2013 during the sample period. The contribution of structural demand shock is not negligible, i.e., 1.5 percent. Both monetary policy and exogenous exchange rate shocks contribute more to the depreciation of the Japanese yen; however, the absolute value of the median ERPT on the consumer price index by demand shock is much higher than those two shocks, see Figures 4 through 6. On the impact, the demand shock ERPT is over 40 percent, and both the monetary policy shock and exogenous exchange rate shock are less than ten percent. The ERPT effect generated by the demand shock impeded the inflationary pressure from the largest depreciation in the first quarter of 2013.

What does the structural demand shock look like?[15] The Bayesian approach in this paper produced the 4,000 draws satisfying the zero and traditional sign restrictions. The associated parameters with each draw generate a unique time series of structural demand shocks. Following the methodology adapted in Keating et al. (2019), Figure 12 depicts the cumulative values of the median demand shocks. The five narrative episodes are represented with vertical lines. The following three observations provide support for the median structural shock adequately to represent the underlying Japanese economy. First, the cumulative demand shocks are in the negative region most of the time.

[15] The demand in this model does not distinguish between private consumption and public spending. Therefore, the demand refers to the aggregate demand in which fluctuating government expenditure should also matter.

These cumulated negative effects correctly capture weak demand in the long-lasting recessional phase of Japan during the sample period. Second, the five episodes are associated with large shocks, sometimes by a quarter lag or lead. The large negative shocks are associated with the Global Financial Crisis and the beginning of the Abe administration. Third, the two-year long upward trend of demand shocks is observed from the first quarter of 2017 to the last quarter of 2018. This upward trend matches the rising figures in some consumer indicator indices, see the Japan Cabinet Office (2018)[16]. In 2017, the general consumption index came back to the previous level of 2013. The online questionary survey toward future consumption has kept rising from 2014 through 2017.

We find that demand-shock-induced exchange rate pass-through derails the BOJ of achieving the inflation targeting of two percent, whereas inflationary pressure from a depreciation of the Japanese yen works as the conventional view when the monetary policy or exchange rate shock is in play. Are these results of shock-dependent exchange rate pass-through peculiar to Japan? In Appendix Figure B1, we put figures of exchange rate pass-through by structural shocks of UK and Japan side by side for comparison. The following three points are noteworthy. First, a demand shock in both UK and Japan leads to 'perverse' ERPT, i.e., simultaneous depreciation and deflation. There is a large difference in magnitude in the first few quarters after the demand shock; however, they both converge to approximately 0.2 in the long run. Second, the ERPT induced by only demand, monetary policy and exogenous exchange rate shocks are statistically significant in Japan; however, all shocks are statistically significant in UK. Third, neither 'persistent' nor 'transitory' global shocks are statistically significant in Japan, while these are the largest contribution to the UK ERPT.

There exist two other studies examining the Japanese ERPT by using the shock-dependent ERPT approach: Forbes, Hjortsoe, and Nenova (2020) and An, Wynne, and Zhang (2021). Forbes et al. (2020) modified their own model of Forbes et al. (2018) by adding three global variables, i.e., weighted foreign gdp, weighted foreign cpi, and weighted foreign interest rates, and removing the two original global variables, resulting as the seven-variable SVAR model. The focus of Forbes et al. (2020) is on the overall examination of 26 countries, and therefore the specific result for each country is not fully described in their paper. However, forecast error variance decomposition and historical decomposition demonstrate that both domestic demand and Japan's monetary policy shocks dominate the Japanese yen movements in the sample between 1990Q1 and 2015Q4. We can conclude that Forbes et al. (2020) and this study both demonstrate that domestic factors, rather than global or foreign factors, are more relevant for fluctuations of the Japanese yen despite that the global variables are differently constructed in this study and in Forbes et al. (2020).

An, Wynne, and Zhang (2021) examine Japan's ERPT by applying the model of Forbes et al. (2018) as in this study. However, numerous differences exist between An et al. (2021) and this study.

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[16] The Japan Cabinet Office publishes the annual report on the Japanese economy (in Japanese). For the 2017-2018 fiscal year issue, section 2 runs the title 'gradual recovery continues for Japanese economy' (translation by the authors of this study). See Figure 1-2-3 on page 28 in the Japan Cabinet Office (2018).

This study uses quarterly data between 2000Q1 and 2019Q4, whereas An et al. (2021) use monthly data between February 1980 and December 2017. This study uses four short-run zero, eight long-run zero, 15 traditional sign, and five episodes as narrative sign restrictions. An et al. (2021) use four short-run zero, four long-run zero, 18 traditional sign, and single episode as narrative sin restrictions. The Plaza Accord episode in 1985 is used in An et al. (2021). In contrast, this study uses the introduction of zero interest rate policy episode in 2000, temporal lift of zero interest rate episode in 2006, the collapse of the Lehman Brothers in 2008, the Great East Japan earthquake and tsunami in 2011, and the beginning of the Abe administration in 2013. In terms of narrative sign restrictions defined by Antolin-Diaz et al. (2018), this study uses the more restrictive, *overwhelming* (Type B) narrative restrictions whereas An et al. (2021) uses the *most important* (Type A) narrative restriction. This study and An et al. (2021) confirm that demand-shock induced exchange rate pass-through is against the conventional view of ERPT. The main difference in shock-dependent exchange rate pass-through between the two studies is that exchange rate pass-through induced by monetary policy shock is negligible in An et al. (2021), whereas it is negative and statistically significant in this study.

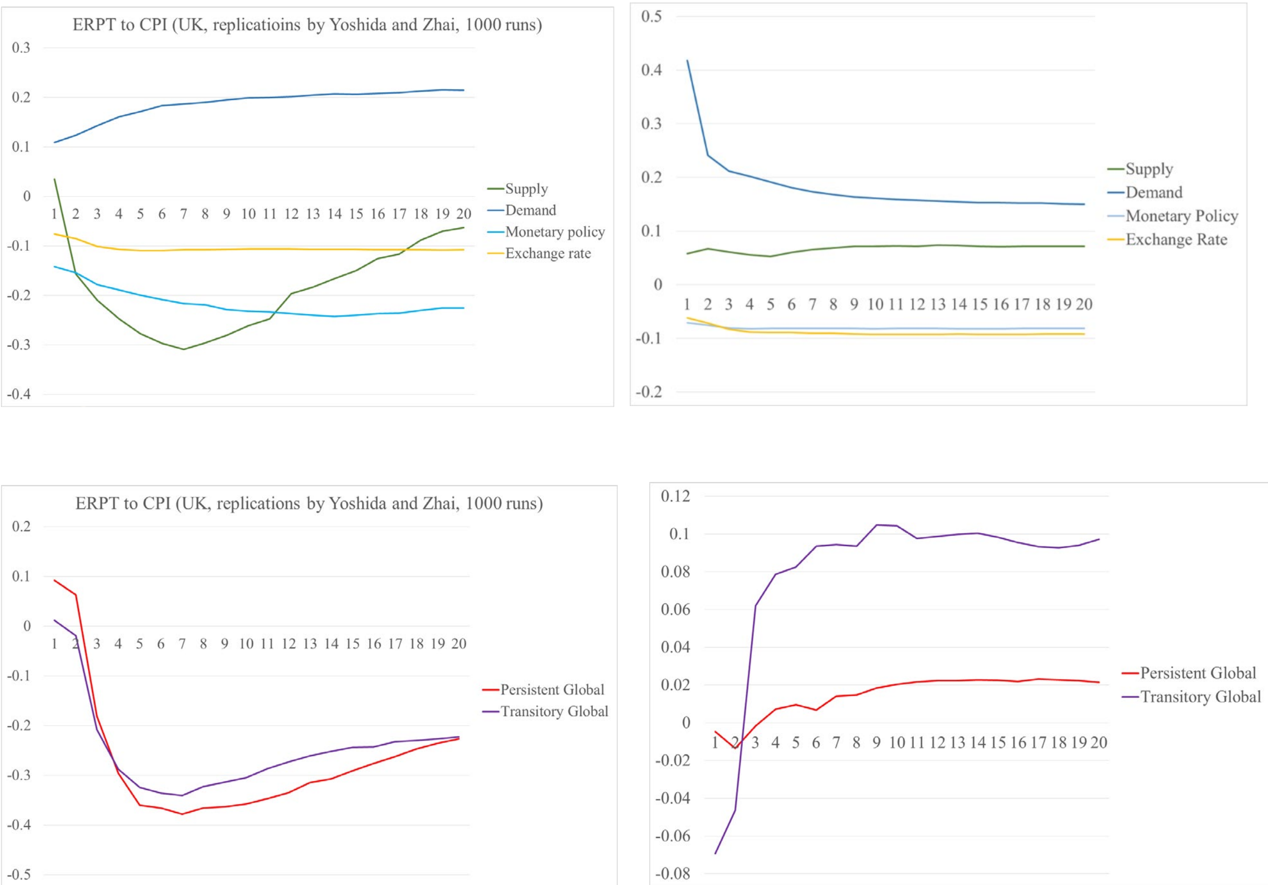
Finally, as a robustness check of our result regarding the transformation of variables, we also re-estimated the SVAR model with de-trended variables by the HP filtering instead of log-differenced variables. The results on the shock-dependent ERPTs remain qualitatively the same. With the 68 percent credible interval, the ERPTs induced by demand, monetary policy, and exogenous exchange rate shocks are significant through twenty quarters after the shocks, see Appendix Figure C1. The ERPTs related to supply and two global shocks are not significant. Even with the 95 percent credible interval, the ERPTs induced by demand, monetary policy, and exogenous exchange rate shocks are statistically significant up to three quarters after the shocks.

6. Conclusion

Despite the continuous effort of quantitative easing by the Bank of Japan, the target rate of annual two percent inflation has never been achieved since its introduction in April 2013. Especially during the sharp depreciation of the Japanese yen that expanded from the last quarter of 2012 to the second quarter of 2015, inflationary pressure from increased import price is expected to raise the inflation rate of the consumer price to the target level. However, this did not happen. We estimated the degree of exchange rate pass-through to the consumer price in Japan for the sample period between 2000 and 2019 and confirmed that exchange rate pass-through can work in the opposite direction for a change in exchange rate associated with a demand shock. If depreciation of the Japanese yen is caused by weak domestic demand, we observe deflationary pressure on the consumer price. Using the structural VAR model for the Japanese economy, we measured the degree of this exchange rate pass-through effect to be about 15 - 20 percent. That means a ten percent depreciation results in one percent deflation at the consumer price level. This one percent is considered large enough to undermine the continuous efforts of the BOJ to achieve the target of a two percent inflation rate.

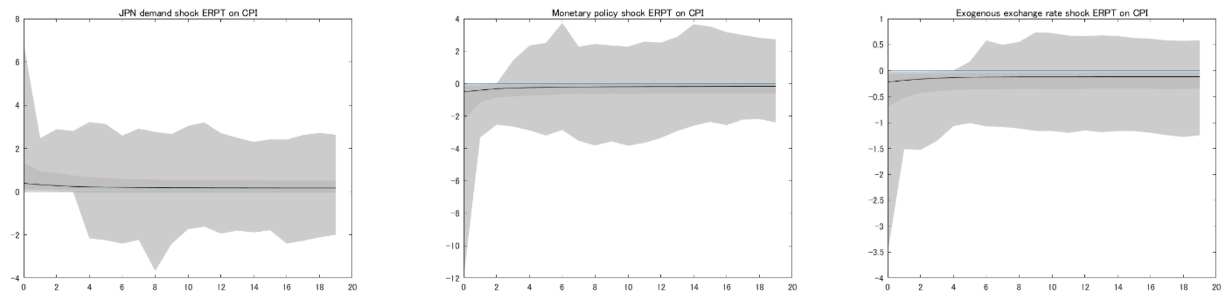
Appendix Figure A1. Impulse responses of six variables to six structural shocks. See the supplementary material.

Appendix Figure B1. Comparison of exchange rate pass-through by shocks between Japan and the replicated version of UK in Forbes et al. (2018)



Notes: The figures on the left-hand side are replicated by the authors of this paper for UK data. The figures on the right-hand side are the impulse response functions for Japan.

Appendix Figure C1. Dynamic shock-dependent ERPT with de-trended variables



Notes: The pointwise median ERPT on CPI by monetary policy shocks is shown in a solid line. The 95 (68) percent credible intervals are shown with light gray (dark gray) shaded areas. All six variables are de-trended by the HP filtering prior to the Bayesian SVAR estimation.

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Table 1. Identification restrictions

	JPN supply shock	JPN demand shock	JPN monetary policy shock	Exchange rate shock	Persistent global shock	Transitory global shock
Short-run restrictions						
JPN GDP	+	+	-			
JPN CPI	-	+	-	-		
JPN interest rate		+	+	-		
Nominal effective exchange rate		+	+	+		
JPN import price						
World export price	**0**	**0**	**0**	**0**	+	+
Long-run restrictions						
JPN GDP		**0**	**0**	**0**		**0**
JPN CPI						
JPN interest rate						
Nominal effective exchange rate						
JPN import price						
World export price	**0**	**0**	**0**	**0**		

Notes: A '0', '+', or '-' sign indicates that the impulse response of the variable listed in the row to the shock in the column is zero, positive, or negative, respectively, in the quarter the shock occurs and in the following quarter.

Table 2. The number of draws satisfying narrative sign restrictions for five episodes

episode	Sign of shock: sign	Sign of shock: number of satisfying draws	Type B: number of satisfying draws	both: number of satisfying draws
(i) 2001Q1, MP shock to ER	negative	914	286	286
(iia) 2006Q3, MP shock to ER	positive	80	342	0
(iib) 2006Q3, demand shock to policy rate	positive	550	4	3
(iii) 2008Q4, MP shock to ER	positive	898	442	442
(iv) 2011Q1, supply shock to production	negative	880	239	238
(v) 2013Q1, exogenous ER shock to ER	negative	867	222	222

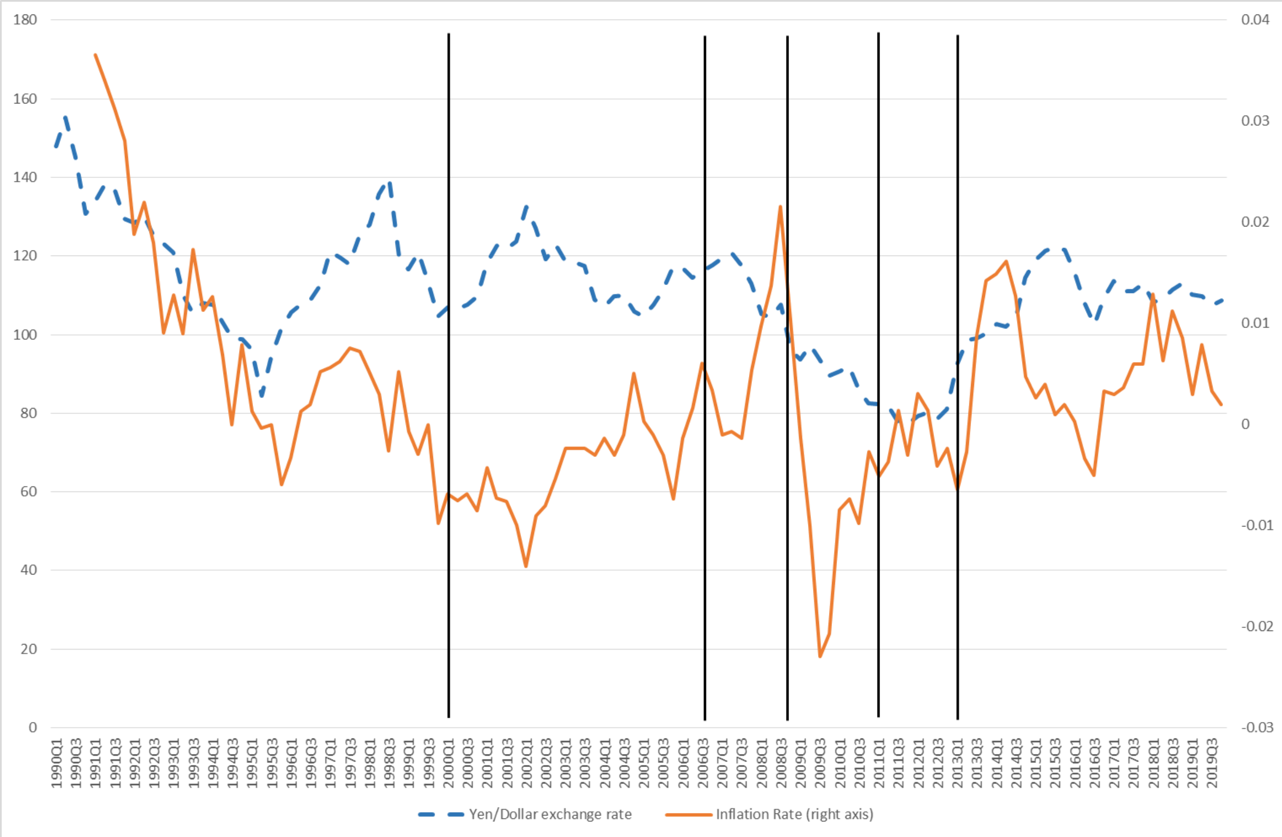
Notes: For the detailed descriptions of episodes, see section 4-3. The figures in the table represent the number of draws satisfying narrative sign restrictions, out of 1,000 draws that satisfy both zero and traditional sign restrictions.

Table 3. Forecast error variance decomposition of exchange rate changes, 2000Q1-2019Q4

period ahead	supply	demand	monetary policy	exogenous exchange rate	persistent global	transitory global
1 quarter	0.06	0.04	0.36	0.35	0.12	0.07
4 quarters	0.06	0.06	0.34	0.32	0.13	0.09
20 quarters	0.06	0.06	0.33	0.32	0.14	0.09

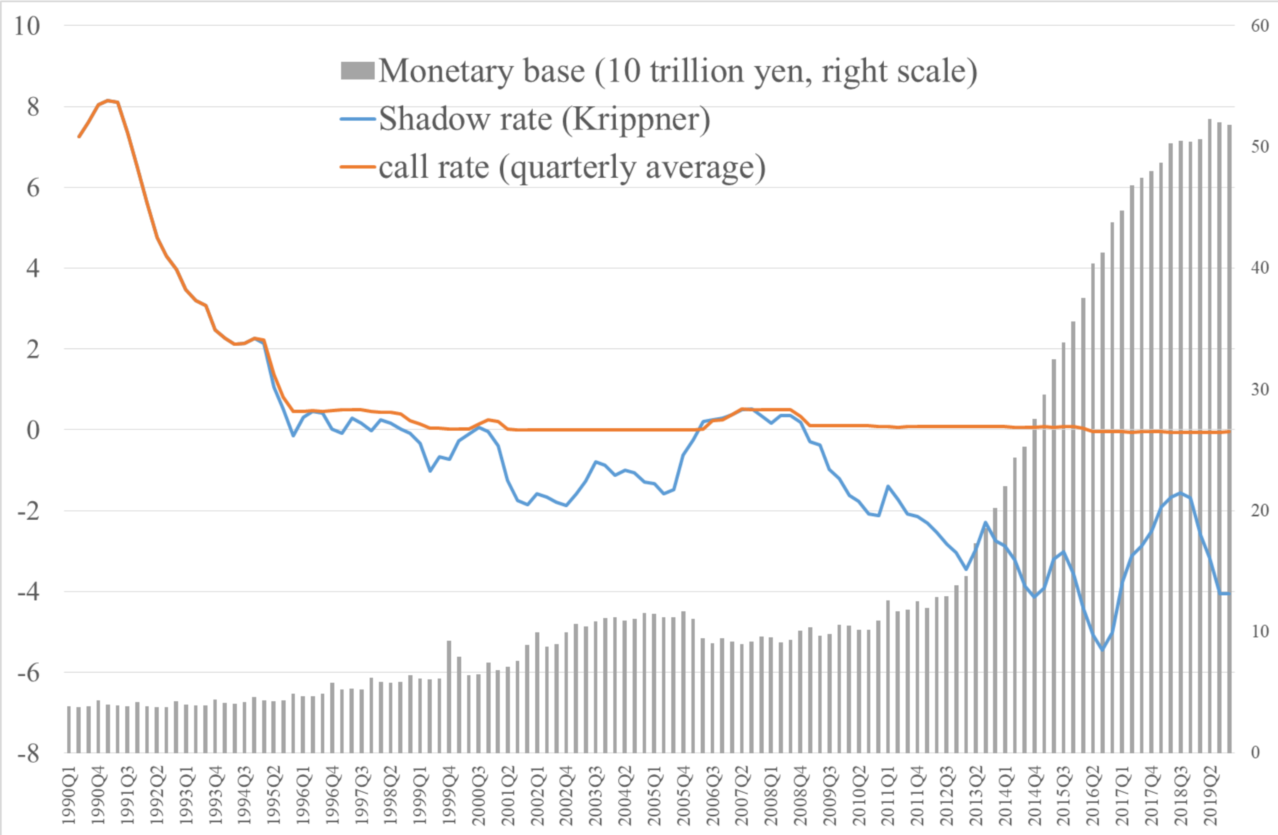
Notes: Figures are the proportion of exchange rate forecast error variance explained by structural shocks.

Figure 1. The inflation rate and exchange rate of Japan, 1990Q1 – 2019Q4



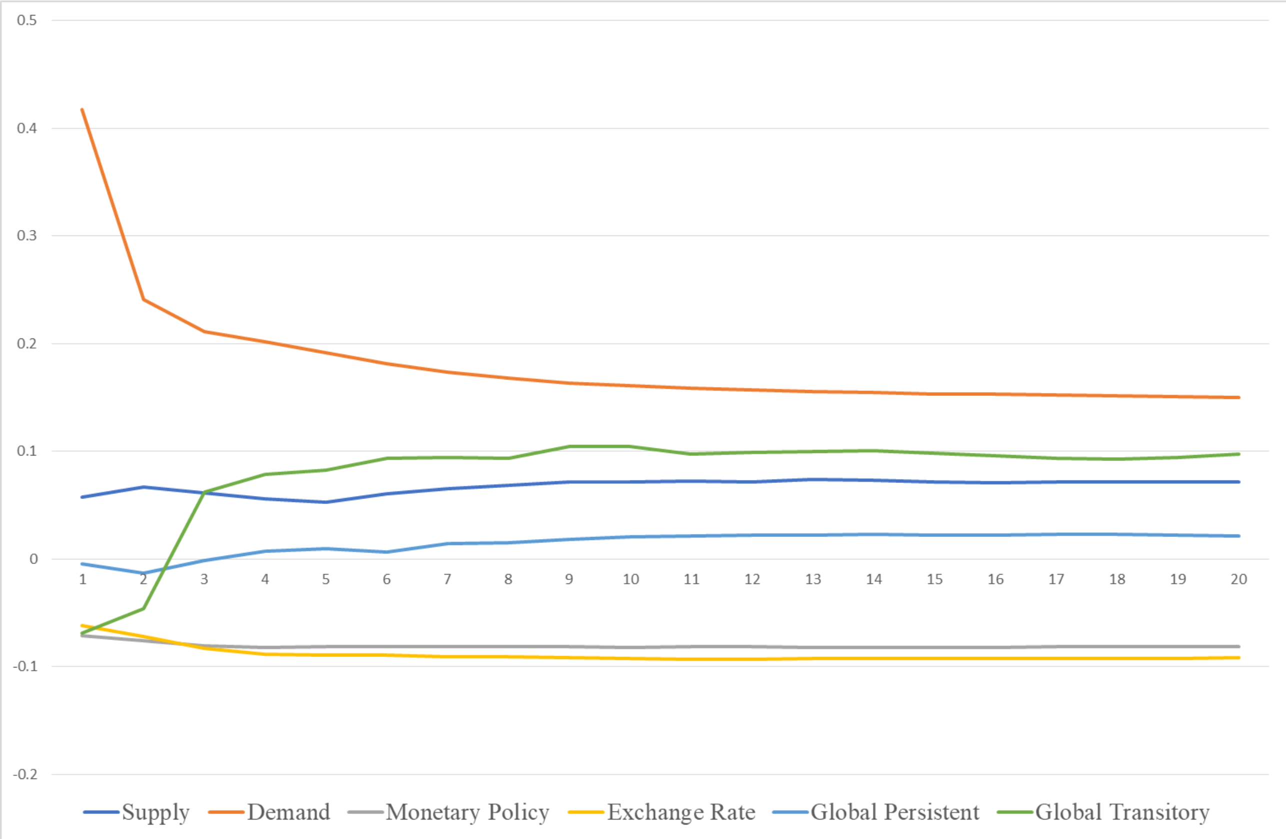
Notes: The inflation rate is the log difference of the consumer price index adjusted for consumption tax, measured for the current quarter change from the same quarter in the previous year. The Yen/Dollar exchange rate is the value of one US dollar in terms of the Japanese yen. The vertical lines indicate five episodes: (i) 2001:Q1 (the introduction of quantitative easing policy), (ii) 2006:Q3 (temporally lift of zero interest rate policy), (iii) 2008:Q4 (the outset of the Global Financial Crisis), (iv) 2011:Q1 (the Great East Japan Earthquake and Tsunami), and (v) 2013:Q1 (the beginning of the Abe administration).

Figure 2. Policy rate, shadow rate, and monetary base in Japan, 1990Q1 – 2019Q4



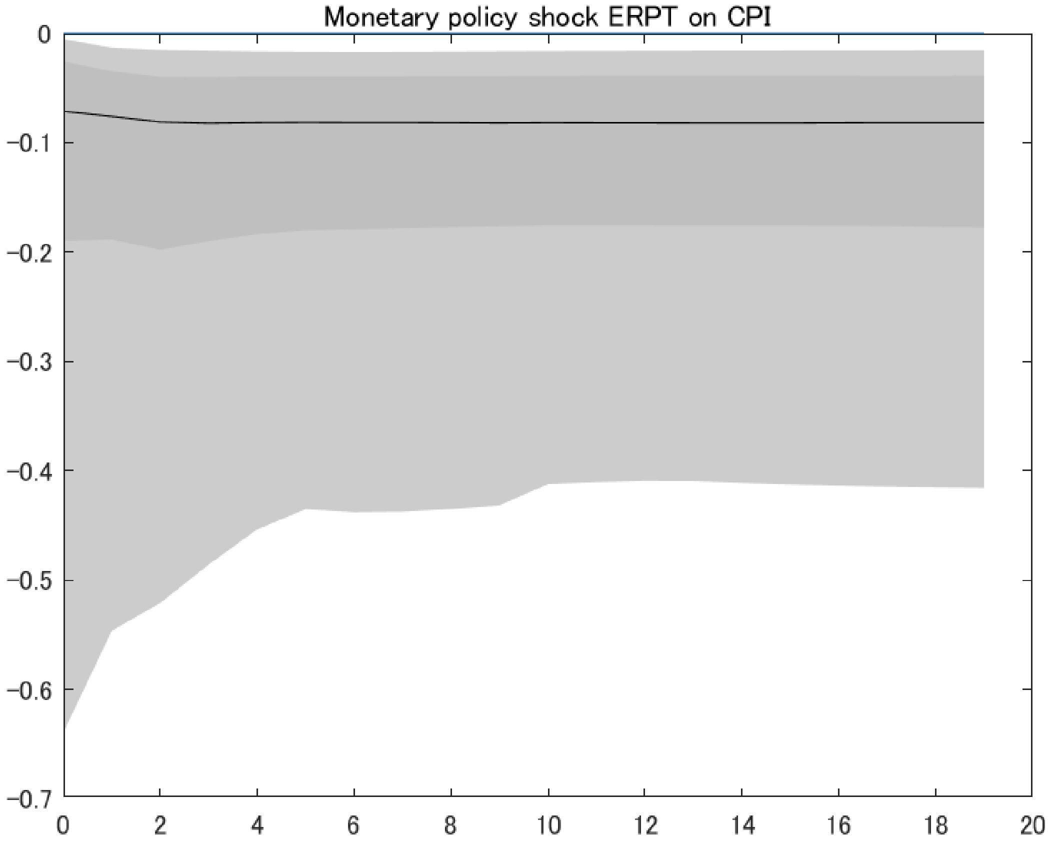
Notes: Quarterly policy rates between 1990Q2 and 1994Q4 are calculated by averaging the monthly average of overnight call rates. The quarterly shadow rate series between 1995Q1 and 2019Q4 is constructed by averaging the daily shadow rate series of Krippner (2013), updated on his website. The monetary base is measured at the end of the month after July 1996 and as a monthly average amount before June 1996.

Figure 3. Japanese ERPT on CPI by structural shocks



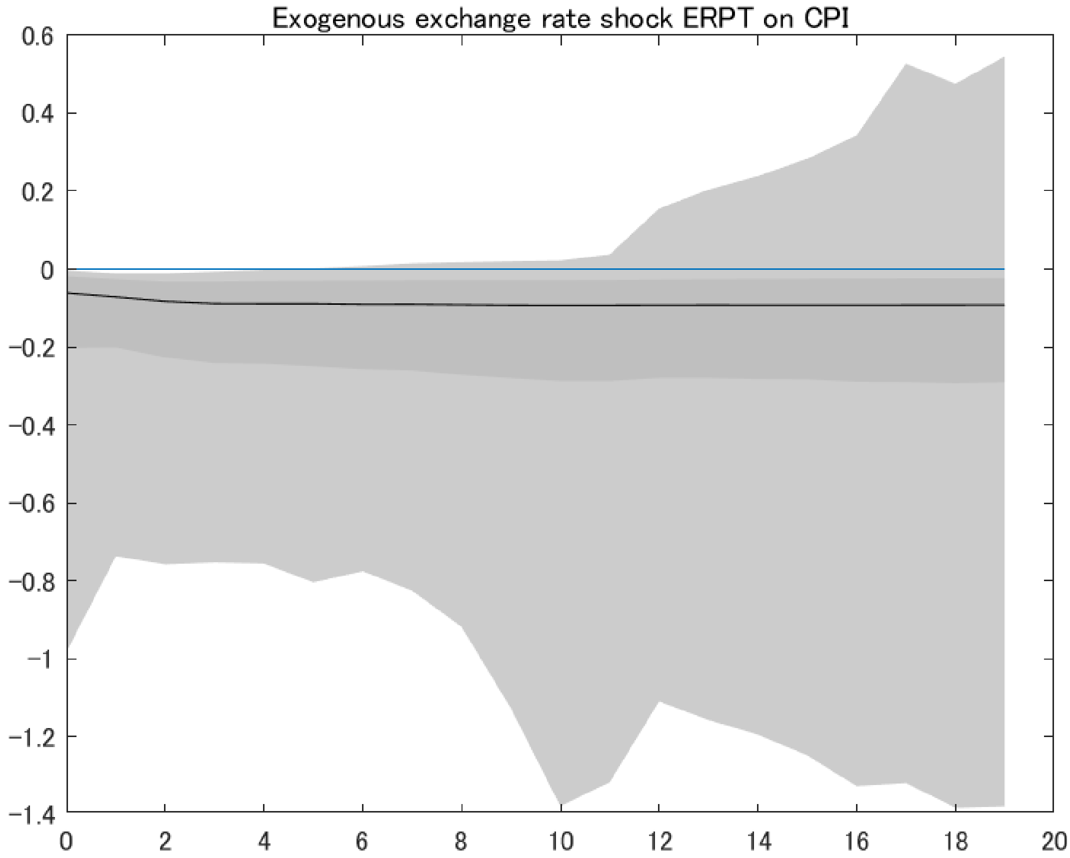
Notes: The median ERPT on CPI by shocks is shown. The ERPT is calculated as the ratio of the cumulated impulse response of consumer price to the cumulated impulse response of the exchange rate index with respective structural shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4. Following Forbes et al. (2018), a burn-in sample of 10,000 is discarded, and random draws are repeated until 1,000 draws stratify all identifying restrictions.

Figure 4. ERPT on CPI by monetary policy shock



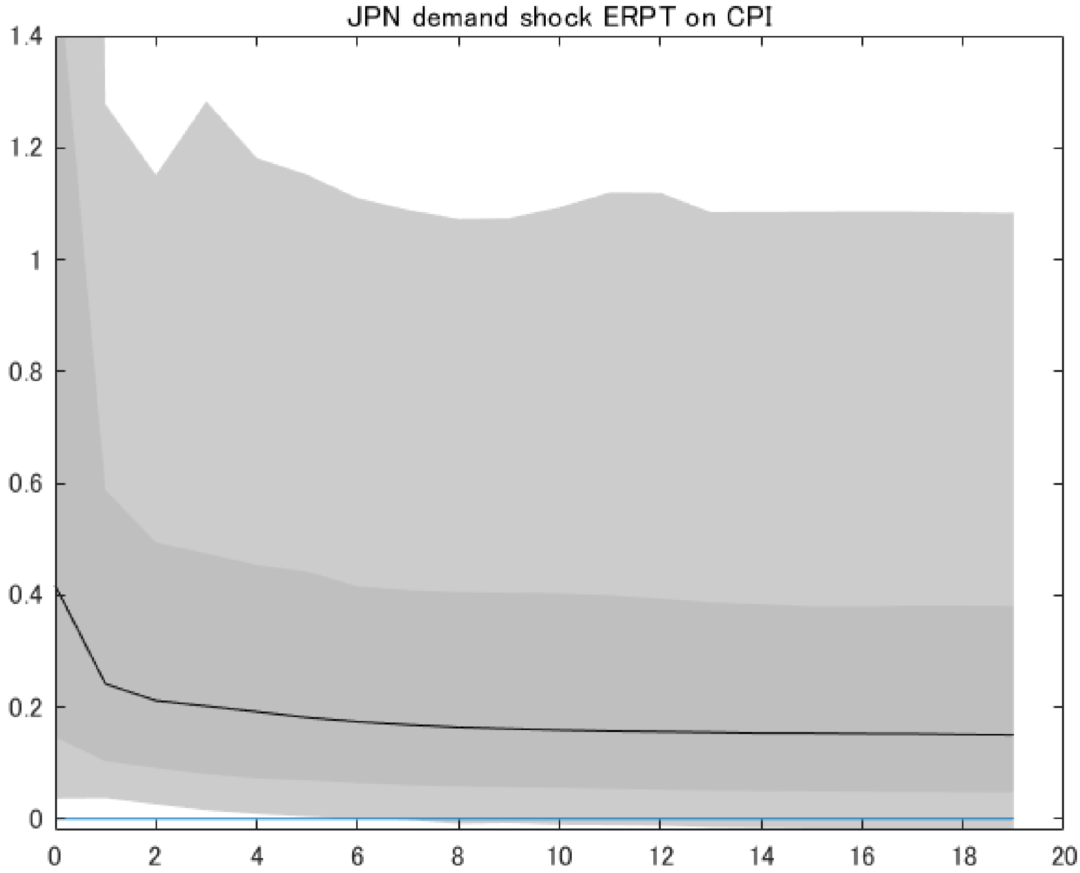
Notes: The pointwise median ERPT on CPI by monetary policy shocks is shown in a solid line. The 95 (68) percent credible intervals are shown with light gray (dark gray) shaded areas. The ERPT is calculated as the ratio of the cumulated impulse response of consumer price to the cumulated impulse response of the exchange rate index with monetary policy shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4.

Figure 5. ERPT on CPI by exchange rate shock



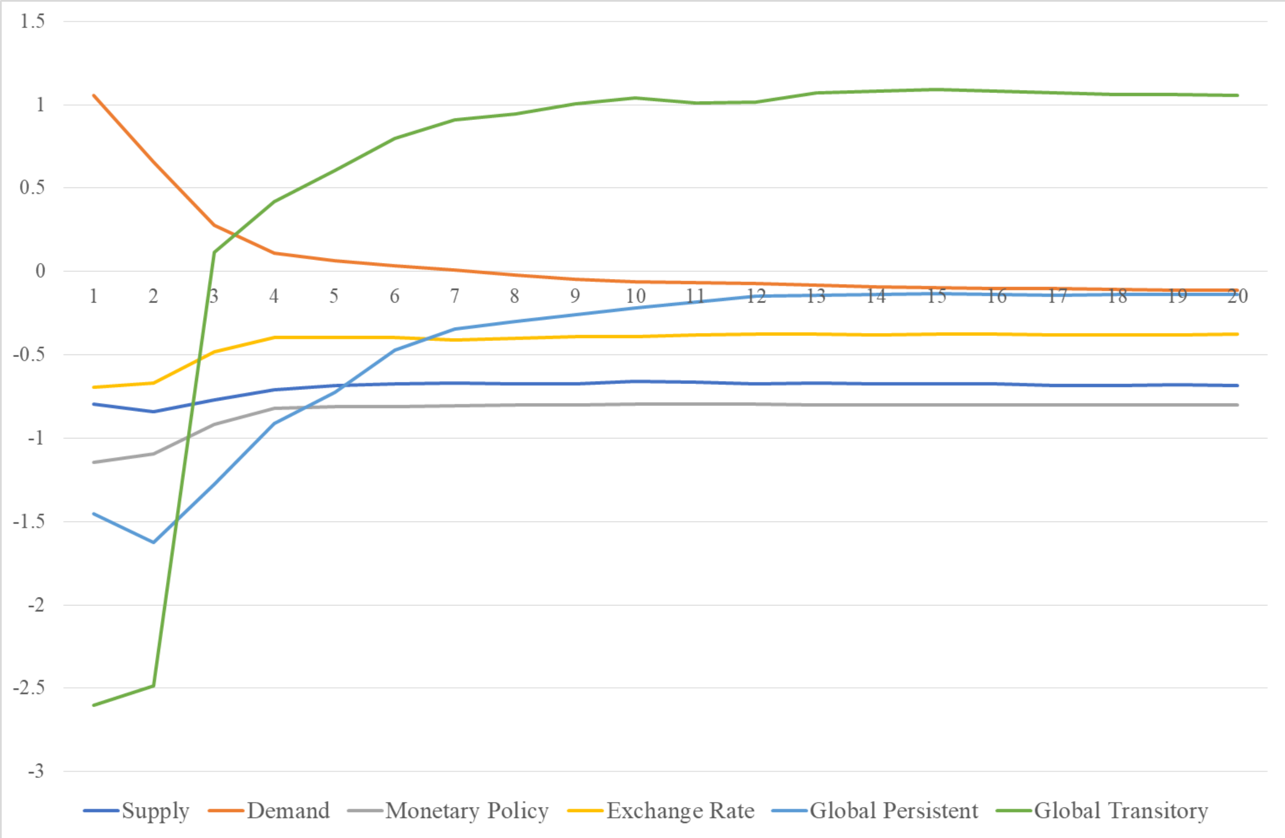
Notes: The pointwise median ERPT on CPI by monetary policy shocks is shown in a solid line. The 95 (68) percent credible intervals are shown with light gray (dark gray) shaded areas. The ERPT is calculated as the ratio of the cumulated impulse response of consumer price to the cumulated impulse response of the exchange rate index with monetary policy shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4.

Figure 6. ERPT on CPI by demand shock



Notes: The pointwise median ERPT on CPI by monetary policy shocks is shown in a solid line. The 95 (68) percent credible intervals are shown with light gray (dark gray) shaded areas. The ERPT is calculated as the ratio of the cumulated impulse response of consumer price to the cumulated impulse response of the exchange rate index with monetary policy shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4.

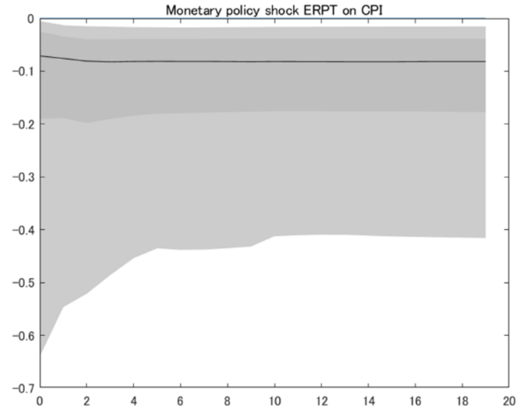
Figure 7. Exchange rate pass-through on import price by structural shocks



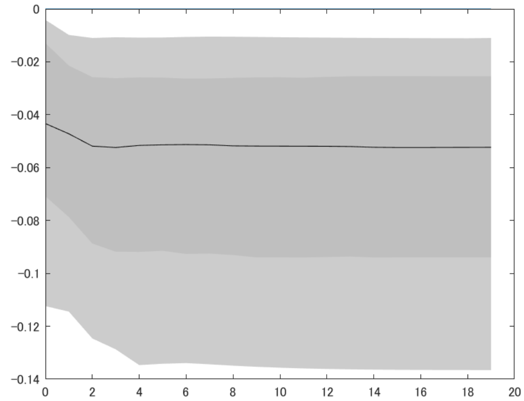
Notes: The median ERPT on import price by shocks are shown. The ERPT is calculated as the ratio of the cumulated impulse response of import price to the cumulated impulse response of exchange rate index, with respective structural shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4. With 95 percent credible intervals, none of the exchange rate pass-throughs by shocks are different from zero. With 68 percent intervals, exchange rate pass-through by monetary policy shocks are significantly different from zero for the first three periods and exchange rate pass-through by persistent global shock for only the first period. Following Forbes et al. (2018), the random draw is repeated 11,000 times, but the initial 10,000 are discarded, and the only final 1000 draws are saved only if the draw satisfies all restrictions.

Figure 8. ERPT on CPI by monetary policy shock with narrative sign restrictions

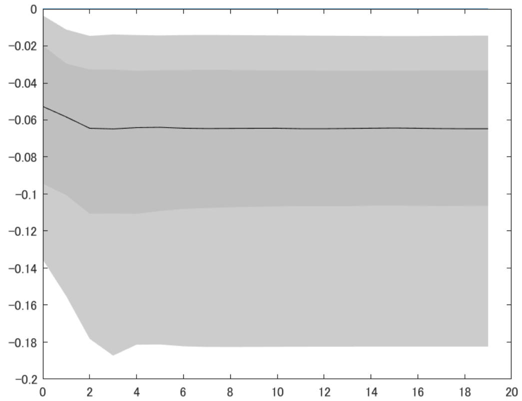
(a) without narrative sign restrictions



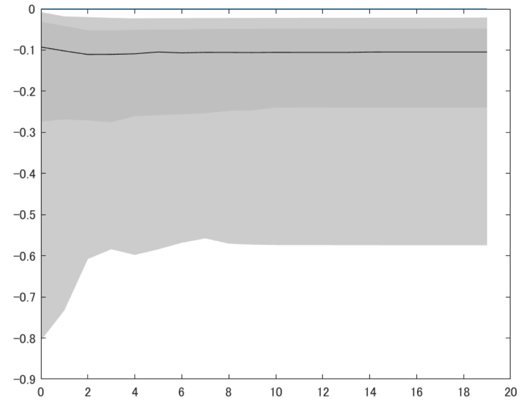
(b) episode i: 2001Q1



(c) episode iii: 2008Q4



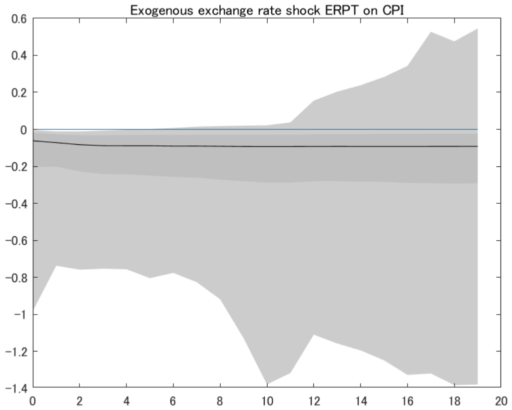
(d) episode v: 2013Q1



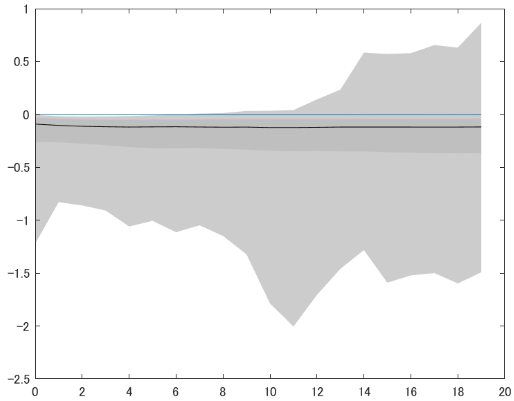
Notes: The pointwise median ERPT on CPI by monetary policy shocks is shown in a solid line. The 95 (68) percent credible intervals are shown with light gray (dark gray) shaded areas. The ERPT is calculated as the ratio of the cumulated impulse response of consumer price to the cumulated impulse response of the exchange rate index with monetary policy shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4.

Figure 9. ERPT on CPI by exchange rate shock with narrative sign restrictions

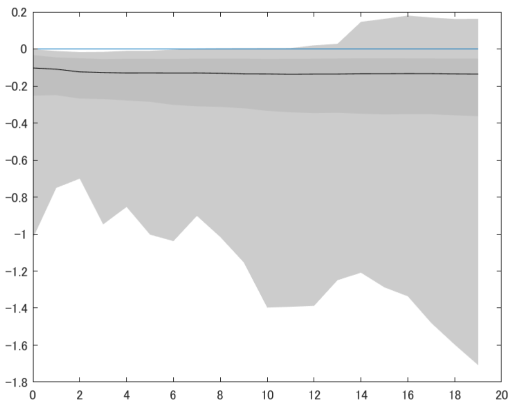
(a) without narrative sign restrictions



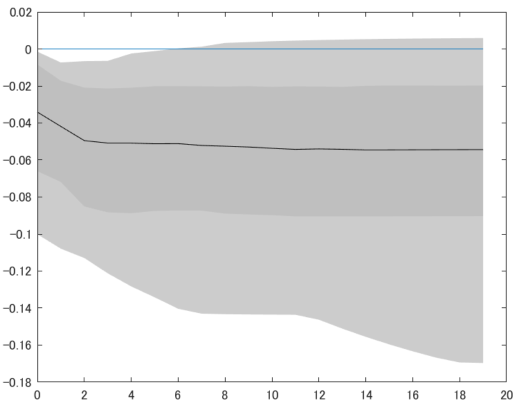
(b) episode i: 2001Q1



(c) episode iii: 2008Q4



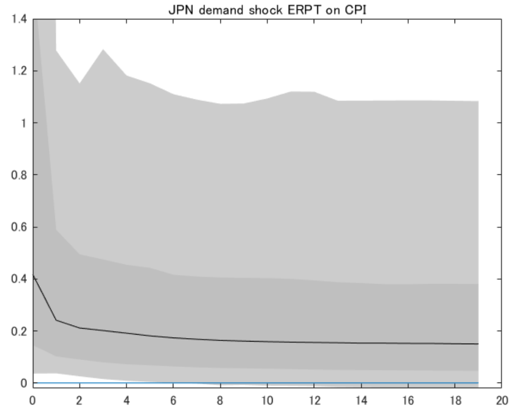
(d) episode v: 2013Q1



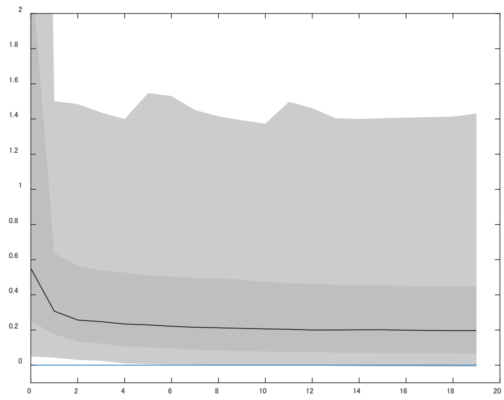
Notes: The pointwise median ERPT on CPI by exchange rate shocks is shown in a solid line. The 95 (68) percent credible intervals are shown with light gray (dark gray) shaded areas. The ERPT is calculated as the ratio of the cumulated impulse response of consumer price to the cumulated impulse response of the exchange rate index with exchange rate shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4.

Figure 10. ERPT on CPI by demand shock with narrative sign restrictions

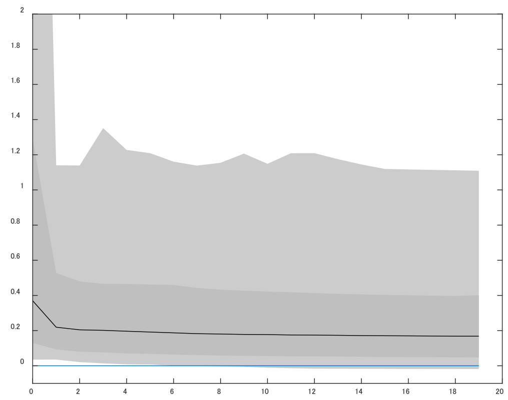
(a) without narrative sign restrictions



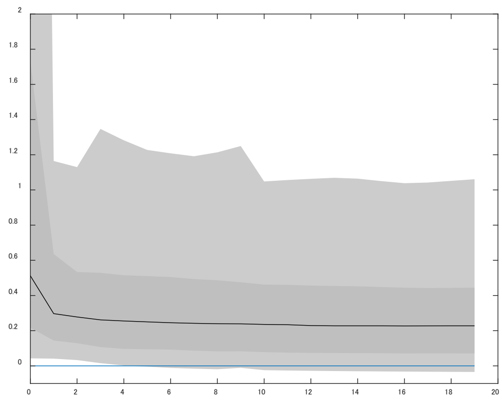
(b) episode i: 2001Q1



(c) episode iii: 2008Q4

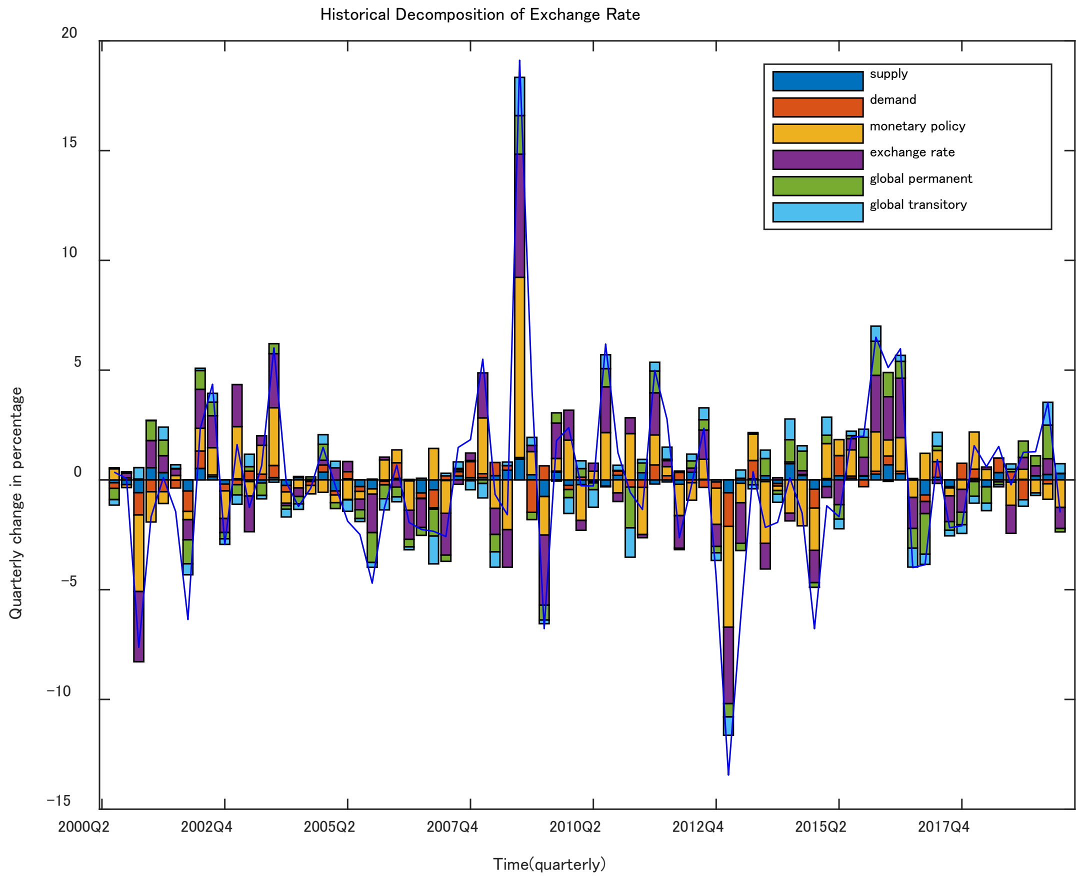


(d) episode v: 2013Q1



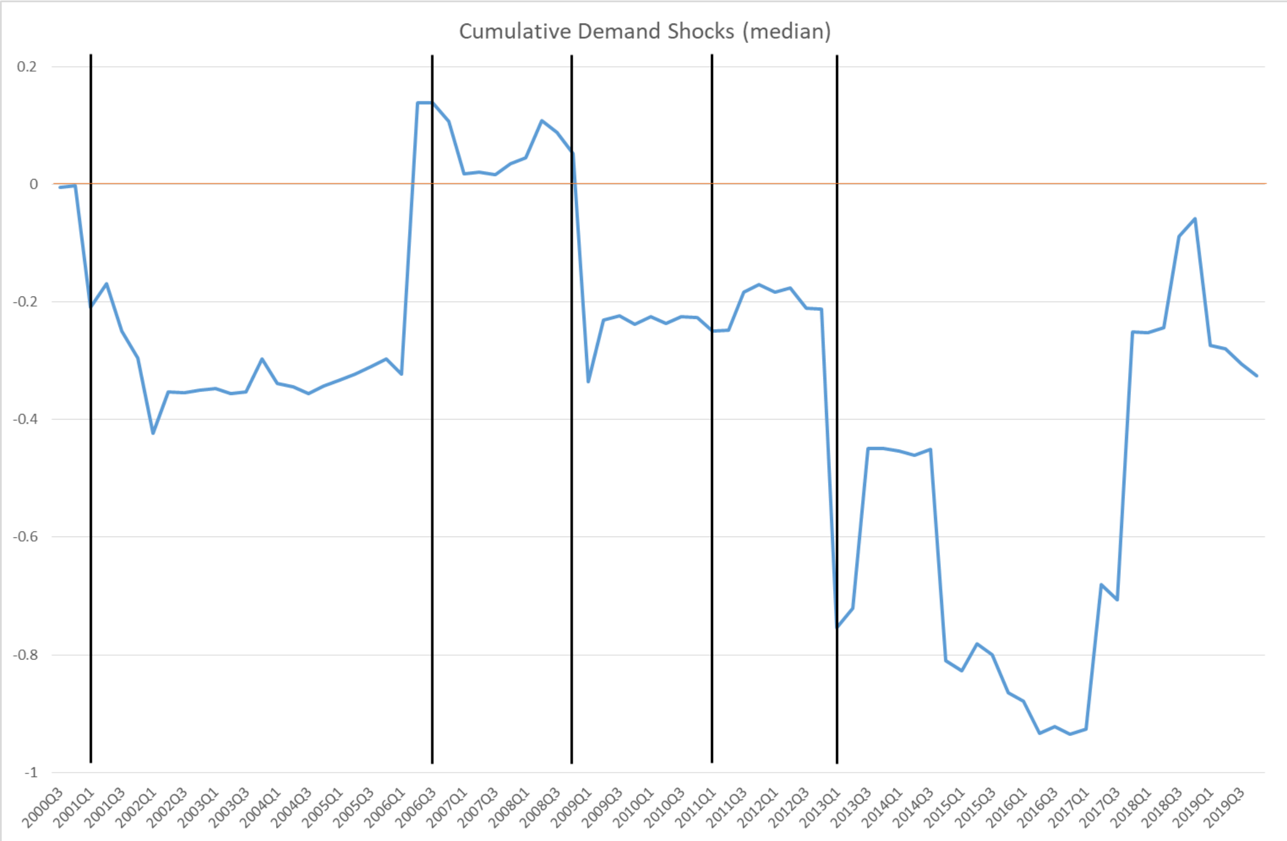
Notes: The pointwise median ERPT on CPI by demand shocks is shown in a solid line. The 95 (68) percent credible intervals are shown with light gray (dark gray) shaded areas. The ERPT is calculated as the ratio of the cumulated impulse response of consumer price to the cumulated impulse response of the exchange rate index with demand shocks. The horizontal axis is the number of quarters after the shock. The data sample is from 2000Q1 to 2019Q4.

Figure 11. Historical decomposition of exchange rate



Notes: The figure represents the means of historical decompositions of 1,000 draws, which satisfy all identification restrictions. The solid line is the actual nominal effective exchange rate. Each bar represents the share of contribution of each corresponding structural shock to the exchange rate movements.

Figure 12. Cumulative demand shocks



Notes: The line indicates the cumulative values of the median demand shocks among the 4,000 draws satisfying the zero and traditional sign restrictions. The vertical lines indicate the five episodes: (i) 2001:Q1 (the introduction of quantitative easing policy), (ii) 2006:Q3 (temporally lift of zero interest rate policy), (iii) 2008:Q4 (the outset of the Global Financial Crisis), (iv) 2011:Q1 (the Great East Japan Earthquake and Tsunami), and (v) 2013:Q1 (the beginning of the Abe administration).