

**Research Unit for Statistical
and Empirical Analysis in Social Sciences (Hi-Stat)**

**External Shocks and Japanese Business Cycles:
Evidence from a Sign-Restricted VAR**

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January 2013

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15 January 2013

Abstract

This paper investigates the sources of Japanese business fluctuations since the 1990s taking into account both external shocks (e.g., risk premium and foreign demand shock) and domestic supply and demand shocks. We use the sign-restricted VAR model based on the theoretical model to identify these. The presented results show that 20% to 40% of the forecast error variances in output can be explained by external shocks. Further, we demonstrate that supply shocks are the main influencing factor in Japanese business fluctuations throughout the sample period and that risk premium shocks have played an important role in post-2008 Lehman shock recession.

Keywords: External shock, DSGE model, sign-restricted VAR

JEL codes: F41, E32

*We would like to thank my supervisor Etsuro Shioji for the helpful comments and encouragement. We also acknowledge Naohito Abe, Tuan Khai Vu, Jun-Hyung Ko for their valuable comments. Finally, We would like to express gratitude to Hitotsubashi University's GCOE Program for the grant that made it possible to complete this study. Of course, all errors are our own.

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1 Introduction

The Japanese economy is greatly influenced by external factors, such as the exchange rate, foreign demand, and oil prices. However, researchers have paid especially close attention to the external shocks that have influenced the Japanese economy since the Lehman shock in 2008, notably because of the subsequent large reduction in the country's output and exports. For example, Kawai and Takagi (2009) and Shioji and Uchino (2011) examine the effect of the Lehman shock using the vector autoregression (VAR) model and emphasize the finding that external shocks play an important role in the Japanese economy. Similarly, Shioji et al. (2011) indicate the importance of external shocks on the Japanese economy by estimating the open economy Dynamic Stochastic General Equilibrium model using the Bayesian MCMC method.

In line with these previous studies, this paper also investigates the role of external shocks in Japanese business cycles. However, it contributes to the body of knowledge on this topic by identifying risk premium and foreign demand shock as external shocks that have affected the Japanese economy since the 1990s in addition to supply and demand shock. Moreover, we employ the sign-restricted VAR model developed by Uhlig (2009) and recently used by Peersman (2005), Mountford and Uhlig (2009), and Pappa (2009) in order to overcome the problems in an identification of structural shocks and misspecification of the model that have limited previous studies. A sign-restricted VAR model identifies shocks by restricting the shape of the impulse response functions (IRFs), making the consideration of the order of exogeneity among the variables unnecessary. In addition, this particular type of model clarifies what kind of shock is identified because the restrictions are based on theoretical models. Given these advantages, the struc-

tural shocks described in this paper are more correctly identified compared with previous studies that have adopted the Cholesky decomposition. Although estimating the model estimation using Bayesian methods allows structural shocks to be explicitly defined in the theoretical model, thereby simplifying their interpretation, the correct results can fail to be estimated if the model is built inaccurately. The sign-restricted VAR can overcome this problem, however.

In this paper, the sign restrictions imposed on the VAR model are derived from the theoretical model, namely the Real Business Cycle (RBC) and New Keynesian (NK) models. First, the theoretical IRF for each structural shock is calculated under these two models and then the features that are common to both models are adopted as restrictions. Through this approach, the paper mitigates the possibility of misspecification in the estimation model.

Specifically, this paper examines the degree to which business fluctuations in Japan can be explained by external shocks and investigates which shocks play an important role in each phase of the business cycle. For that purpose, we perform the forecast error variance decomposition (FEVD) and historical decomposition (HD) as well as IRF analysis. These methods enable us to evaluate the effect of external shocks not only qualitatively but also quantitatively. Although a number of previous studies have used these tools to analyze Japanese business cycles (e.g., Miyao, 2000, 2006), to our knowledge this paper is the first to perform a HD taking external shocks into consideration.

The results of the FEVD indicate that 20% to 40% of the variations in output can be explained by external shocks. Further, the HD clarifies that supply shock mainly explains the growth in output throughout the sample period. However, the findings also demon-

strate that external shocks play a major role in the phases of all business fluctuations. In particular, foreign demand shock has contributed to the economic recovery since 2002, while risk premium shock explains a large part of the reduction in output and exports since the Lehman shock. These results confirm the importance of external factors in line with the findings of previous studies.

The remainder of this paper is organized as follows. In Section 2, the theoretical model is built in order to ascertain the feasible sign restrictions. The theoretical IRFs are also drawn under various parameterizations and restrictions are derived from the common IRF features. In Section 3, we describe the empirical methods and data used in this paper. Section 4 presents the estimation results of the IRF, FEVD, and HD analyses. Section 5 concludes.

2 Theoretical model

This section derives the sign restrictions from the theoretical model. First, we construct a small open economy NK model that is a variant of the one presented by Leeper et al. (2011). Their model is a medium-scale two-country model that has real and nominal rigidities and that was built to analyze the effect of fiscal policy. Therefore, a Non-Ricardian, who is faced with liquidity constraints, and debt financing are incorporated into the model. Further, a local currency pricing approach is adopted; in other words, domestic intermediate goods firms set their export prices in a foreign currency unit.

The most important feature of their model is that the benchmark NK model nests the RBC model. By contrast, in previous studies that have adopted the sign-restricted VAR model (e.g., Braun and Shioji (2007); Pappa (2009)), sign restrictions have been

based on the common features of the IRFs generated from the RBC and NK models. On this point, Leeper et al. (2011)'s model has advantageous characteristics for the present analysis.

However, this paper does not estimate the model using Bayesian methods; it rather employs a simpler model compared with that of Leeper et al. (2011). Specifically, several of the settings used to capture the properties of the actual data (e.g., habit formation and capital utilization rate) are omitted from the model proposed herein. Instead, we explicitly introduce import goods firms that set their import goods prices under Calvo (1983)-type price stickiness in order to examine how the degree of pass-through influences such prices.

2.1 Households

The economy consists of two types of households: (i) optimizing or Ricardian households denoted by R and (ii) rule-of-thumb or Non-Ricardian households denoted by N . While Ricardians can access capital markets, Non-Ricardians do not own any assets and simply consume their current disposable incomes in each period. A fraction $\mu \in [0, 1]$ of the population is Non-Ricardians and the remaining is Ricardians. Regardless of the type of household, each household belongs to the type i labor union. Thus, each provides a differentiated labor input, $n(i)$ and obtains a nominal wage, $W(i)$.

Ricardian households choose their real consumption $c_t^R(i)$ and hours worked $n_t^R(i)$ to maximize lifetime utility

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{c_t^R(i)^{1-\gamma} - 1}{1-\gamma} - \frac{n_t^R(i)^{1+\lambda}}{1+\lambda} \right] \quad (1)$$

subject to the flow budget constraint

$$\begin{aligned} P_t c_t^R(i) + P_t i_t^R(i) + B_t^R(i) + S_t F_t^R(i) + P_t \tau_t^R(i) \\ = R_{t-1} B_{t-1}^R(i) + R_{t-1}^* S_t F_{t-1}^R(i) + W_t(i) n_t^R(i) + P_t r_t^k k_{t-1}^R(i) + D_t^R(i) \end{aligned} \quad (2)$$

and the capital accumulation equation

$$k_t^R(i) = (1 - \delta) k_{t-1}^R(i) + \left\{ 1 - s \left(\frac{i_t^R(i)}{i_{t-1}^R(i)} \right) \right\} i_t^R(i) \quad (3)$$

where β , γ , and λ denote the discount rate, risk aversion, and inverse of the Frisch labor elasticity, respectively. Capital letters denote nominal variables, and P_t is the price of a final good. Ricardians receive interest payments from domestic and international one-period risk-free nominal bonds denoted by B_t and F_t , respectively as well as wage income $W_t n_t$, rental income from capital $r_t^k k_t$, and dividends D_t . However, they consume c_t^R and invest i_t^R , and they pay a lump-sum tax denoted by τ_t^R . The gross nominal interest rate paid for domestic and international bonds are R_t and R_t^* . Since the international bond and its interest payment are denominated in foreign currency units, they are converted into home currency units by multiplying by a nominal exchange rate S_t . Concerning capital accumulation, we assume an investment adjustment cost $s(\cdot) i^R$ as in Christiano

et al. (2005), where $s(1) = s'(1) = 0$ and $s''(1) > 0$.¹

In return, Non-Ricardians simply consume all their current disposable incomes. By denoting the consumption of and hours worked by type i Non-Ricardians as $c_t^N(i)$ and $n_t^N(i)$, they thus face the following budget constraint in each period:

$$P_t c_t^N(i) = W_t(i) n_t^N(i) - P_t \tau_t^N(i) \quad (4)$$

where τ_t^N denotes the lump-sum tax paid by Non-Ricardians.

2.2 Wage setting

As mentioned above, each household provides a differentiated labor input $n_t(i)$ for intermediate goods firms. A perfectly competitive labor force produces a composite effective labor n_t according to

$$n_t = \left[\int_0^1 n_t(i)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} di \right]^{\frac{\varepsilon_w}{\varepsilon_w - 1}} \quad (5)$$

where ε_w denotes the elasticity of substitution across the different types of labor inputs.

As a result of the labor bundler's problem, the demand function for each differentiated labor input is expressed as

$$n_t(i) = \left(\frac{W_t(i)}{W_t} \right)^{-\varepsilon_w} n_t, \quad \text{for all } i, \quad (6)$$

¹In this paper, we define investment adjustment cost as $\kappa \equiv 1/s''(1)$

and the aggregate nominal wage is equal to

$$W_t = \left[\int_0^1 W_t(i)^{1-\varepsilon_w} di \right]^{\frac{1}{1-\varepsilon_w}}. \quad (7)$$

Here, we assume that labor demand is uniformly distributed regardless of types of households.

With respect to wage setting, we follow the modeling used in Galí et al. (2007) and Colciago (2011), in which each labor union i sets its nominal wage $W_t(i)$ to maximize the weighted average of the lifetime utility of Ricardians and Non-Ricardians. In each period, a labor union resets the optimal nominal wage $W_t^*(i)$ with a probability $1 - \rho_w$. Thus, the problem for a labor union i is written as

$$\max_{W_t^*(i)} E_t \sum_{s=0}^{\infty} \rho_w \Lambda_{t,t+s} \left[(1 - \mu) \frac{c_{t+s}^R(i)^{1-\gamma} - 1}{1 - \gamma} + \mu \frac{c_{t+s}^N(i)^{1-\gamma} - 1}{1 - \gamma} - \frac{n_{t+s}(i)^{1+\lambda}}{1 + \lambda} \right] \quad (8)$$

subject to (2), (4), and (6), where $\Lambda_{t,t+s} = \beta^s (c_{t+s}^R/c_t^R)^{-1}$ denotes the stochastic discount factor. In the symmetric equilibrium, the first-order condition can be expressed as

$$W_t^*(i) = \frac{\varepsilon_w}{\varepsilon_w - 1} \frac{E_t \sum_{s=0}^{\infty} \rho_w \Lambda_{t,t+s} n_{t+s}^{1+\lambda}}{E_t \sum_{s=0}^{\infty} \rho_w^s \Lambda_{t,t+s} \left[(1 - \mu) \frac{n_{t+s}}{P_{t+s} c_{t+s}^R} + \mu \frac{n_{t+s}}{P_{t+s} c_{t+s}^N} \right]}, \quad (9)$$

and combining this with (7), the evolution of the aggregate nominal wage is given by

$$W_t = [(1 - \rho_w) W_t^{*1-\varepsilon_w} + \rho_w W_{t-1}^{1-\varepsilon_w}]^{\frac{1}{1-\varepsilon_w}}. \quad (10)$$

2.3 Firms

2.3.1 Final goods firms

Final goods firms are assumed to face perfectly competitive markets. They produce final goods $y_{n,t}$ by combining a bundle of domestic intermediate goods $y_{h,t}$ and a bundle of imported intermediate goods $y_{f,t}$ according to the following CES production function:

$$y_{n,t} = \left[\omega^{\frac{1}{\eta}} y_{h,t}^{\frac{\eta-1}{\eta}} + (1-\omega)^{\frac{1}{\eta}} y_{f,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad (11)$$

where η is the elasticity of substitution between domestic and imported intermediate goods, and $\omega \in [0, 1]$ denotes the degree of home bias in producing final goods. Similar to final goods, bundles of domestic and imported intermediate goods are produced according to the following technology

$$y_{h,t} = \left[\int_0^1 y_{h,t}(j)^{\frac{\theta_p-1}{\theta_p}} dj \right]^{\frac{\theta_p}{\theta_p-1}}, \quad \text{and} \quad y_{f,t} = \left[\int_0^1 y_{f,t}(m)^{\frac{\theta_p-1}{\theta_p}} dm \right]^{\frac{\theta_p}{\theta_p-1}} \quad (12)$$

where θ_p is the elasticity of substitution between differentiated intermediate goods.

2.3.2 Domestic intermediate goods firms

Domestic intermediate goods firms $j \in [0, 1]$ that are faced with a monopolistically competitive market produce differentiated intermediate goods according to the Cobb–Douglas production function:

$$y_{h,t}(j) = A_t k_{t-1}(j)^\alpha n_t(j)^{1-\alpha}. \quad (13)$$

where A_t denotes total factor productivity (TFP), which is given exogenously. Intermediate goods are assumed to be not only purchased by final goods firms in the home country, but also exported abroad.

Although the market for intermediate goods is monopolistically competitive, the factor market faced by intermediate goods firms is assumed to be competitive. As a result of the cost minimization problem for intermediate goods firms, the real marginal cost mc_t is given by

$$mc_t = \frac{w_t}{(1-\alpha)A_t} \left(\frac{(1-\alpha)r_t^k}{\alpha w_t} \right)^\alpha. \quad (14)$$

2.4 Price setting

2.4.1 Domestic intermediate goods firms

As noted above, domestic intermediate goods firms sell their goods in both home and foreign markets. These prices are charged separately according to the demand in each market. In the home market, demand for firm j 's output $y_{h,t}(j)$ is given by

$$y_{h,t}(j) = \omega \left(\frac{P_{h,t}(j)}{P_{h,t}} \right)^{-\theta_p} \left(\frac{P_{h,t}}{P_t} \right)^{-\eta} y_{n,t}, \quad (15)$$

where $P_{h,t}(j)$ is the output price in the home market set by firm j and $P_{h,t}$ is an aggregate price index of domestic intermediate goods, which is derived from a profit maximization problem of final goods firms and intermediate goods bundlers. Similarly, demand for firm

j 's output $y_{x,t}(j)$ in the foreign market is assumed to be

$$y_{x,t}(j) = \left(\frac{P_{x,t}^*(j)}{P_{x,t}^*} \right)^{-\theta_x} y_t^{For} \quad (16)$$

where $P_{x,t}^*(j)$ and $P_{x,t}^*$ are the export price charged by firm j and an aggregate exported goods price index, respectively, which are denominated in the foreign currency unit, while y_t^{For} is aggregate foreign demand, which is given exogenously.

According to the demand functions (15) and (16), intermediate goods firms set their domestic and export prices under a Calvo (1983) mechanism. Therefore, the problem of domestic intermediate goods firms j setting $P_{h,t}(j)$ is written as

$$\max_{P_{h,t}(j)} E_t \sum_{s=0}^{\infty} \rho_h^s \Lambda_{t,t+s} [P_{h,t}(j) y_{h,t+s}(j) - P_{t+s} y_{h,t+s}(j) m c_{t+s}] \quad (17)$$

subject to (15), where ρ_h denotes the probability that they cannot reoptimize their domestic prices. Likewise, the problem of setting export prices $P_{x,t}^*(j)$ is

$$\max_{P_{x,t}^*(j)} E_t \sum_{s=0}^{\infty} \rho_x^s \Lambda_{t,t+s} [P_{x,t}^*(j) S_{t+s} y_{x,t+s}(j) - P_{t+s} y_{x,t+s}(j) m c_{t+s}] \quad (18)$$

subject to (16), where ρ_x also denotes the probability that they can not reoptimize their export prices.

Solving these problems, a log-linearized NK Phillips curve (NKPC) is obtained as follows:

$$\hat{\pi}_{h,t} = \beta E_t \hat{\pi}_{h,t+1} + \frac{(1 - \rho_p)(1 - \beta \rho_p)}{\rho_p} [\hat{m}c_t - \hat{P}_{h,t} + \hat{P}_t] \quad (19)$$

$$\hat{\pi}_{x,t}^* = \beta E_t \hat{\pi}_{x,t+1}^* + \frac{(1 - \rho_x)(1 - \beta \rho_x)}{\rho_x} [\hat{m}c_t - \hat{S}_t - \hat{P}_{x,t}^* + \hat{P}_t] \quad (20)$$

where a hat denotes the log deviation from the steady state.

2.4.2 Imported goods firms

Imported goods firms $m \in [0, 1]$ import differentiated foreign goods $y_{f,t}(m)$ at prices $P_{f,t}^*$ denominated in the foreign currency unit and sell them to final goods firms at prices $P_{f,t}(m)$ denominated in the home currency unit. It is assumed that imported goods firms are also faced with a monopolistically competitive market and thus set their prices $P_{f,t}(m)$ under Calvo (1983)-type price stickiness. Thus, in each period they reset their prices with a probability $1 - \rho_f$ in order to maximize the discounted sum of profit flows

$$\max_{P_{f,t}(m)} E_t \sum_{s=0}^{\infty} \rho_f^s \Lambda_{t,t+s} [P_{f,t}(m) y_{f,t+s}(m) - P_{t+s} y_{f,t+s}(m) S_{t+s} P_{f,t+s}^*] \quad (21)$$

subject to demand for imported goods $y_{f,t}(m)$

$$y_{f,t}(m) = (1 - \omega) \left(\frac{P_{f,t}(m)}{P_{f,t}} \right)^{-\theta_p} \left(\frac{P_{f,t}}{P_t} \right)^{-\eta} y_{n,t} \quad (22)$$

where $P_{f,t}$ is the aggregate import price index. As for the problem of domestic intermediate goods firms, the NKPC is given by

$$\hat{\pi}_{f,t} = \beta E_t \hat{\pi}_{f,t+1} + \frac{(1 - \rho_f)(1 - \beta \rho_f)}{\rho_f} [\hat{P}_{f,t}^* + \hat{S}_t - \hat{P}_{f,t} + \hat{P}_t]. \quad (23)$$

2.5 Fiscal policy and monetary policy

The government budget constraint is

$$B_t + P_t\tau_t = P_t g_t + R_{t-1}B_{t-1} \quad (24)$$

where g_t denotes real government spending and is regarded as an exogenous variable. As shown in Gali et al. (2007) and Leeper et al. (2011), tax is assumed to respond to the debt-to-GDP ratio. Hence, a fiscal rule is written by

$$\hat{\tau}_t = \phi_b \hat{b}_{t-1} + \phi_g \hat{g}_t \quad (25)$$

where $\hat{\tau}_t \equiv (\tau_t - \tau)/y$, $\hat{b}_t \equiv (B_t/P_t - B/P)/y$, and $\hat{g}_t \equiv (g_t - g)/y$.

In return, the monetary authority sets the nominal interest rate r_t following the Taylor rule

$$\hat{r}_t = \phi_\pi \pi_t + \phi_s \hat{S}_t \quad (26)$$

where \hat{r}_t denotes the log deviation of the net nominal interest rate from the steady-state value. Further, the nominal interest rate is also assumed to respond to the log deviation of an exchange rate \hat{S}_t by following Lubik and Schorfheide (2005) and Adolfson et al. (2007).

2.6 Rest of the model

2.6.1 Risk premium and foreign assets

As described in Shioji et al. (2011), the interest rate of a foreign bond denominated in the foreign currency unit r_t^* is linked to a constant world interest rate r^w through the uncovered interest rate parity condition with a risk premium term that depends on the net foreign asset position ($S_t F_t / P_t Y_t$)

$$r_t^* = r^w + \psi \left\{ \exp \left(-\frac{S_t F_t}{P_t Y_t} \right) - 1 \right\} + u_t^{risk} \quad (27)$$

where u_t^{risk} denotes the risk premium following an exogenous process. In this specification, if the home country is a net borrower (i.e., $F_t < 0$), it has to pay an interest payment higher than the world interest rate to the foreign country.

In addition, the dynamics of the net foreign asset are written by

$$S_t F_t = R_{t-1}^* S_t F_{t-1} + S_t P_{x,t}^* y_{x,t} - P_{f,t} y_{f,t}. \quad (28)$$

This implies that the trade balance equals the capital account balance in each period.

2.6.2 Market clearing condition and resource constraint

Aggregate consumption, lump-sum taxes, capital, investment, domestic and international bonds, and dividends are given by

$$\begin{aligned}c_t &= (1 - \mu)c_t^R + \mu c_t^N; & k_t &= (1 - \mu)k_t^R; & B_t &= (1 - \mu)B_t^R; \\ \tau_t &= (1 - \mu)\tau_t^R + \mu\tau_t^N; & i_t &= (1 - \mu)i_t^R; & F_t &= (1 - \mu)F_t^R; \\ D_t &= (1 - \mu)D_t^R.\end{aligned}$$

The clearing conditions in the factor and goods markets are expressed as

$$\begin{aligned}n_t &= \int_0^1 n_t(j) dj; & k_t &= \int_0^1 k_t(j) dj; \\ y_{n,t} &= c_t + i_t + g_t\end{aligned}$$

and the resource constraint is

$$y_t = y_{h,t} + y_{x,t}.$$

2.6.3 Exogenous variables

With respect to the evolution of exogenous variables u_t^{risk} , y_t^{for} , A_t , g_t , we assume the following AR(1) process

$$\hat{u}_t^{risk} = \rho_{risk}\hat{u}_{t-1}^{risk} + e_t^{risk} \quad (29)$$

$$\hat{y}_t^{for} = \rho_{for}\hat{y}_{t-1}^{for} + e_t^{for} \quad (30)$$

$$\hat{A}_t = \rho_a\hat{A}_{t-1} + e_t^a \quad (31)$$

$$\hat{g}_t = \rho_g\hat{g}_{t-1} + e_t^g \quad (32)$$

where e_t^{risk} , e_t^{for} , e_t^a , e_t^g represent risk premium, foreign demand, supply, and demand (government spending) shocks, respectively.

2.7 Calibration

The model period is assumed to be one month in order to match the frequency of the data used in the empirical analysis. The calibration parameters are set based on the findings of previous studies. Some parameters that characterize the degree of rigidity and stance of monetary policy take two kinds of values. Specifically, we choose the share of Non-Ricardians, an investment adjustment cost, Calvo parameters on prices and wage, and the monetary policy response of the exchange rate as our parameters. By doing so, the IRF that corresponds to various economic situations can be computed using a combination of these parameter values. Finally, only robust signs are adopted as the restrictions imposed on the empirical model.

In previous analyses using macro data, the share of Non-Ricardians in Japan has

been estimated to be approximately 30% (Hatano, 2004; Iwata, 2008). Conversely, in the study by Kohara and Horioka (2006) that uses micro data, the same value has been estimated to be between 8% and 15%. In this paper, we set the share of Non-Ricardians as $[0.001, 0.5]$ in order to include the values estimated by previous studies.

The baseline value of the investment adjustment cost, which grows as the value of lowers, is set as 0.15 based on the findings of Sugo and Ueda (2008), while the lower bound is set as 5, at which point investment can be carried out at a lower cost compared with that in the baseline case.

For the upper values of prices and wage rigidities, we choose 0.8, which is somewhat larger than the average values estimated by Iiboshi et al. (2008), Sugo and Ueda (2008), and Iwata (2008). Likewise, the lower values of these parameters are set as 0.2 for two main reasons. First, an extremely small value (e.g., 0.001) is unrealistic, as it makes it difficult to ascertain the common features of IRFs. Second, since Pappa (2009) adopts 0.25 for the degree of price stickiness in the RBC case, this paper adopts a smaller value.

The feedback parameter for the exchange rate under the Taylor rule is most controversial. First, it is uncertain whether the central bank determines the interest rate in response to the exchange rate. Moreover, the interest rate in Japan since the second half of the 1990s has fallen into a static state because of the country's zero interest rate policy.

However, some studies have found that the interest rate reacts to the exchange rate. For example, Nakazawa et al. (2002) estimates a VAR model and reports that the call rate negatively responds to depreciation shock in the exchange rate. Nakazawa (2002) also confirms that monetary policy reacts to a variation in the exchange rate by estimating the Taylor rule directly. However, the values of the feedback parameter for the exchange

rate estimated by Nakazawa (2002) are small or not significant in the sample period used (1987M7–2001M3). Therefore, this paper adopts 0.001 as the lower bound of at which point the interest rate hardly reacts to the exchange rate, and 0.1 as the upper bound, which is twice the value used by Nakazawa et al. (2002).

All other parameters are summarized in Table 1. In the next subsection, we draw theoretical IRFs under these parameterizations and ascertain the sign restrictions imposed on the VAR model from their common features.

2.8 Sign restrictions

Figure 1 shows the theoretical impulse response of the real exchange rate, real exports, output, and price to risk premium, foreign demand, supply, and demand shock.

The first row in Figure 1 depicts the responses to risk premium shock. Risk premium shock raises the real exchange rate (i.e., depreciation) and increases export quantities through a fall in the export price. When price rigidity is high, export quantities grow by a low degree in order for export price to remain relatively steady. The response of the final goods price takes various signs according to the values of the parameters in the short run. Similarly, the responses of output also differ for each parameter value, and the specific quantitative feature cannot be ascertained.

The responses to foreign demand shock are shown in the second row. Export quantities naturally increase and output also rises in response to foreign demand shock. However, as price rigidity lowers, the export price reacts more positively to a rise in foreign demand and the persistency of responses in exports and output is thus small. In response to foreign demand shock, the real exchange rate appreciates as expected. With respect to

aggregate price, a particular sign cannot be determined since its response varies according to the degree of stickiness in the import price.

The third row indicates the responses to supply shock. As seen in traditional theoretical analysis, supply shock reduces aggregate price and increases output because any technological improvement lowers marginal cost. Moreover, a decrease in marginal cost lowers the export price. Hence, export quantities positively respond to supply shock. Further, the real exchange rate depreciates because of a falling domestic price.

Finally, the last row in Figure 1 shows the responses to demand shock. Similar to supply shock, positive responses to price and output are obtained in line with traditional theory. Although the real exchange rate does not indicate a significant sign at the moment of the shock, it shows a positive response from the second period to the seventh period. Further, reflecting the growth in the real exchange rate, the sign of exports is indeterminant in the first period, but positive thereafter.

Based on these results, we create sign restrictions, which are summarized in Table 2. These sign restrictions are generally imposed for the first three months, which are divided into two periods; the first period (i.e., the moment of the shock) and the periods thereafter. For example, the theoretical responses of the exchange rate and exports to demand shock do not show significant signs in the first period. In such a case, sign restrictions are only imposed from the second to the third periods. By contrast, a positive restriction is imposed on the response of output to foreign demand shock in the first period in order to be consistent with the result of the theoretical model. For the response of the exchange rate, no restrictions are imposed in the first period by taking the J-curve effect

into consideration, although the theoretical result indicates a positive sign.²

The short-run restrictions imposed on the first three periods can distinguish foreign demand shock from other shocks and supply and demand shock. More precisely, foreign demand shock is the only shock that causes an appreciation in the exchange rate. Moreover, supply and demand shocks are identified by a price response. However, risk premium shock is not discriminable from supply and demand shock by using such short-run restrictions.

Thus, this paper additionally adopts the following conditions based on the calibration results. First, it is assumed that the response of output to demand shock in the first period is larger than that of risk premium shock in order to disentangle risk premium and demand shock. Further, risk premium and supply shock are discriminated by the condition that output responds to supply shock more greatly from the 10th period to the 12th period compared with risk premium shock. In other words, supply shock is assumed to have a long-run effect on output compared with risk premium shock. These conditions are represented by one asterisk (*) and two asterisks (**) in Table 2. The four structural shocks can be identified by all these restrictions.

²The J-curve effect implies that the response of trade balance to a variation in the exchange rate shows the opposite sign to that expected in the short run. Gupta-Kapoor and Ramakrishnan (1999) and Hsing (2005) indicate the existence of the J-curve effect in Japan.

3 Estimation Model and Data

3.1 Sign-restricted VAR model

The sign-restricted VAR model is estimated by the following process. First, we estimate the reduced form VAR model:

$$Y_t = B_0 + B_1 Y_{t-1} + B_2 Y_{t-2} + \dots + B_p Y_{t-p} + u_t \quad (33)$$

$$u_t = A_0 \varepsilon_t \quad (34)$$

$$u_t \sim N(0, \Sigma), \varepsilon_t \sim N(0, I) \quad (35)$$

where Y_t is a vector of endogenous variables, $B = [B_0, B_1, \dots, B_p]$ is a vector of constants and matrices with coefficients, and u_t is a vector of reduced form residuals with the variance-covariance matrix, Σ . A_0 is a lower triangular matrix given by the Cholesky decomposition of Σ and ε_t is a vector of structural shocks that are mutually independent and normalized to be of variance 1.

Second, we draw random samples of B and Σ from their posterior distributions. Using the non-informative Normal-Wishart family as the prior distribution, the posterior distributions of $vec(B)$ and Σ^{-1} respectively become $N(vec(\hat{B}), \hat{\Sigma} \otimes (X'X)^{-1})$ and $W(\hat{\Sigma}^{-1}/T, T)$, where \hat{B} and $\hat{\Sigma}$ are OLS estimators, X is the matrix of the explanatory variables, and T is the sample size. Third, the structural shocks and matrix of contemporaneous relations among the endogenous variables are calculated from each draw. In this step, we randomly generate the orthogonal matrix Q , namely $Q'Q = I$. Using this

matrix, eq. (34) can be rewritten as

$$\begin{aligned} u_t &= A_0 Q' Q \varepsilon_t \\ &= A \tilde{\varepsilon}_t. \end{aligned} \tag{36}$$

Then,

$$\begin{aligned} E [A \tilde{\varepsilon}_t \tilde{\varepsilon}_t' A'] &= E [A_0 Q' Q \varepsilon_t \varepsilon_t' Q' Q A_0'] \\ &= A_0' A_0 = \Sigma \end{aligned} \tag{37}$$

Therefore, we construct a new set of structural shocks, $\tilde{\varepsilon}_t$ and contemporaneous relations, A , with the variance-covariance structure maintained. Some numbers of IRFs can be calculated from a set of (B, Σ) by generating a Q matrix randomly. As explained by Fry and Pagan (2007), the present paper generates a Q matrix as the following procedure. In a four-variable VAR model, we use a 4×4 Givens matrix Q_{12} , Q_{13} , Q_{14} , Q_{23} , Q_{24} , and Q_{34} , where $Q_{ij}(\theta)$ is a matrix with $\cos(\theta)$ in the (i, i) and the (j, j) elements, $-\sin(\theta)$ in the (j, i) element, and $\sin(\theta)$ in the (i, j) element. The diagonal element of this matrix is one, while the off-diagonal elements are equal to zero. Then, the Q matrix is defined as

$$Q = Q_{12}(\theta_1) Q_{13}(\theta_2) Q_{14}(\theta_3) Q_{23}(\theta_4) Q_{24}(\theta_5) Q_{34}(\theta_6)$$

where $\theta_k, k = 1, \dots, 6$ are drawn randomly from a uniform distribution $U(0, \pi)$.

Finally, the IRFs are calculated based on each draw (B, Σ, A) . If they satisfy the sign restriction in Table 2, they are candidates as valid IRFs and are reserved; otherwise, they

are discarded. We repeat this process until we have 300 valid IRFs as our final samples.

3.2 Data and specification

The endogenous variables in our VAR model are the log of the real effective exchange rate (REER), real exports, consumer price index (CPI), and indices of all industry activity (IIA), which is regarded as a proxy of GDP.³ The data are all monthly and the sample period is 1990M1–2011M10 (see Figure 2). Except for the REER, the series are seasonally adjusted.⁴ In the actual estimation, because an increase in the REER implies depreciation, we multiply it by -1 to make it consistent with the specification presented in the theoretical model. Hereafter, the term “output” indicates the IIA.

The estimated system contains a constant term and a consumption tax dummy (1997M4). In addition, it is estimated in levels because taking a difference may lose important information contained in the original series, as pointed out by Sims et al. (1990). The number of lags is chosen to be six as suggested by the Akaike information criterion. In this framework, based on the sign restrictions derived from the theoretical model, we identify four types of structural shock, risk premium (exchange rate), foreign demand, aggregate supply, and aggregate demand, respectively: $\varepsilon'_t = [\varepsilon_t^{risk} \ \varepsilon_t^f \ \varepsilon_t^s \ \varepsilon_t^d]$.

³Data for the REER and real exports are downloaded from the Bank of Japan website. Data on the CPI and IIA are from the Ministry of Internal Affairs and Communication and the Ministry of Economy, Trade, and Industry, respectively. These data are taken from the Nikkei NEEDS-Financial QUEST database.

⁴With respect to real exports and the IIA, seasonally adjusted series can be obtained from the data source. By contrast, because the series of the CPI, especially before 2000, is not seasonally adjusted in this data source, we perform a seasonal adjustment using X-12-ARIMA.

4 Empirical results

4.1 IRF analysis

Figure 3 depicts the estimated IRFs. The solid lines and shaded areas indicate the median of sampled IRFs and one standard error bands, respectively. This figure confirms that the IRFs follow the sign restrictions. However, it is worthwhile exploring the responses for which no sign restrictions are imposed. First, output responds to risk premium shock negatively, while price responds positively, in line with the findings of Shioji et al. (2011). Second, the price response to foreign demand shock shows a negative sign in the short run. In addition, it is confirmed that both supply and demand shock have a long-run effect on output, meaning that the IRFs are different from zero at a significant level.

4.2 FEVD

The results of the FEVD are presented in Figure 4. The estimated time horizon is 15 months as in the IRF analysis. This figure shows the relative importance of each shock in terms of the variations in each variable. The primary finding is that external shocks (i.e., risk premium and foreign demand shock) explain approximately 20% to 40% of the forecast error variances in output, as shown in the bottom right-hand figure. This result is somewhat larger than the values reported by Shioji et al. (2011) because the effects of shocks that are identified only in their paper (e.g., monetary policy and foreign price shock) might be included in external shocks in our analysis.

Additionally, a large part of the variation in real exports can be explained by foreign demand shock in the first period. From the second period onwards, foreign demand shock

continues to play a major role in the variation in real exports. In addition, the bottom right-hand figure shows that price is mainly explained by domestic shock, (i.e., supply and demand shock). These results concur with the findings of Shioji et al. (2011). With regard to the real exchange rate, we find that foreign demand shock (supply shock) is the main influencing factor on its fluctuation in the short (long) run. The results of the FEVD confirm that some of the fluctuations in output are caused by external shocks. Hence, it can be concluded that the Japanese economy is subject to external factors.

4.3 HD

The result of the HD of output is shown in Figure 5. The solid line denotes the estimated series of output and the dotted line denotes the decomposed series of each shock. Further, the shaded areas show the recessions dated by the Cabinet Office, the Government of Japan. First, we find that the supply shock series roughly traces the movement of output throughout the sample period. This finding implies that supply shock (i.e., variation in TFP) plays an important role in Japanese business cycles, as previously pointed by Hayashi and Prescott (2002) and Miyao (2006). In the next step, we investigate the sources of these business fluctuations by dividing the whole sample period into three sub-periods: the depression of the 1990s following the collapse of the bubble economy, the recovery since 2002, and the recession after the Lehman shock.

First, two factors are mainly recognized as having caused the depression in the 1990s (i) a shortage of aggregate demand and (ii) a downturn in productivity (i.e., TFP). This paper supports both these hypotheses.

In the two charts on the right-hand side of Figure 5, the contributions of demand and

foreign demand shock show a downward trend at the beginning of the 1990s and explain the majority of the movement in output. However, the contribution of demand shock changes to an upward trend after November 1992, while the negative trend in supply shock is observed from the mid-1990s. This negative supply shock is considered to have caused the low growth in output after moving out of recession at the beginning of the 1990s. Further, foreign demand shock denotes a negative contribution from 1997, which might reflect the fall in exports because of the onset of the Asian currency crisis.

Additionally, the influence of fiscal policy is confirmed in our results. The contribution of demand shock changes at several time points in the bottom chart on the right-hand side (e.g., 92M11, 95M04, 95M10). These points roughly correspond to the announcements or implementation of fiscal stimulus packages by the government,⁵ which is evidence that fiscal policy positively affected the economy in the 1990s. In summary, the long depression in the 1990s was caused by negative (but not simultaneous) shocks in demand and supply. A shortage in demand was first caused by overinvestment in the bubble period, which led to low productivity growth throughout the decade.

Second, the export-led recovery from 2002 stemmed from a boom in the US and economic growth in emerging countries. In this paper, the positive contribution of foreign demand shock is observed in this period, supporting such a view. Moreover, as shown in the bottom chart on the left-hand side in Figure 5, supply shock also plays an important role in economic recovery. This implies that not only depression but also economic recovery can be explained by the variation in TFP.⁶ By contrast, the contribution of demand shock is small albeit with an upward trend. In other words, consumption and investment

⁵Fukuda and Yamada (2011) detail when fiscal packages were announced.

⁶Inaba (2007) also points out the importance of supply shock in the recovery period after 2002.

seldom increased despite it being perceived as a genuine period of economic recovery.

On the final point, the results presented in this paper indicate that negative risk premium shock and demand shock mainly explain the fall in output following the Lehman shock in September 2008, while the negative contribution of supply shock is also confirmed throughout this recessionary period.

Surprisingly, the contribution of foreign demand shock to output is small. The top right-hand chart in Figure 6 helps explain that a fall in real exports following the Lehman shock can be explained by risk premium shock. This result suggests that a fall in real exports is not caused by a decrease in foreign demand, but rather by an endogenous response to an appreciation in the exchange rate. In this period, the data indicate that the exchange rate appreciates before of the reduction in exports. Since the fall in real exports is an endogenous response, the movement of output can also be explained by risk premium shock as opposed to foreign demand shock. Indeed, Figure 7 confirms the low degree of influence of foreign demand shock on output.

In summary, we can conclude that the rapid fall in output after the Lehman shock was mainly caused by negative risk premium shock, i.e., an appreciation of the real exchange rate. The negative contribution of supply shock also played a major role throughout the recessionary period from August 2008. These results indicate that business fluctuations were caused by different shocks for each period and that the role of external shocks has grown in recent years.

5 Conclusion

This paper investigated the sources of Japanese business fluctuations by taking account of external shocks, such as risk premium and foreign demand shock. For this purpose, an NK open macroeconomics model was first constructed in order to ascertain the features of each structural shock. Then, we estimated the sign-restricted VAR model based on theoretical IRFs and conducted the FEVD and HD as well as IRF analysis. From these analyses, the effects of external shocks were evaluated qualitatively and quantitatively.

The results of the FEVD clarify that 20% to 40% of the forecast error variances in output can be explained by external shocks, supporting the well-recognized notion that the Japanese economy is greatly influenced by external factors. This finding confirms the importance of taking account of external shocks when examining the Japanese economy.

In addition, the results of the HD allow us to draw four main conclusions. First, in the whole study period, supply shock explains the variation in output more than any other shock. Second, the long depression in the 1990s was caused by a combination of negative supply and demand shock; however, these negative shocks did not happen simultaneously. While negative demand shock explained the fall in output at the beginning of the 1990s, negative supply shock played a major role in the second half of the 1990s. Third, the economic recovery since 2002 has stemmed from an increase in foreign demand and an improvement in productivity. Finally, the main factor behind the rapid fall in output and exports since the Lehman shock has been negative risk premium shock. In other words, the rapid appreciation of the real exchange rate has reduced real exports endogenously, leading to a considerable decline in output.

The first three findings are consistent with the results presented by previous studies.

By contrast, the latter result is a novel finding by this paper. Further, the finding that an appreciation of the exchange rate is a main factor in the reduction in output is different from that presented by Shioji and Uchino (2011).

We also show that the role of external shocks is larger in recent business fluctuations, namely from the economic recovery from 2002 to the recession since the Lehman shock. This finding implies that the Japanese economy has been increasingly affected by opening its borders to global trade partners. Therefore, future analyses based on an open economy framework in Japan are crucial when the effects of a policy can be predicted or verified.

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Appendix A Table and Figure

Table 1: Calibration Parameters

Parameter	Value	Description
β	0.9975	Subjective discount rate
δ	0.01	Depreciation rate
α	0.3	Share of capital
γ	1.5	Risk aversion
λ	2	Inverse labor supply elasticity
ω	0.88	Degree of home bias
μ	[0.001, 0.5]	Share of Non-Ricardians
κ	[0.15, 5]	Investment adjustment cost
ρ_p, ρ_x	[0.2, 0.8]	Calvo parameters on domestic and exported prices
ρ_f	[0.2, 0.8]	Calvo parameters on imported prices
ρ_w	[0.2, 0.8]	Calvo parameters on wages
θ_p	6	Elasticity of substitution in production
ε_w	6	Elasticity of substitution in labor input
θ_x	1	Price elasticity of exported goods
η	1	Elasticity of substitution bet. domestic and imported goods
ψ	0.01	Parameter on the risk premium
s_g	0.2	Steady-state share of government spending
ϕ_g	0.03	Elasticity of tax to government spending
ϕ_b	0.12	Elasticity of tax to debt
ϕ_π	1.5	Monetary policy response of an inflation rate
ϕ_S	[0.001, 0.1]	Monetary policy response of an exchange rate
ρ_i	0.95	persistence of exogenous shocks

Notes: The values of parameters are basically set up according to the previous studies. With respect to the value of ω , it is set on the basis of the import inducement coefficient in the Input-Output Table as in Shioji et al. (2011).

Table 2: Sign restrictions

	exchange rate			exports			output			price		
	1	2-3	10-12	1	2-3	10-12	1	2-3	10-12	1	2-3	10-12
Risk premium shock	+	+			+		*		**			
Foreign demand shock	-	-		+	+		+					
Supply shock	+	+		+	+		+	+		-	-	
Demand shock		+			+		+	+		+	+	

Note: Sign restrictions are set to be consistent with the theoretical impulse response functions. Blank spaces mean that no sign restrictions are imposed. In this table, one asterisk (*) represents that the response of output to demand shock in the first period is larger than that of risk premium shock, while two asterisk (**) denotes that supply shock has a long-run effect on output compared with risk premium shock. In addition, no sign restriction are imposed in the response of exports to risk premium shock at the first period by taking into the J-curve effect into consideration, although the theoretical result indicates a positive sign.

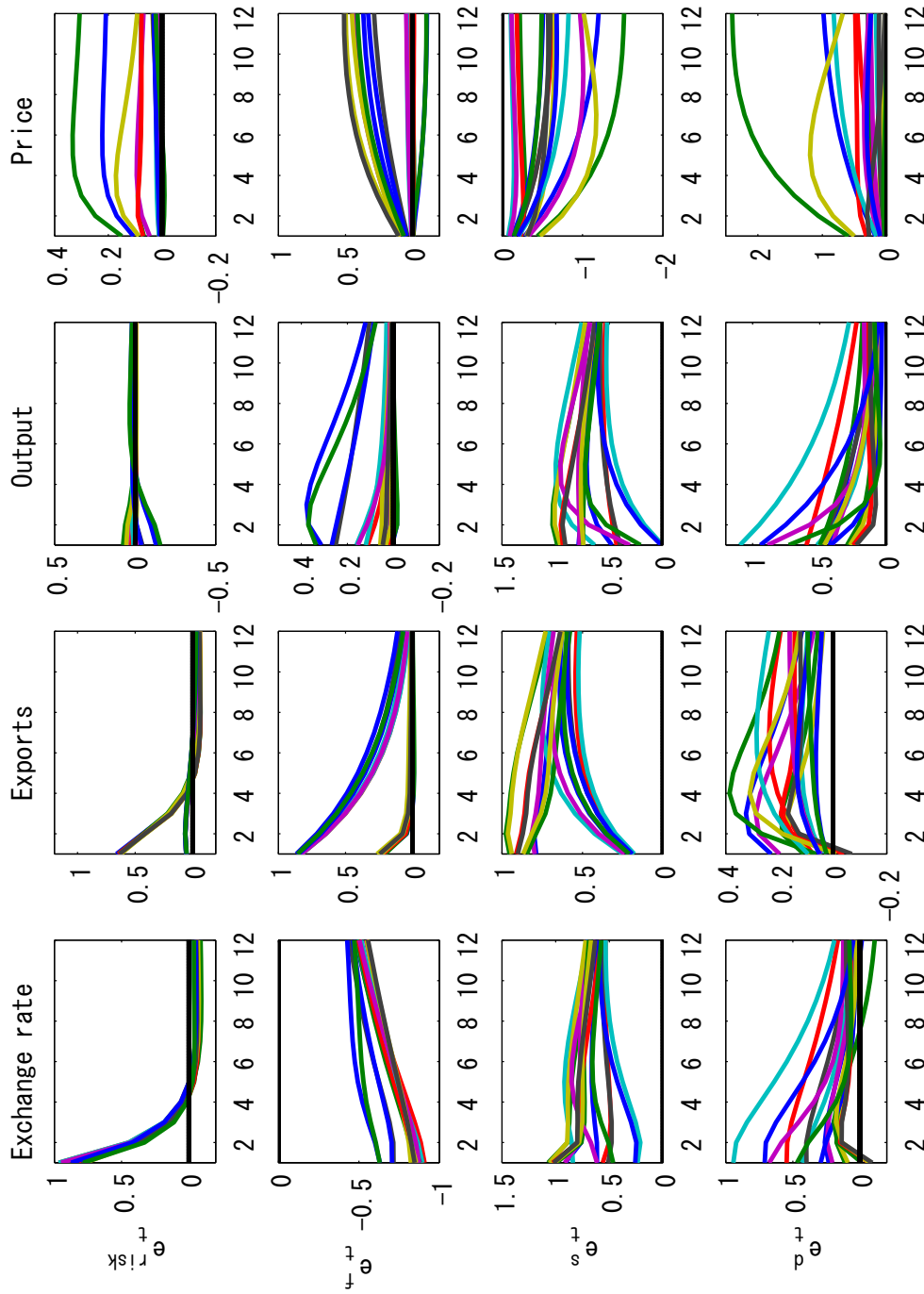


Figure 1: Impulse Response Function (Theoretical model)

Note: The impulse response functions are drawn under the each parameter value in Table 1.

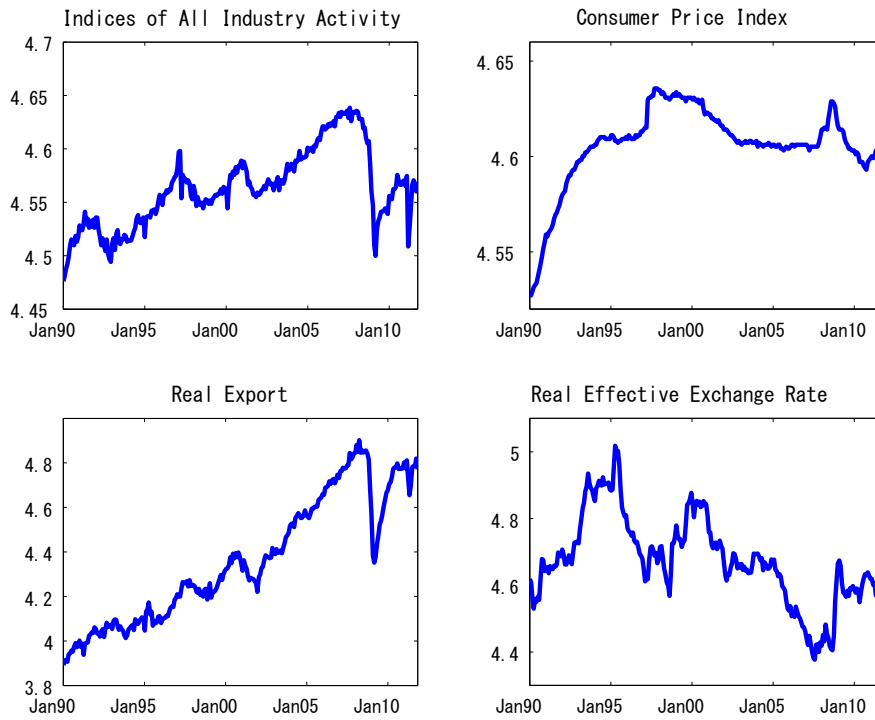


Figure 2: Data

Note: All data has taken logarithm, and seasonally adjusted except for the real effective exchange rate. The real exports and the real effective exchange rate are downloaded from Bank of Japan's web page. The series of Indices of All industry Activity (IIA) and CPI are obtained from Ministry of Economy, Trade and Industry and, Ministry of Internal Affairs and Communication, respectively.

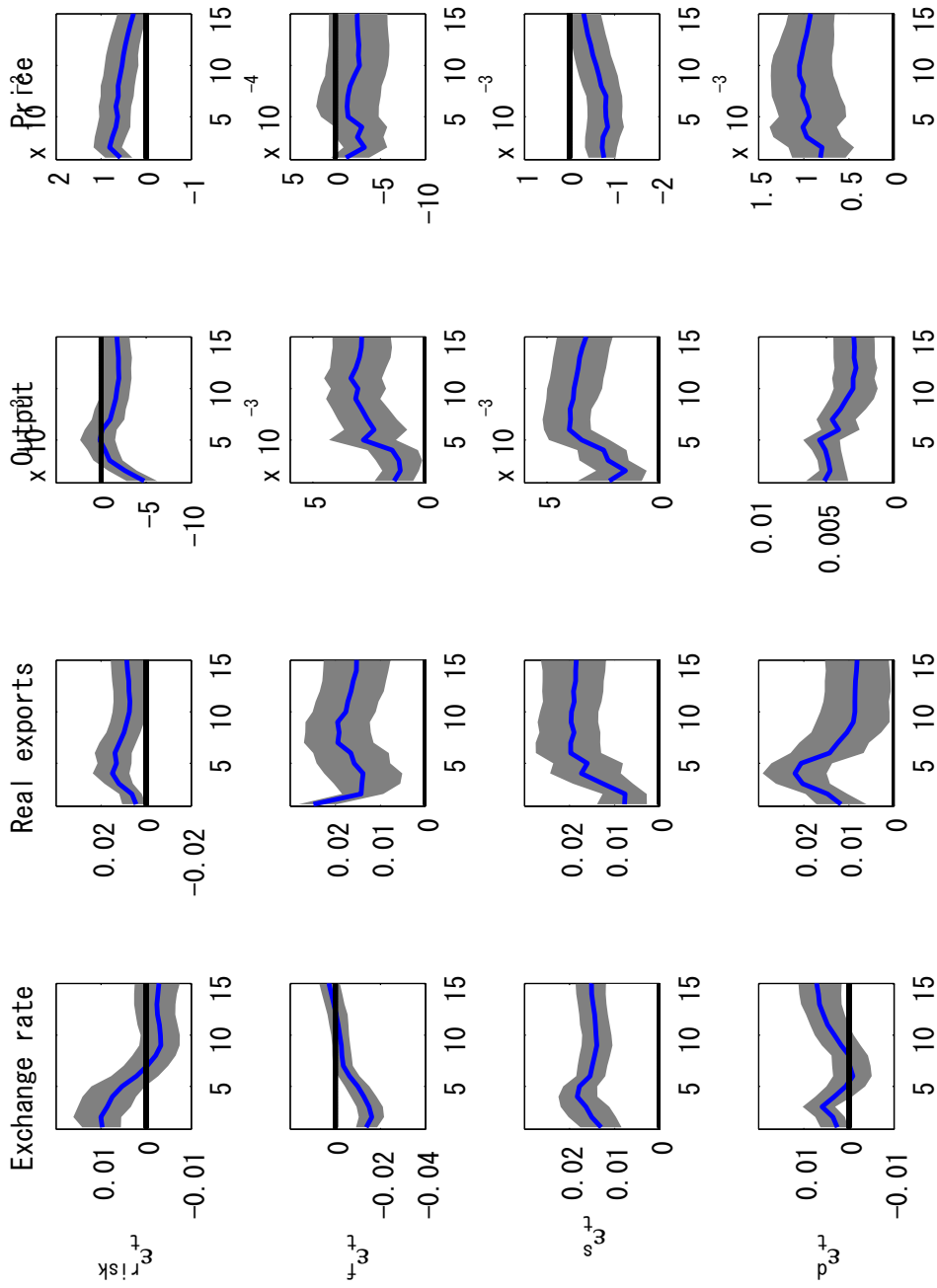


Figure 3: Impulse Response Function (Empirical model)

Note: This figure shows the impulse response functions to one standard deviation innovation in each shock. A blue solid lines is a median of the sampled impulse response functions. A shaded area denotes a 68% credible interval.

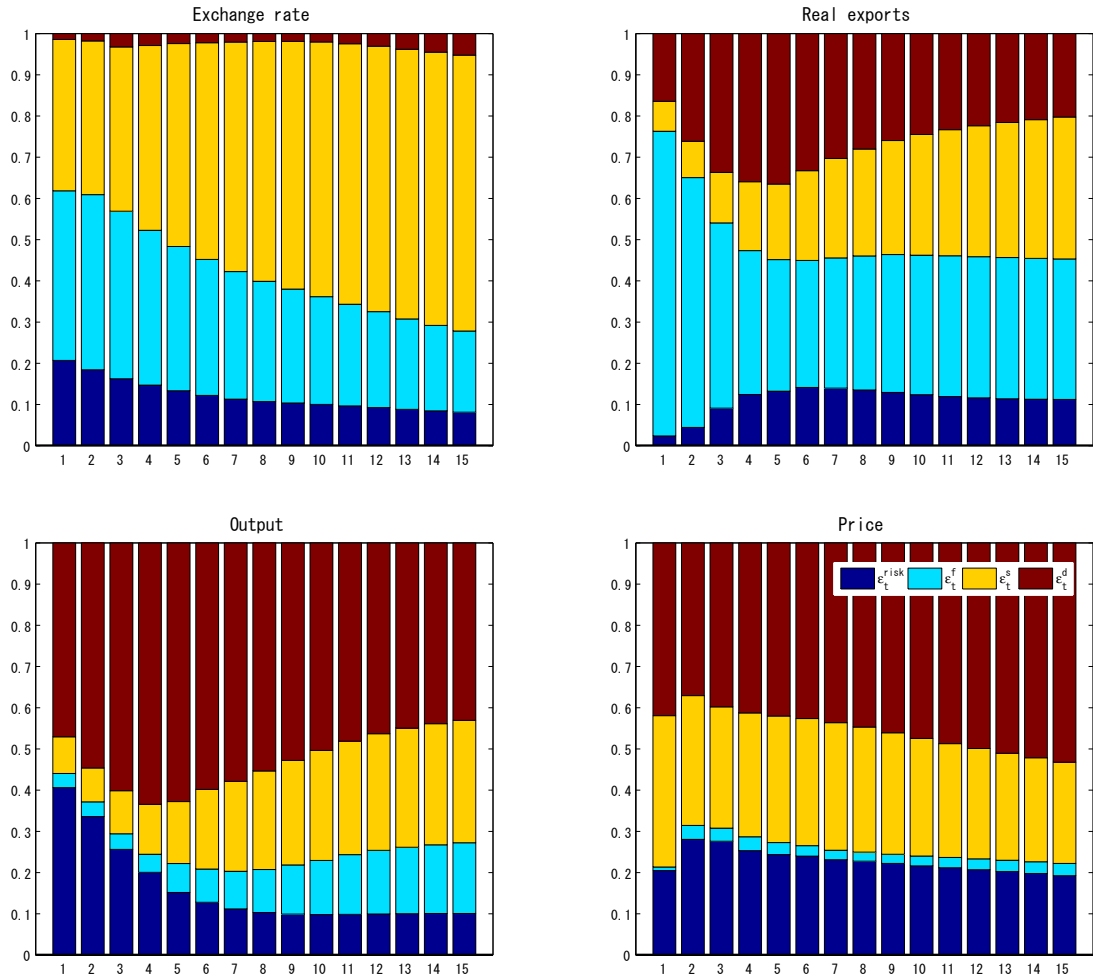


Figure 4: Forecast error variance decomposition

Note: This figure shows the results of the forecast error variance decomposition. In this figure, colored regions indicate the ratio explained by a risk premium, a foreign demand, a supply and a demand shock in an order from bottom.

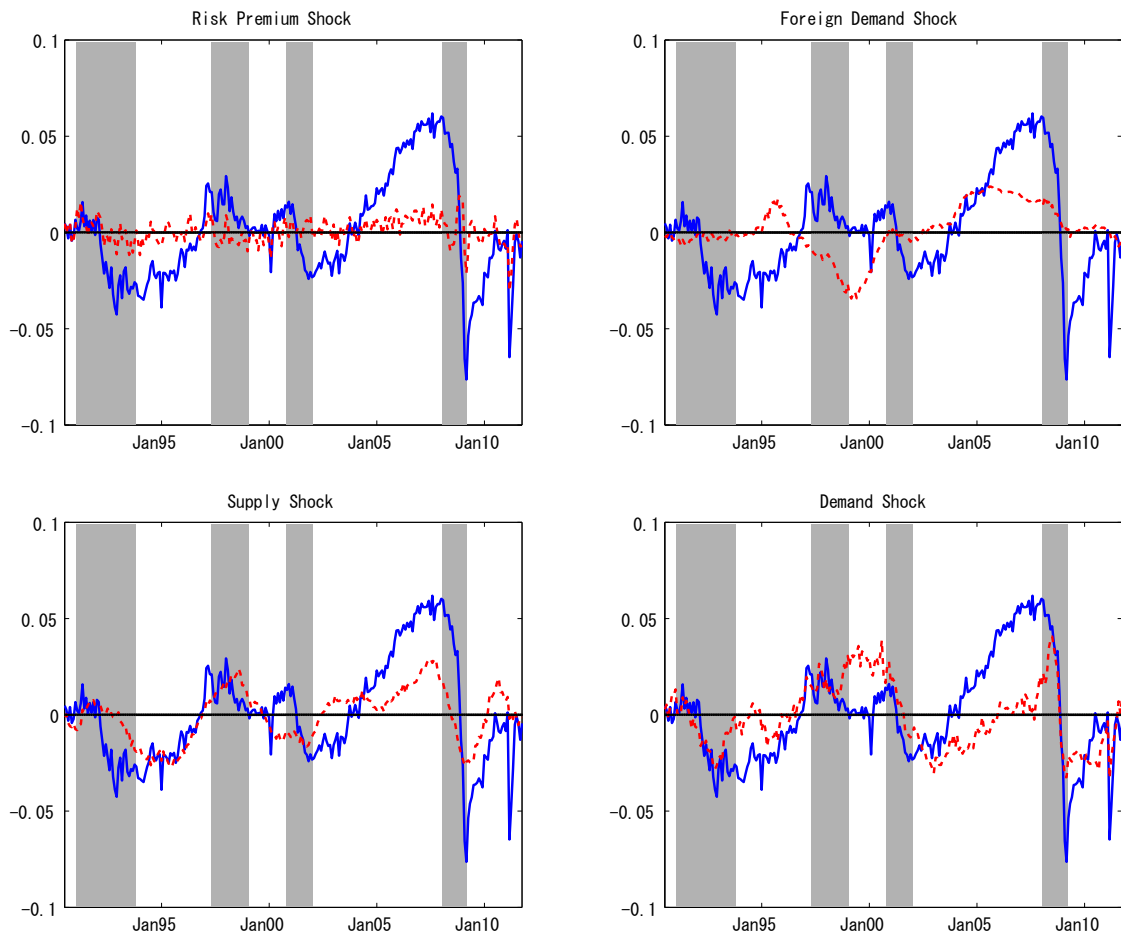


Figure 5: Historical decomposition in output

Note: This figure shows the result of the historical decomposition in output. A solid line and a dotted line denote the estimated series of output and the portion explained by each structural shock. Further, the shaded areas show the recessions dated by Cabinet Office, Government of Japan.

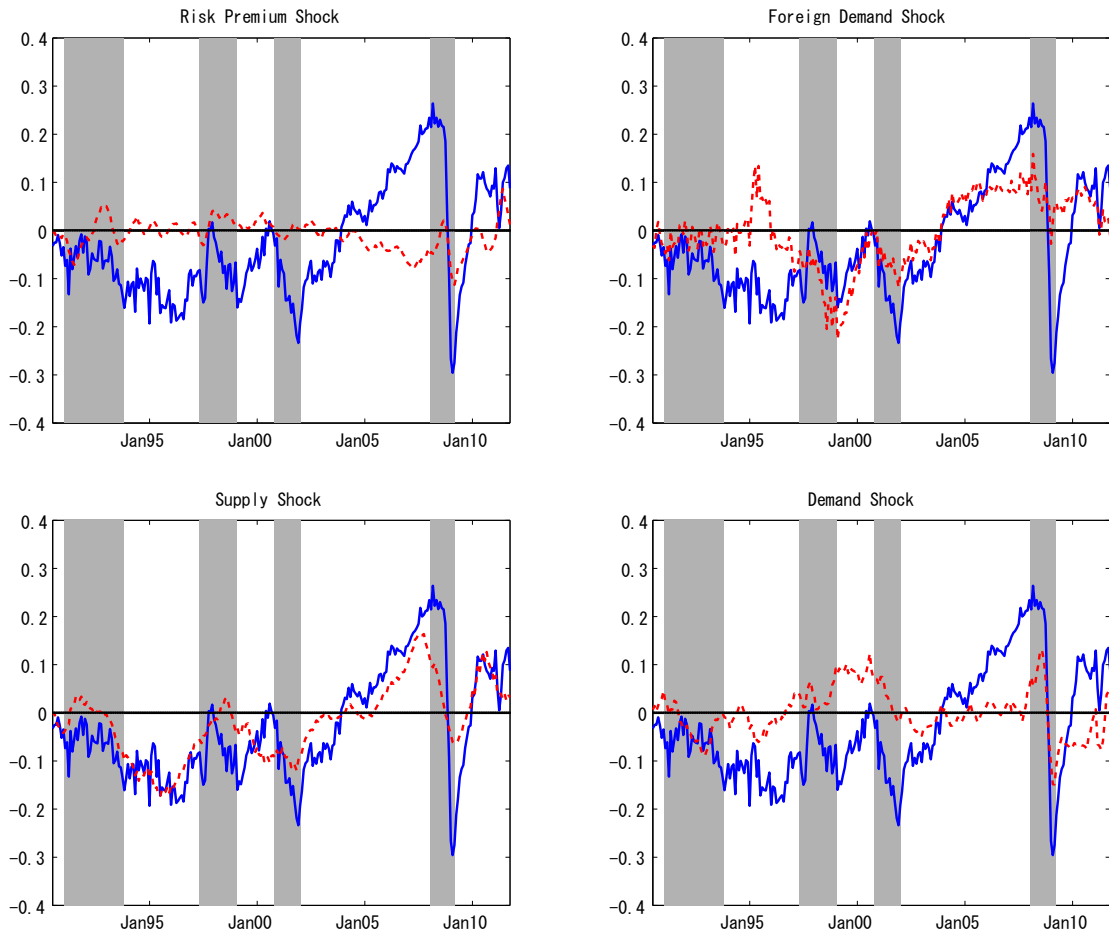


Figure 6: Historical decomposition in real exports

Note: This figure shows the result of the historical decomposition in real exports. A solid line and a dotted line denote the estimated series of real exports and the portion explained by each structural shock. Further, the shaded areas show the recessions dated by Cabinet Office, Government of Japan.

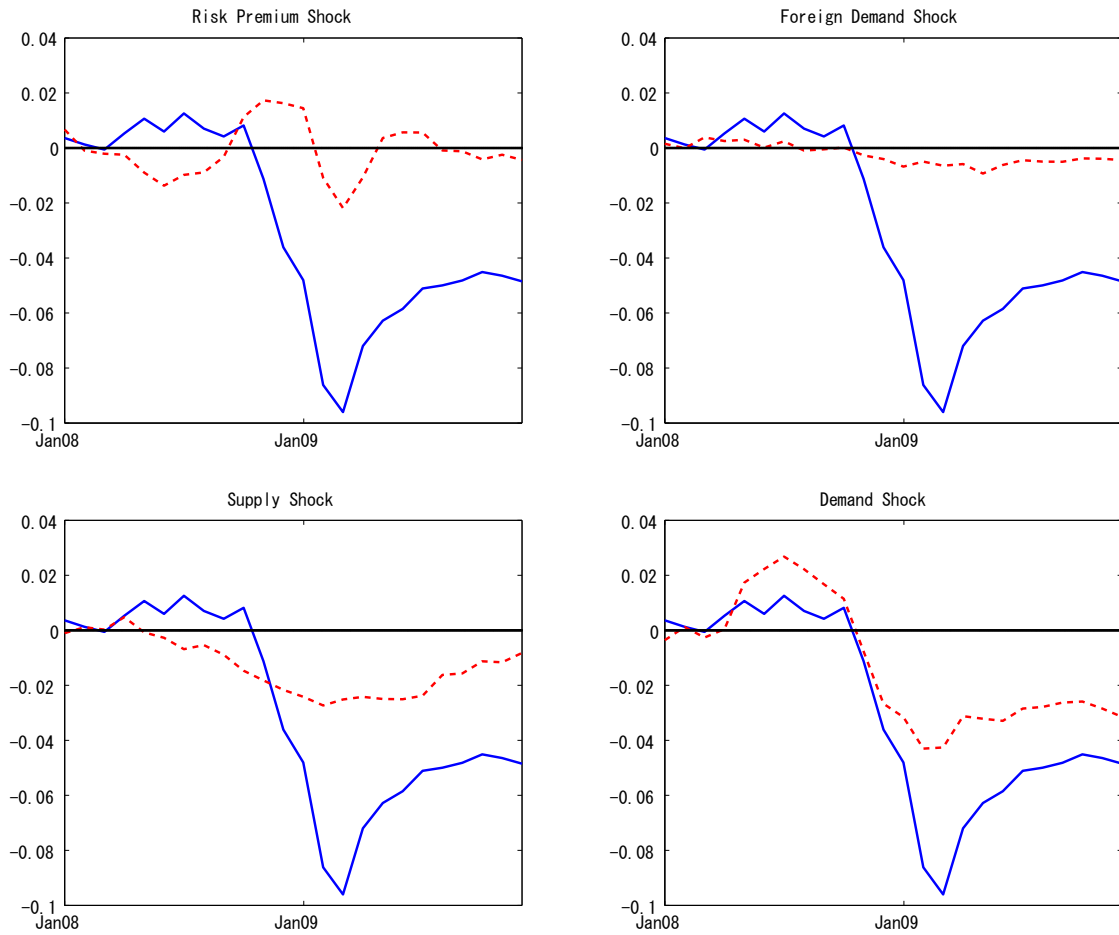


Figure 7: Historical decomposition in output conditioning on the data before 2008

Note: This figure shows the result of the historical decomposition in output conditioning on the data before January 2008. A solid line and a dotted line denote the estimated series of output and the portion explained by each structural shock.