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Sohei Kaihatsu*
souhei.kaihatsu@boj.or.jp

Takushi Kurozumi*
takushi.kurozumi@boj.or.jp

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Bank of Japan
2-1-1 Nihonbashi Hongoku-cho, Chuo-ku, Tokyo 103-8660

* Monetary Affairs Department, Bank of Japan.

Sources of Business Fluctuations: Financial or Technology Shocks?*

Sohei Kaihatsu[†] Takushi Kurozumi[‡]

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Abstract

Despite the widespread belief that technology shocks are the main source of business fluctuations, recent empirical studies find that an investment efficiency shock mainly drives such fluctuations and reflects financial conditions for investment. This poses the question as to what is the major source of the fluctuations, financial or technology shocks. We thus incorporate a financial accelerator mechanism into a DSGE model with stochastic trends in neutral and investment-specific technological changes, and replace the investment efficiency shock with two financial shocks to the external finance premium and to entrepreneurs' net worth. This model is estimated by Bayesian methods with data including the relative price of investment and credit growth. We show that, in both Japan and the U.S., the main driving force of output fluctuations is neutral technology shocks, and financial shocks are at least as important for investment fluctuations as technology shocks. We also show that a sharp decline and a subsequent hike in the external finance premium, caused by shocks to this premium, induced the boom and bust cycles of investment via the financial accelerator mechanism during the late 1980s and the 1990s in Japan and since 2004 in the U.S.

Keywords: Business fluctuations; Financial accelerator; Trend in technological changes; External finance premium; Boom and bust cycle

JEL Classification: E22; E32; E51

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[†]Bank of Japan. E-mail address: souhei.kaihatsu@boj.or.jp

[‡]Bank of Japan. E-mail address: takushi.kurozumi@boj.or.jp

1 Introduction

In the business cycle literature, technology shocks have been considered the main source of business fluctuations. As Justiniano, Primiceri, and Tambalotti (2010a) point out, previous studies with general equilibrium models tend to attribute a dominant role in business cycles to neutral technology shocks.[1] However, the recent severe economic downturn due to the collapse of credit bubbles has provoked a re-evaluation of this conventional view on business fluctuations. Justiniano, Primiceri, and Tambalotti (2010b) empirically demonstrate that the shock to the marginal efficiency of investment, which was first proposed by Greenwood, Hercowitz, and Huffman (1988), is the main driving force of fluctuations in investment and output in the U.S., and that this shock reflects corporate financial conditions for investment spending. Similarly, Hirose and Kurozumi (2010) show that the boom and bust cycle of investment during the late 1980s and the 1990s in Japan was driven by an investment efficiency shock, and that this shock is related to the financial position of firms in Japan. These empirical findings pose the question as to what is the major source of business fluctuations, financial or technology shocks.

To address this question, we incorporate the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999) into a dynamic stochastic general equilibrium (DSGE) model with stochastic trends in neutral and investment-specific technological changes, and replace the investment efficiency shock with two financial shocks to the external finance premium and to entrepreneurs' net worth. This model is estimated by Bayesian methods with Japanese and the U.S. data that include the relative price of investment and credit growth. It is important to stress that our paper develops a DSGE model for non-stationary variables which grow at rates given by the stochastic trends in neutral and investment-specific technological changes, and that our paper estimates not only parameters of the model but also such stochastic trends using the non-detrended data. This is in stark contrast to previous empirical studies on the financial accelerator mechanism, which build a DSGE model for stationary variables and estimate such a model with data detrended by, for example, the Hodrick-Prescott filter.[2] This difference in the modeling and estimation strategy is of crucial importance in investigating the sources of business fluctuations, because the estimates of the stochastic trends determine the magnitude and direction of the business cycle component of the data.

[1] For a comprehensive assessment of this point, see King and Rebelo (1999).

[2] See e.g. Christensen and Dib (2008), De Graeve (2008), Fuchi, Muto, and Ugai (2005), and Hirose (2008).

In the literature, the most closely related study is done by Gilchrist, Ortiz, and Zakrajsek (2009), who use Bayesian methods to estimate a financial accelerator DSGE model of the U.S. economy with a deterministic trend in neutral technological changes. In their analysis, however, there are two critical flaws in gauging financial shocks. First, Gilchrist, Ortiz, and Zakrajsek do not include investment-specific technological changes in their model, despite the fact that the presence of such technological changes is suggested by the data on the relative price of investment to consumption. The absence of investment-specific technological changes may potentially contaminate the estimates of the trend in investment and hence the estimates of financial shocks, which are related to the business cycle component of the investment data via the financial accelerator mechanism. Second, Gilchrist, Ortiz, and Zakrajsek do not use the data on the relative price of investment in their estimation. As emphasized by Justiniano, Primiceri, and Tambalotti (2010b) and Hirose and Kurozumi (2010), this data is critical to the estimation of a stochastic trend in investment-specific technological changes, which gives an estimated trend in investment. By contrast, the present paper estimates the financial accelerator DSGE model with stochastic trends in neutral and investment-specific technological changes, using the relative price data.

This paper obtains three main empirical findings. First, the major driving force of output fluctuations in both Japan and the U.S. is technology shocks. More importantly, neutral technology shocks are the main source of output fluctuations, which is in line with the results of previous studies using general equilibrium models, whereas investment-specific technology shocks play a very minor role in both countries.[3] Second, financial shocks are at least as important for investment fluctuations in both Japan and the U.S. as technology shocks. Particularly, shocks to the external finance premium are the primary source of investment fluctuations in the U.S. and are a major one in Japan. As Gilchrist, Ortiz, and Zakrajsek (2009) point out, an external finance premium shock represents a shock to the supply of credit that captures changes in the efficiency of the financial intermediation process or a shock to the financial sector that boosts the external finance premium beyond the level warranted by currently available information about the state of the economy and the stance of monetary policy. This feature of external finance premium shocks leads to the last main finding that a sharp decline and a

[3]Schmitt-Grohe and Uribe (2008) and Justiniano, Primiceri, and Tambalotti (2010b) show that the contribution to the U.S. business fluctuations by investment-specific technology shocks is negligible. Hirose and Kurozumi (2010) obtain a similar result with respect to Japan's business fluctuations.

subsequent hike in the external finance premium, caused by the premium shocks, induced the boom and bust cycles of investment via the financial accelerator mechanism during the late 1980s and the 1990s in Japan and since 2004 in the U.S.

The remainder of the paper proceeds as follows. Section 2 describes a DSGE model with a financial accelerator mechanism. Section 3 presents data and strategy for estimating this model. Section 4 illustrates results of the empirical analysis. Finally, Section 5 concludes.

2 The DSGE model with a financial accelerator mechanism

We incorporate the financial accelerator mechanism proposed by Bernanke, Gertler, and Gilchrist (1999) into a DSGE model with stochastic trends in neutral and investment-specific technological changes. This accelerator mechanism is in line with those of previous empirical studies, such as Christensen and Dib (2008), De Graeve (2008), Gilchrist, Ortiz, and Zakrajsek (2009), and Hirose (2008). As is similar to Gilchrist, Ortiz, and Zakrajsek, our model introduces two financial shocks to the external finance premium and to entrepreneurs' net worth.

The model economy consists of a continuum of households $h \in [0,1]$, entrepreneurs, a financial intermediary, a continuum of retailers $f_r \in [0,1]$, a representative consumption-good-producing firm, a continuum of investment-good-producing firms $f_i \in [0,1]$, a representative capital-good-producing firm, and a central bank. Each agent's behavior is described in turn.

2.1 Households

Each household $h \in [0,1]$ derives utility from purchasing consumption goods $C_t(h)$ and supplying differentiated labor services $l_t(h)$ to entrepreneurs under monopolistic competition. This household's preferences are represented by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \exp(z_t^b) \left[\frac{(C_t(h) - \theta C_{t-1}(h))^{1-\sigma}}{1-\sigma} - \frac{(Z_t^*)^{1-\sigma} \exp(z_t^l)\,(l_t(h))^{1+\chi}}{1+\chi} \right],$$

where E_t is the expectation operator conditional on information available in period t, $\beta \in (0,1)$ is the subjective discount factor, $\sigma > 0$ represents the degree of relative risk aversion, $\theta \in (0,1)$ represents the degree of internal habit persistence in consumption preferences, $\chi > 0$ is the inverse of the labor supply elasticity, and z_t^b and z_t^l denote an intertemporal preferences shock and a labor supply shock, respectively. As in Erceg, Guerrieri, and Gust (2006) and Hirose and Kurozumi (2010), the labor disutility term contains $(Z_t^*)^{1-\sigma}$, where Z_t^* is the composite technological level explained later, in order to ensure the existence of a balanced growth path for the model economy. The household's budget constraint is given by

$$P_t C_t(h) + D_t(h) = r_{t-1}^n D_{t-1}(h) + P_t W_t(h) l_t(h) + T_t(h),$$

where P_t is the price of consumption goods, $D_t(h)$ is deposits in a financial intermediary, r_t^n is the gross nominal deposit rate, which is assumed to be equal to the monetary policy rate, $W_t(h)$ is the real wage, and $T_t(h)$ consists of profits received from firms and a lump-sum public transfer.

In the presence of complete insurance markets, the levels of consumption and deposits are identical among households, and hence the first-order conditions for optimal decisions on consumption and deposits become

$$\Lambda_t = \exp(z_t^b)\left(C_t - \theta C_{t-1}\right)^{-\sigma} - \beta\theta E_t \exp(z_{t+1}^b)\left(C_{t+1} - \theta C_t\right)^{-\sigma}, \tag{1}$$

$$1 = E_t\, \beta \frac{\Lambda_{t+1}}{\Lambda_t} \frac{r_t^n}{\pi_{t+1}}, \tag{2}$$

where Λ_t is the marginal utility of consumption and $\pi_t = P_t/P_{t-1}$ is the gross consumption-good price inflation rate.

Under monopolistic competition, entrepreneurs' demand for household h's labor services is given by $l_t(h) = l_t(W_t(h)/W_t)^{-\theta_t^w}$, where $l_t = \left[\int_0^1 (l_t(h))^{(\theta_t^w-1)/\theta_t^w}\, dh\right]^{\theta_t^w/(\theta_t^w-1)}$ is an aggregate of differentiated labor services with the substitution elasticity $\theta_t^w > 1$ and where

$$W_t = \left[\int_0^1 \left(W_t(h)\right)^{1-\theta_t^w} dh\right]^{\frac{1}{1-\theta_t^w}} \tag{3}$$

is the corresponding aggregate real wage. Household h's real wage $W_t(h)$ is set on a staggered basis à la Calvo (1983). In each period, a fraction $1 - \xi_w \in (0, 1)$ of wages is reoptimized, while the remaining fraction ξ_w is set by indexation to both the gross trend rate of balanced growth explained later, z^*, and a weighted average of past and steady-state inflation rates, $\pi_{t-1}^{\gamma_w}\pi^{1-\gamma_w}$, where $\gamma_w \in [0, 1]$ is the relative weight on the past inflation rate. Then, each wage reoptimized in period t is chosen so as to maximize

$$E_t \sum_{j=0}^{\infty} (\beta\xi_w)^j \left[\begin{array}{l} \Lambda_{t+j}\, l_{t+j|t}(h) \dfrac{P_t W_t(h)}{P_{t+j}} \displaystyle\prod_{k=1}^{j} \left(z^* \pi_{t+k-1}^{\gamma_w} \pi^{1-\gamma_w}\right) \\ -\dfrac{\exp(z_{t+j}^b)(Z_{t+j}^*)^{1-\sigma} \exp(z_{t+j}^l)\left(l_{t+j|t}(h)\right)^{1+\chi}}{1+\chi} \end{array} \right]$$

subject to

$$l_{t+j|t}(h) = l_{t+j} \left[\frac{P_t W_t(h)}{P_{t+j} W_{t+j}} \prod_{k=1}^{j} \left(z^* \pi_{t+k-1}^{\gamma_w} \pi^{1-\gamma_w} \right) \right]^{-\theta_{t+j}^w}.$$

The first-order condition for the reoptimized wage W_t^o is given by

$$E_t \sum_{j=0}^{\infty} \left\{ \begin{array}{l} (\beta \xi_w)^j \dfrac{\Lambda_{t+j}}{\lambda_{t+j}^w} l_{t+j} \left[\dfrac{(z^*)^j W_t^o}{W_{t+j}} \displaystyle\prod_{k=1}^{j} \left\{ \left(\dfrac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \dfrac{\pi}{\pi_{t+k}} \right\} \right]^{-\frac{1+\lambda_{t+j}^w}{\lambda_{t+j}^w}} \\ \times \left[\begin{array}{l} (z^*)^j W_t^o \displaystyle\prod_{k=1}^{j} \left[\left(\dfrac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \dfrac{\pi}{\pi_{t+k}} \right] \\ -\left(1+\lambda_{t+j}^w\right) \dfrac{\exp(z_{t+j}^b) \exp(z_{t+j}^l) (Z_{t+j}^*)^{1-\sigma}}{\Lambda_{t+j}} \\ \times \left(l_{t+j} \left\{ \dfrac{(z^*)^j W_t^o}{W_{t+j}} \displaystyle\prod_{k=1}^{j} \left[\left(\dfrac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \dfrac{\pi}{\pi_{t+k}} \right] \right\}^{-\frac{1+\lambda_{t+j}^w}{\lambda_{t+j}^w}} \right)^{\chi} \end{array} \right] \end{array} \right\} = 0, \tag{4}$$

where $\lambda_t^w \equiv 1/(\theta_t^w - 1) > 0$ denotes the wage markup. The aggregate wage equation (3) can be reduced to

$$1 = (1-\xi_w) \left(\left(\frac{W_t^o}{W_t} \right)^{-\frac{1}{\lambda_t^w}} + \sum_{j=1}^{\infty} (\xi_w)^j \left\{ \frac{(z^*)^j W_{t-j}^o}{W_t} \prod_{k=1}^{j} \left[\left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right] \right\}^{-\frac{1}{\lambda_t^w}} \right). \tag{5}$$

2.2 Entrepreneurs and financial intermediary

Entrepreneurs produce output Y_t^E under perfect competition by adjusting labor input l_t and the capital utilization rate u_t, given the capital stock K_{t-1} that was purchased at the real price Q_{t-1} from the capital-good firm at the end of the previous period. This purchase is financed not only by entrepreneurs' real net worth N_{t-1} but also by real borrowing

$$B_{t-1} = Q_{t-1} K_{t-1} - N_{t-1} \tag{6}$$

at the gross real interest rate $E_{t-1} r_t^E$ from a financial intermediary, which obtains funds from households' deposits at the gross real interest rate $E_{t-1}(r_{t-1}^n / \pi_t)$. Entrepreneurs' production function is given by

$$Y_t^E = (Z_t \, l_t)^{1-\alpha} (u_t K_{t-1})^{\alpha} - \phi Z_t^*. \tag{7}$$

Here, Z_t represents the level of neutral technology, and this level is assumed to follow the stochastic process

$$\log Z_t = \log z + \log Z_{t-1} + z_t^z, \tag{8}$$

where $z > 1$ denotes the gross trend rate of neutral technological changes and z_t^z represents a neutral technology shock. The parameter $\alpha \in (0,1)$ represents the capital elasticity of output. The last term in the production function (7), $-\phi Z_t^*$, is the fixed cost of producing output. Here, ϕ is a positive constant, and Z_t^* is the composite technological level given by $Z_t^* = Z_t(\Psi_t)^{\alpha/(1-\alpha)}$, where Ψ_t represents the level of investment-specific technology explained later. This composite technological level can be derived using the Cobb-Douglas production function (7). Then, the logarithm of the composite technological changes, $\log(Z_t^*/Z_{t-1}^*)$, turns out to be the gross rate of balanced growth, and the associated trend rate is given by $z^* = z\psi^{\alpha/(1-\alpha)}$, where $\psi > 1$ is the gross trend rate of investment-specific technological changes.

After production, entrepreneurs sell their products to retailers at the real price that is equal to their real marginal cost mc_t because of perfect competition in the market for entrepreneurs' products. Capital is depreciated at the rate $\delta(u_t)$. As in Greenwood, Hercowitz, and Huffman (1988), it is assumed that a higher utilization rate of capital leads to a higher depreciation rate of capital. Thus, the depreciation rate function $\delta(\cdot)$ has properties of $\delta' > 0$, $\delta'' > 0$, $\delta(1) = \delta \in (0,1)$, and $\mu = \delta'(1)/\delta''(1) > 0$. Entrepreneurs sell the resulting capital $(1-\delta(u_t))K_{t-1}$ to the capital-good firm at the real price Q_t and pay back $(E_{t-1}r_t^E)B_{t-1}$ to the financial intermediary.

As in Bernanke, Gertler, and Gilchrist (1999), entrepreneurs are assumed to be risk neutral, and thus their demand for capital is determined so that the expected marginal cost and the expected marginal return from purchasing capital are equal

$$E_t r_{t+1}^E = E_t \left[\frac{u_{t+1} R_{t+1}^k + Q_{t+1}\left(1 - \delta(u_{t+1})\right)}{Q_t} \right], \tag{9}$$

where R_t^k denotes the marginal product of capital. Also, the real borrowing rate is the real funding rate plus the external finance premium

$$E_t r_{t+1}^E = E_t \left[\frac{r_t^n}{\pi_{t+1}} F\left(\frac{N_t}{Q_t K_t} \right) \exp(z_t^{efp}) \right], \tag{10}$$

where the external finance premium function $F(\cdot)$ depends on entrepreneurs' leverage ratio $N_t/(Q_t K_t)$ and satisfies $F' < 0$ and $F(1) = 1$ and where z_t^{efp} denotes a shock to the external finance premium. This shock is referred to by Gilchrist, Ortiz, and Zakrajsek (2009) as a "credit supply shock," and it represents a shock to the supply of credit that captures changes in the efficiency of the financial intermediation process or a shock to the financial sector that boosts the external finance premium beyond the level warranted by currently available information about the state of the economy and the stance of monetary policy. Moreover, entrepreneurs are assumed to face the probability of surviving until the next period of $\eta_t = \eta \exp(\tilde{z}_t^{nw}) / (1 - \eta + \eta \exp(\tilde{z}_t^{nw})) \in (0,1)$, where $\tilde{z}_t^{nw}$ is a shock to this probability.[4] Entrepreneurs' real net worth then evolves according to

$$N_t = \eta_t \left[r_t^E Q_{t-1} K_{t-1} - \left(E_{t-1} r_t^E \right) B_{t-1} \right] + (1 - \eta_t)\, x Z_t^*, \tag{11}$$

where r_t^E denotes the ex-post marginal return from purchasing capital given by

$$r_t^E = \frac{u_t R_t^k + Q_t \left(1 - \delta(u_t)\right)}{Q_{t-1}} \tag{12}$$

and $x Z_t^*$ is the transfer that newly entering entrepreneurs receive from entrepreneurs who die and depart from the scene.

The first-order conditions for entrepreneurs' optimal decisions on labor input and the capital utilization rate become

$$\frac{1 - \alpha}{\alpha} = \frac{W_t l_t}{R_t^k u_t K_{t-1}}, \tag{13}$$

$$R_t^k = Q_t\, \delta'(u_t). \tag{14}$$

Then, the real marginal cost is given by

$$mc_t = \left(\frac{W_t}{(1-\alpha) Z_t} \right)^{1-\alpha} \left(\frac{R_t^k}{\alpha} \right)^{\alpha}. \tag{15}$$

2.3 Retailers

Each retailer $f_r \in [0,1]$ purchases entrepreneurs' products at the real price mc_t and differentiates them at no cost. Under monopolistic competition, this retailer f_r faces the consumption-good firm's demand $Y_t(f_r) = Y_t(P_t(f_r)/P_t)^{-\theta_t^p}$, where Y_t is the consumption-good firm's output, $P_t(f_r)$ is the price of differentiated goods produced by the retailer f_r, and $\theta_t^p > 1$ is the elasticity of substitution between retail goods. Then, retailers set prices of their differentiated products on a staggered basis à la Calvo (1983). In each period, a fraction $1 - \xi_p \in (0,1)$ of retailers reoptimizes prices, while the remaining fraction ξ_p indexes prices to a weighted average of past and steady-state inflation rates $\pi_{t-1}^{\gamma_p} \pi^{1-\gamma_p}$, where $\gamma_p \in [0,1]$ is the relative weight on the past inflation rate. Hence, retailers that reoptimize prices in the current period choose their prices

[4] This assumption ensures that entrepreneurs' net worth will never be sufficient to entirely finance their purchase of capital.

so as to maximize

$$E_t \sum_{j=0}^{\infty} \xi_p^j \left(\beta^j \frac{\Lambda_{t+j}}{\Lambda_t} \right) \left[\frac{P_t(f_r)}{P_{t+j}} \prod_{k=1}^{j} \left(\pi_{t+k-1}^{\gamma_p} \pi^{1-\gamma_p} \right) - mc_{t+j} \right] Y_{t+j|t}(f_r)$$

subject to

$$Y_{t+j|t}(f_r) = Y_{t+j} \left[\frac{P_t(f_r)}{P_{t+j}} \prod_{k=1}^{j} \left(\pi_{t+k-1}^{\gamma_p} \pi^{1-\gamma_p} \right) \right]^{-\theta_{t+j}^p},$$

where $\beta^j \Lambda_{t+j}/\Lambda_t$ shows the stochastic discount factor between period t and period $t+j$. The first-order condition for the reoptimized price P_t^o is given by

$$E_t \sum_{j=0}^{\infty} \left(\begin{array}{c} (\beta \xi_p)^j \dfrac{\Lambda_{t+j}}{\Lambda_t \lambda_{t+j}^p} Y_{t+j} \left\{ \dfrac{P_t^o}{P_t} \displaystyle\prod_{k=1}^{j} \left[\left(\dfrac{\pi_{t+k-1}}{\pi} \right)^{\gamma_p} \dfrac{\pi}{\pi_{t+k}} \right] \right\}^{-\frac{1+\lambda_{t+j}^p}{\lambda_{t+j}^p}} \\ \times \left\{ \frac{P_t^o}{P_t} \prod_{k=1}^{j} \left[\left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_p} \frac{\pi}{\pi_{t+k}} \right] - \left(1 + \lambda_{t+j}^p \right) mc_{t+j} \right\} \end{array} \right) = 0, \tag{16}$$

where $\lambda_t^p \equiv 1/(\theta_t^p - 1) > 0$ denotes the retail-good price markup.

2.4 Consumption-good firm

The consumption-good firm produces output Y_t by choosing a combination of retail goods $\{Y_t(f_r)\}$ so as to maximize profit $P_t Y_t - \int_0^1 P_t(f_r) Y_t(f_r) df_r$ subject to the production technology $Y_t = (\int_0^1 Y_t(f_r)^{(\theta_t^p-1)/\theta_t^p} df_r)^{\theta_t^p/(\theta_t^p-1)}$. The first-order condition for profit maximization yields the consumption-good firm's demand for retailer f_r's goods given by $Y_t(f_r) = Y_t(P_t(f_r)/P_t)^{-\theta_t^p}$, as mentioned above.

Perfect competition in the consumption-good market leads to the price P_t given by

$$P_t = \left(\int_0^1 P_t(f_r)^{1-\theta_t^p} df_r \right)^{\frac{1}{1-\theta_t^p}}.$$

From the Calvo-style staggered price-setting of retailers, this equation can be reduced to

$$1 = (1 - \xi_p) \left(\left(\frac{P_t^o}{P_t} \right)^{-\frac{1}{\lambda_t^p}} + \sum_{j=1}^{\infty} (\xi_p)^j \left\{ \frac{P_{t-j}^o}{P_{t-j}} \prod_{k=1}^{j} \left[\left(\frac{\pi_{t-k}}{\pi} \right)^{\gamma_p} \frac{\pi}{\pi_{t-k+1}} \right] \right\}^{-\frac{1}{\lambda_t^p}} \right). \tag{17}$$

Aggregating the production function (7) over entrepreneurs yields

$$Y_t d_t = (Z_t l_t)^{1-\alpha} (u_t K_{t-1})^{\alpha} - \phi Z_t^*, \tag{18}$$

where $d_t = \int_0^1 (P_t(f_r)/P_t)^{-\theta_t^p} df_r$ represents the retail-good price dispersion. Note that this dispersion is of second order under the staggered price-setting and its steady-state value is one.

2.5 Investment-good firms

Each investment-good firm f_i uses the production technology that converts one unit of consumption goods into Ψ_t units of differentiated investment goods. Thus, Ψ_t represents the level of investment-specific technology. This level is assumed to follow the stochastic process

$$\log \Psi_t = \log \psi + \log \Psi_{t-1} + z_t^{\psi}, \tag{19}$$

where z_t^{ψ} is an investment-specific technology shock. The cost minimization of investment-good firms shows that their real marginal cost is equal to the inverse of the investment-specific technological level, $1/\Psi_t$. Hence the marginal cost is identical among investment-good firms.

Under monopolistic competition, investment-good firm f_i faces the capital-good firm's demand

$$I_t(f_i) = I_t \left(\frac{P_t^i(f_i)}{P_t^i} \right)^{-\theta_t^i}, \tag{20}$$

where $P_t^i(f_i)$ is the price of investment goods produced by firm f_i, $I_t = (\int_0^1 I_t(f_i)^{(\theta_t^i-1)/\theta_t^i} df_i)^{\theta_t^i/(\theta_t^i-1)}$ is an aggregate of differentiated investment goods with the substitution elasticity $\theta_t^i > 1$, and

$$P_t^i = \left(\int_0^1 P_t^i(f_i)^{1-\theta_t^i} df_i \right)^{\frac{1}{1-\theta_t^i}} \tag{21}$$

is the corresponding aggregate price of investment goods. Then, investment-good firm f_i sets its price $P_t^i(f_i)$ so as to maximize profit $\left(P_t^i(f_i)/P_t - 1/\Psi_t\right) I_t(f_i)$. The first-order condition for profit maximization yields the price given by $P_t^i(f_i) = (1+\lambda_t^i)P_t/\Psi_t$, where $\lambda_t^i \equiv 1/(\theta_t^i - 1) > 0$ is the investment-good price markup over nominal marginal cost P_t/Ψ_t. This equation shows that prices of investment goods are identical, and hence it follows from (20) that output of investment goods is identical. Then, (21) yields

$$P_t^i = \frac{P_t(1+\lambda_t^i)}{\Psi_t} = P_t^i(f_i). \tag{22}$$

Also, combining this equation and (20) implies

$$I_t = I_t(f_i). \tag{23}$$

From (22), the gross rate of the relative price of investment goods to consumption goods is given by[5]

$$r_t^i \equiv \frac{P_t^i/P_t}{P_{t-1}^i/P_{t-1}} = \frac{1+\lambda_t^i}{1+\lambda_{t-1}^i} \frac{\Psi_{t-1}}{\Psi_t}. \tag{24}$$

[5] As Hirose and Kurozumi (2010) point out, when the investment-good markets are perfectly competitive

The market clearing condition for consumption goods is now given by

$$Y_t = C_t + \int_0^1 \frac{I_t(f_i)}{\Psi_t} df_i + gZ_t^* \exp(\tilde{z}_t^g) = C_t + \frac{I_t}{\Psi_t} + gZ_t^* \exp(\tilde{z}_t^g), \tag{25}$$

where the second equality follows from (23) and where the last term $gZ_t^* \exp(\tilde{z}_t^g)$ denotes demand for consumption goods other than households' consumption demand and investment-good firms' demand, and $\tilde{z}_t^g$ represents a shock to this exogenous consumption-good demand.

2.6 Capital-good firm

The capital-good firm purchases capital $(1-\delta(u_t))K_{t-1}$ back from entrepreneurs and makes an investment $I_t = (\int_0^1 I_t(f_i)^{(\theta_t^i-1)/\theta_t^i} df_i)^{\theta_t^i/(\theta_t^i-1)}$ by purchasing a combination of investment goods $\{I_t(f_i)\}$. This investment is subject to adjustment costs represented by $S(I_t/(I_{t-1}z^*\psi)) = [I_t/(I_{t-1}z^*\psi) - 1]^2/(2\zeta)$, where ζ is a positive constant. The capital accumulation equation is thus given by

$$K_t = (1-\delta(u_t))K_{t-1} + \left(1 - S\left(\frac{I_t}{I_{t-1}z^*\psi}\right)\right) I_t. \tag{26}$$

Then, the capital-good firm sells capital K_t to entrepreneurs.

The capital-good firm's problem is to choose investment I_t and a combination of investment goods $\{I_t(f_i)\}$ so as to maximize profit

$$E_t \sum_{j=0}^{\infty} \beta^j \frac{\Lambda_{t+j}}{\Lambda_t} \left[Q_t \left(K_t - (1-\delta(u_t))K_{t-1}\right) - \frac{P_{t+j}^i}{P_{t+j}} I_{t+j} \right]$$

subject to the capital accumulation equation (26). The first-order condition for optimal decisions on investment I_t is given by

$$\begin{aligned} \frac{P_t^i}{P_t} &= Q_t \left[1 - S\left(\frac{I_t}{I_{t-1}z^*\psi}\right) - S'\left(\frac{I_t}{I_{t-1}z^*\psi}\right) \frac{I_t}{I_{t-1}z^*\psi} \right] \\ &\quad + E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} Q_{t+1}\, z^*\psi S'\left(\frac{I_{t+1}}{I_t z^*\psi}\right) \left(\frac{I_{t+1}}{I_t z^*\psi}\right)^2, \end{aligned} \tag{27}$$

and the first-order condition for the cost-minimizing combination of investment goods yields the capital-good firm's demand for firm f_i's investment goods given by $I_t(f_i) = I_t(P_t^i(f_i)/P_t^i)^{-\theta_t^i}$, as mentioned above.

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as in Justiniano, Primiceri, and Tambalotti (2010a, 2010b), we have $\lambda_t^i = 0$ in each period t, and hence (22) becomes $P_t^i/P_t = 1/\Psi_t$. That is, the inverse of the investment-specific technological level must equal the relative price of investment goods. In contrast to this restrictive specification, our model assumes the monopolistically competitive investment-good markets with the time-varying price markup. This markup gives rise to a wedge between investment-specific technological changes and the rate of the relative price of investment goods, as shown in (24).

2.7 Central bank

Last, the central bank conducts monetary policy by adjusting the policy rate. Interest rate policy is assumed to be a Taylor (1993) style rule

$$\log r_t^n = \phi_r \log r_{t-1}^n + (1-\phi_r)\left\{\log r^n + \phi_\pi\left(\frac{1}{4}\sum_{j=0}^{3}\log\frac{\pi_{t-j}}{\pi}\right) + \phi_y \log\frac{Y_t}{Y_t^*}\right\} + z_t^r. \tag{28}$$

Here, $\phi_r \in [0,1)$ represents the degree of policy rate smoothing, r^n is the gross steady-state policy rate, $\phi_\pi, \phi_y \geq 0$ represent the degrees of policy responses to inflation and the output gap, and Y_t^* is the potential output given by

$$Y_t^* = (Z_t\, l)^{1-\alpha}\left(uk\, Z_{t-1}^*\Psi_{t-1}\right)^\alpha - \phi Z_t^*, \tag{29}$$

where l and k are steady-state values of the aggregate labor services l_t and a detrended aggregate capital stock k_t defined later. Hence, the specification of the output gap, $\log(Y_t/Y_t^*)$, is consistent with the output-gap measure estimated by the so-called "production function approach," for instance, the U.S. Congressional Budget Office's estimates and the Bank of Japan's estimates (Hara et al., 2006), both of which are used in estimating the model. The disturbance z_t^r represents a monetary policy shock.

2.8 Log-linearized equilibrium conditions

The conditions for equilibrium in the model economy are (1), (2), (4)–(6), (9)–(18), (22), (25)–(29), together with the stochastic processes of neutral and investment-specific technological levels, (8), (19), and stochastic processes of the other exogenous shocks. Each of exogenous variables is assumed to follow a univariate stationary first-order autoregressive process.

In the model, the levels of neutral and investment-specific technologies have unit roots with different drifts. Consequently, the growth rate of the variables related to investment and capital accumulation is different from that of the variables related to other real economic activities. Thus the equilibrium conditions are rewritten in terms of variables detrended by Z_t^* and Ψ_t: $y_t = Y_t/Z_t^*$, $c_t = C_t/Z_t^*$, $w_t = W_t/Z_t^*$, $\lambda_t = \Lambda_t(Z_t^*)^\sigma$, $i_t = I_t/(Z_t^*\Psi_t)$, $k_t = K_t/(Z_t^*\Psi_t)$, $r_t^k = R_t^k\Psi_t$, $q_t = Q_t\Psi_t$, $n_t = N_t/Z_t^*$, $b_t = B_t/Z_t^*$, and $y_t^* = Y_t^*/Z_t^*$. Log-linearizing the equilibrium conditions represented in terms of the detrended variables and using steady-state conditions to rearrange the resulting equations lead to

$$
\begin{aligned}
\hat{\lambda}_t &= -\frac{1}{1-\theta\pi/r^n}\left\{\frac{\sigma}{1-\theta/z^*}\left(\hat{c}_t - \frac{\theta}{z^*}\left(\hat{c}_{t-1} - z_t^*\right)\right) - z_t^b\right\} \\
&\quad + \frac{\theta\pi/r^n}{1-\theta\pi/r^n}\left\{\frac{\sigma}{1-\theta/z^*}\left(E_t\hat{c}_{t+1} + E_t z_{t+1}^* - \frac{\theta}{z^*}\hat{c}_t\right) - E_t z_{t+1}^b\right\}, \\
\hat{\lambda}_t &= E_t\hat{\lambda}_{t+1} - \sigma E_t z_{t+1}^* + \hat{r}_t^n - E_t\hat{\pi}_{t+1}, \\
\hat{w}_t &= \hat{w}_{t-1} - \hat{\pi}_t + \gamma_w\hat{\pi}_{t-1} - z_t^* + \frac{z^*\pi}{r^n}\left(E_t\hat{w}_{t+1} - \hat{w}_t + E_t\hat{\pi}_{t+1} - \gamma_w\hat{\pi}_t + E_t z_{t+1}^*\right) \\
&\quad + \frac{(1-\xi_w)(1-\xi_w z^*\pi/r^n)}{\xi_w\{1+\chi(1+\lambda^w)/\lambda^w\}}\left(\chi\hat{l}_t - \hat{\lambda}_t - \hat{w}_t + z_t^b\right) + z_t^w, \\
\hat{b}_t &= \frac{1+\lambda^i}{1+\lambda^i - n/k}\left(\hat{q}_t + \hat{k}_t\right) + \left(1 - \frac{1+\lambda^i}{1+\lambda^i - n/k}\right)\hat{n}_t, \\
E_t\hat{r}_{t+1}^E &= \left(1 - \frac{1-\delta}{r^E\psi}\right)E_t\hat{r}_{t+1}^k + \frac{1-\delta}{r^E\psi}E_t\hat{q}_{t+1} - \hat{q}_t - E_t z_{t+1}^\psi, \\
E_t\hat{r}_{t+1}^E &= \hat{r}_t^n - E_t\hat{\pi}_{t+1} - \mu^E\left(\hat{n}_t - \hat{q}_t - \hat{k}_t\right) + z_t^{efp}, \\
\frac{z^*}{\eta r^E}\hat{n}_t &= \frac{1+\lambda^i}{n/k}\left[\left(1 - \frac{1-\delta}{r^E\psi}\right)\hat{r}_t^k + \frac{1-\delta}{r^E\psi}\hat{q}_t - \hat{q}_{t-1} - z_t^\psi\right] - \left(\frac{1+\lambda^i}{n/k} - 1\right)E_{t-1}\hat{r}_t^E \\
&\quad + \hat{n}_{t-1} - z_t^* + z_t^{nw}, \\
0 &= \hat{w}_t + \hat{l}_t - \left(\hat{r}_t^k + \hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi\right), \\
\hat{u}_t &= \mu\left(\hat{r}_t^k - \hat{q}_t\right), \\
\hat{mc}_t &= (1-\alpha)\hat{w}_t + \alpha\hat{r}_t^k, \\
\hat{\pi}_t &= \gamma_p\hat{\pi}_{t-1} + \frac{z^*\pi}{r^n}\left(E_t\hat{\pi}_{t+1} - \gamma_p\hat{\pi}_t\right) + \frac{(1-\xi_p)(1-\xi_p z^*\pi/r^n)}{\xi_p}\hat{mc}_t + z_t^p, \\
\hat{y}_t &= \left(1 + \frac{\phi}{y}\right)\left\{(1-\alpha)\,\hat{l}_t + \alpha\left(\hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi\right)\right\}, \\
\hat{y}_t &= \frac{c}{y}\hat{c}_t + \frac{i}{y}\hat{\imath}_t + z_t^g, \\
\hat{k}_t &= \frac{1-\delta-r^n\psi/\pi}{z^*\psi}\,\hat{u}_t + \frac{1-\delta}{z^*\psi}\left(\hat{k}_{t-1} - z_t^* - z_t^\psi\right) + \left(1 - \frac{1-\delta}{z^*\psi}\right)\hat{\imath}_t, \\
\hat{q}_t &= \frac{1}{\zeta}\left(\hat{\imath}_t - \hat{\imath}_{t-1} + z_t^* + z_t^\psi + z_t^i\right) - \frac{z^*\pi}{\zeta r^n}\left(E_t\hat{\imath}_{t+1} - \hat{\imath}_t + E_t z_{t+1}^* + E_t z_{t+1}^\psi + E_t z_{t+1}^i\right) + z_t^\nu, \\
\hat{r}_t^n &= \phi_r\hat{r}_{t-1}^n + (1-\phi_r)\left\{\frac{\phi_\pi}{4}\sum_{j=0}^{3}\hat{\pi}_{t-j} + \phi_y(\hat{y}_t - \hat{y}_t^*)\right\} + z_t^r, \\
\hat{y}_t - \hat{y}_t^* &= \left(1 + \frac{\phi}{y}\right)\left\{(1-\alpha)\,\hat{l}_t + \alpha\left(\hat{u}_t + \hat{k}_{t-1}\right)\right\}, \\
z_t^x &= \rho_x z_{t-1}^x + \varepsilon_t^x, \quad \varepsilon_t^x \sim \text{i.i.d. } N(0,\sigma_x^2), \quad x \in \{b, g, w, p, \nu, r, z, \psi, efp, nw\},
\end{aligned}
$$

where hatted variables represent log-deviations from steady-state values associated with the capital utilization rate of one, $z_t^* = z_t^z + \alpha/(1-\alpha)z_t^\psi$ is the composite technology shock, $z_t^g \equiv (1 - c/y - i/y)\tilde{z}_t^g$, $z_t^{nw} \equiv (1 - z^*/r^E)\tilde{z}_t^{nw}$, z_t^ν and z_t^p are shocks associated with the investment-good price markup λ_t^i and with the retail-good price markup λ_t^p, and z_t^w is a composite shock relevant to the labor disutility z_t^l and the wage markup λ_t^w.

3 The data and strategy for estimation

This section describes data and strategy for estimating the model presented in the preceding section.

3.1 The data for estimation

For each country, ten quarterly time series are used in the estimation: output Y_t, consumption C_t, investment I_t, the real wage W_t, hours worked l_t, the price of consumption goods P_t, the relative price of investment goods P_t^i/P_t, the monetary policy rate r_t^n, the output gap Y_t/Y_t^*, and real borrowing B_t. The U.S. data on P_t is the PCE price index. Then, the six time series, Y_t, C_t, I_t, W_t, l_t, r_t^n, are the same as those in Smets and Wouters (2007), except that nominal series of GDP, consumption, investment, and the wage are expressed in real terms by dividing them with the PCE price index. The remaining three time series, P_t^i/P_t, Y_t/Y_t^*, B_t, are the investment deflator divided by the PCE price index, the U.S. Congressional Budget Office's estimates of the output gap, and the credit market borrowing by non-financial sectors in the U.S. Flow of Funds Statistics, divided by the PCE price index. For Japan, the data on P_t is the CPI (excluding fresh foods), and then the four time series, Y_t, C_t, I_t, P_t^i/P_t, are given by dividing nominal GDP, nominal consumption, nominal investment, and the investment deflator with the CPI. The three time series, W_t, l_t, r_t^n, are the same as those in Sugo and Ueda (2008).[6] The remaining two time series, Y_t/Y_t^*, B_t, are the Bank of Japan's estimates of the output gap (Hara et al., 2006) and the sum of non-financial corporations' loans and securities other than shares in Japan's Flow of Funds Statistics, divided by the CPI.

The sample periods for Japan and the U.S. are from 1981:1Q to 1998:4Q and from 1985:1Q to 2008:4Q, respectively. The end of these sample periods follows from the fact that the effect of zero lower bounds on monetary policy rates emerged from 1999:1Q in Japan and from 2009:1Q

[6] Note that the data on W_t is given by dividing the nominal wage with the CPI as in Sugo and Ueda (2008), but we do not detrend the data.

in the U.S. but the estimation strategy used in this paper is not able to take into account such an effect. The corresponding measurement equations are

$$\begin{bmatrix} 100\Delta\log Y_t \\ 100\Delta\log C_t \\ 100\Delta\log I_t \\ 100\Delta\log W_t \\ 100\log l_t \\ 100\Delta\log P_t \\ 100\Delta\log\left(P_t^i/P_t\right) \\ 100\log r_t^n \\ 100\log\left(Y_t/Y_t^*\right) \\ 100\Delta\log B_t \end{bmatrix} = \begin{bmatrix} \overline{z^*} \\ \overline{z^*} \\ \overline{z^*}+\overline{\psi} \\ \overline{z^*} \\ \bar{l} \\ \overline{\pi} \\ -\overline{\psi} \\ \overline{r^n} \\ 0 \\ \overline{z^*} \end{bmatrix} + \begin{bmatrix} z_t^* + \hat{y}_t - \hat{y}_{t-1} \\ z_t^* + \hat{c}_t - \hat{c}_{t-1} \\ z_t^* + z_t^\psi + \hat{\imath}_t - \hat{\imath}_{t-1} \\ z_t^* + \hat{w}_t - \hat{w}_{t-1} \\ \hat{l}_t \\ \hat{\pi}_t \\ -z_t^\psi + z_t^\nu - z_{t-1}^\nu \\ \hat{r}_t^n \\ \hat{y}_t - \hat{y}_t^* \\ z_t^* + \hat{b}_t - \hat{b}_{t-1} \end{bmatrix},$$

where $\overline{z^*} = 100\log z^*$, $\overline{\psi} = 100\log\psi$, $\bar{l} = 100\log l$, $\overline{\pi} = 100\log\pi$, and $\overline{r^n} = 100\log r^n$. The steady-state values $\bar{l}$, $\overline{r^n}$ are set at the sample mean, and the steady-state inflation rate is chosen at $\overline{\pi} = 1/4$ for Japan and at $\overline{\pi} = 2/4$ for the U.S.

3.2 The strategy for estimation

Most parameters of the model are estimated but some are fixed to avoid identification issues. The steady-state ratios of consumption and investment to output, c/y, i/y, are set at the sample mean. The steady-state depreciation rate, the capital elasticity of output, and the steady-state wage markup are chosen from Levin, Onatski, Williams, and Williams (2006) for the U.S. (i.e. $\delta = 0.025$, $\alpha = 0.36$, $\lambda^w = 0.2$) and from Sugo and Ueda (2008) for Japan (i.e. $\delta = 0.06$, $\alpha = 0.37$, $\lambda^w = 0.2$). For both countries, the steady-state investment-good price markup is set at $\lambda^i = 0.2$.

The prior distributions of parameters for the U.S. are shown in the second to fourth columns of Table 1. For the structural parameters that also appear in the model of Smets and Wouters (2007) (i.e. σ, θ, χ, $1/\zeta$, ϕ/y, γ_w, ξ_w, γ_p, ξ_p, ϕ_r, ϕ_π, ϕ_y), the same prior mean and the same prior standard deviations as theirs are used.[7] Since our specification of adjustment cost of the

[7] For the parameters σ, χ, $1/\zeta$, ϕ/y, ϕ_π, and ϕ_y, Gamma distributions are used instead of Normal ones, since these parameters are assumed to be positive. The prior distributions of the other parameters (i.e. θ, γ_w, ξ_w, γ_p, ξ_p, ϕ_r) are the same as those in Smets and Wouters (2007).

capital utilization rate differs from Smets and Wouters, we choose the Gamma distribution with the mean of one and the standard deviation of 0.2 for the steady-state elasticity of the adjustment cost μ. The prior distributions of the trend rates of balanced growth and IST changes (i.e. $\overline{z^*}$, $\overline{\psi}$) are set to be Gamma distributions with the standard deviation of 0.1 and the mean given by the sample mean of the output growth rate and the rate of decline in the relative price of investment, respectively. As for the parameters related to the financial accelerator mechanism, the prior distributions of the steady-state survival probability η and the steady-state net worth-capital ratio n/k are the same as those in Hirose (2008). Also, the prior distribution of the steady-state elasticity of the external finance premium μ^E is the same as that in Gilchrist, Ortiz, and Zakrajsek (2009). Moreover, the prior distribution of the steady-state real borrowing rate $\overline{r^E} = 100 \log r^E$ is set to be the Gamma distribution with the mean of 1.24 and the standard deviation of 0.05, since Hirose (2008) chooses this standard deviation and since Bernanke, Gertler, and Gilchrist (1999) use the steady-state borrowing-policy rate spread of 0.5 (i.e. 200bps. at an annualized rate) and we have set the steady-state inflation and policy rates at $\overline{\pi} = 0.5$ and $\overline{r^n} = 1.24$. For the parameters of shocks, we choose fairly wide prior distributions. The Beta distribution with the mean of 0.5 and the standard deviation of 0.2 is used for the autoregressive coefficient of each shock (i.e. ρ_x, $x \in \{b, g, w, p, r, \nu, z, \psi, efp, nw\}$) and the Inverse Gamma distribution with the mean of 0.5 and the standard deviation of an infinity is employed for the standard deviation of each shock innovation (i.e. σ_x, $x \in \{b, g, w, p, r, \nu, z, \psi, efp, nw\}$).

As for Japan, the prior distributions are presented in the second to fourth columns of Table 2. The prior distributions for the non-financial structural parameters (i.e. σ, θ, χ, $1/\zeta$, ϕ/y, γ_w, ξ_w, γ_p, ξ_p) are the same as those in Sugo and Ueda (2008), and the ones for the interest rate policy parameters (i.e. ϕ_r, ϕ_π, ϕ_y) are the same as those in Iiboshi, Nishiyama, and Watanabe (2006), since the non-financial private-sector part of our model is similar to that of Sugo and Ueda and the interest rate policy rule of our model is similar to that of Iiboshi, Nishiyama, and Watanabe. The prior distribution of the steady-state elasticity of the external finance premium μ^E is the same as that in Hirose (2008). For the other parameters, the prior distributions are set in the same way as that for the U.S.

Similarly to recent studies that estimate DSGE models by Bayesian methods, this paper uses the Kalman filter to evaluate the likelihood function for the system of log-linearized equilibrium conditions, and applies the Metropolis-Hastings algorithm to generate draws from the posterior distribution of model parameters.[8] Based on these draws, this paper obtains estimates of parameters, historical and variance decompositions of model variables, and Kalman smoothed mean estimates of unobservable model variables.

4 Results of the empirical analysis

This section presents results of the empirical analysis. First, the estimates of model parameters are explained. Then, historical and variance decompositions of key macroeconomic variables in Japan and the U.S. are examined.

4.1 Parameter estimates

Each parameter's posterior mean and 90% posterior interval for the U.S. are reported in the last two columns of Table 1.[9] Our estimates of $\sigma = 1.50$, $\theta = 0.78$, $\chi = 2.65$, $\gamma_w = 0.41$, $\gamma_p = 0.26$, $\xi_p = 0.84$, $\phi_r = 0.70$, and $\overline{z^*} = 0.39$ are similar to those in Smets and Wouters (2007) and Gilchrist, Ortiz, and Zakrajsek (2009). Also, our estimates of $1/\zeta = 3.14$, $\phi/y = 0.41$, $\xi_w = 0.69$, $\phi_\pi = 1.72$, and $\phi_y = 0.12$ are similar to those in Smets and Wouters but differ from those in Gilchrist, Ortiz, and Zakrajsek. Relative to our estimates, Gilchrist, Ortiz, and Zakrajsek obtain the larger estimates of $1/\zeta = 6.75$, $\phi/y = 0.65$, and $\xi_w = 0.93$ with 90% intervals of $[5.45, 7.83]$, $[0.58, 0.71]$, and $[0.92, 0.95]$, respectively, and the smaller estimates of $\phi_\pi = 1.12$ and $\phi_y = 0.01$ with 90% intervals of $[1.05, 1.20]$ and $[0.00, 0.01]$, respectively. Moreover, our estimates of $\xi_p = 0.84$ are larger than those in Smets and Wouters (i.e. $\xi_p = 0.66$ with the 90% interval of $[0.56, 0.74]$) and those in Gilchrist, Ortiz, and Zakrajsek (i.e. $\xi_p = 0.74$ with the 90% interval of $[0.70, 0.78]$), suggesting that the degree of price stickiness is higher than those in the previous studies. With respect to the key parameter of the financial accelerator mechanism, our estimates of the steady-state elasticity of the external finance premium of

[8] For the subsequent analysis, three chains of 500,000 draws were generated and the first half of these draws was discarded. The scale factor for the jumping distribution in the Metropolis-Hastings algorithm was adjusted so that an acceptance rate of 24% was obtained. The Brooks and Gelman (1998) measure was used to check the convergence of the parameters.

[9] Table 5 shows each parameter's posterior mean and 90% posterior interval when the sample period for the U.S. is extended to 2009:4Q. The parameter estimates with the extended sample period data are similar to those with the baseline sample period data.

$\mu^E = 0.038$ are very close to those in Gilchrist, Ortiz, and Zakrajsek (i.e. $\mu^E = 0.04$ with the 90% interval of $[0.03, 0.05]$).

As for Japan, the last two columns of Table 2 show each parameter's posterior mean and 90% posterior interval. Since our model extends that of Hirose and Kurozumi (2010) by incorporating the financial accelerator mechanism and by replacing an investment efficiency shock with the two financial shocks to the external finance premium and to entrepreneurs' net worth, our parameter estimates are compared with theirs. For most parameters in the non-financial part of the model, this paper obtains similar estimates to those in Hirose and Kurozumi, but our estimates of the steady-state elasticity of adjustment cost for investment and the capital utilization rate, $1/\zeta = 0.58$ and $\mu = 0.96$, are much smaller than theirs (i.e. $1/\zeta = 7.00$ and $\mu = 2.90$ with 90% intervals of $[3.94, 9.86]$ and $[1.47, 4.24]$, respectively). With respect to the parameters related to the financial accelerator mechanism, our estimates are similar to those in Hirose (2008). Our estimates of the steady-state elasticity of the external finance premium of $\mu^E = 0.029$ are significantly different from zero, which implies that the financial accelerator mechanism is operative in Japan's business fluctuations.

Most of the parameter estimates are similar between Japan and the U.S. A remarkable difference is the estimates of the autoregressive coefficients and the standard deviations of the intertemporal preferences shock and the net worth shock, ρ_b, σ_b, ρ_{nw}, and σ_{nw}. Relative to Japan's ones, the U.S. estimates of ρ_b and σ_b are larger while those of ρ_{nw} and σ_{nw} are smaller.[10]

4.2 Historical and variance decompositions

We now investigate our main question as to what is the major source of business fluctuations, financial or technology shocks. This subsection begins with the U.S. business fluctuations. Figure 1 presents the historical decomposition of the U.S. output growth rate. This decomposition identifies the contribution to the U.S. output growth rate by the (total) technology shocks, the

[10] As Tables 3 and 4 present below, the variance decompositions show that the intertemporal preferences shock makes the largest contribution to the variance of consumption growth in the U.S. and that the net worth shock plays an important role for the variance of investment growth in Japan. Since our model contains the financial accelerator mechanism for investment but not for consumption, the largest contribution to consumption fluctuations by the preferences shock might suggest the importance of a financial accelerator mechanism for consumption in the U.S. The contribution to investment fluctuations by the net worth shock in Japan might imply that this shock captures movements in the value of collateral for bank lending, which was the main source of corporate external finance during the sample period (1981:1Q–1998:4Q).

(total) financial shocks, and other shocks in each period. The figure shows that the technology shocks are the main driving force of the U.S. output growth. Also, the financial shocks played an important role in the boom and bust cycles of output from 1996 to 2002 and from 2004 onward.

As for investment in the U.S., Figure 2 shows the historical decomposition of the growth rate. The financial shocks mainly drive investment growth. Particularly, these shocks generated the boom and bust cycles of investment from 1996 to 2002 and from 2004 onward.

These features of the sources of output and investment growth in the U.S. are also confirmed by variance decompositions. Table 3 reports the relative contribution by each shock to the variances of the output growth rate and the investment growth rate as well as hours worked and the consumption growth rate in the U.S. at each forecast horizon $T = 8, 32, \infty$. This table shows that the relative contribution to the variance of output growth by the neutral technology shock (z^z) is around 40% and is higher than that of any other shock. The investment-specific technology shock (z^ψ) plays a very minor role, which is in line with the empirical results of Schmitt-Grohe and Uribe (2008) and Justiniano, Primiceri, and Tambalotti (2010b). Therefore, the main driving force of the U.S. output growth is the neutral technology shock. In addition, the external finance premium shock (z^{efp}) makes a major contribution to output fluctuations. As for the contribution to the variance of investment growth, the external finance premium shock accounts for over half of investment fluctuations. The neutral technology shock makes the second largest contribution. One point we emphasize here is that the neutral technology shock makes the largest or the second largest contribution to fluctuations in hours worked and consumption growth as well as output growth and investment growth and thereby generate comovements in these four variables.

We turn next to Japan's business fluctuations. Figure 3 shows the historical decomposition of Japan's output growth rate. As is the case with the U.S., the technology shocks are the main driving force of Japan's output growth. Also, in the boom and bust cycle of output during the period from 1987 to 1993, the financial shocks played a crucial role.

The historical decomposition of Japan's investment growth rate is presented in Figure 4. The financial shocks are major sources of Japan's investment growth. These shocks generated the boom and bust cycle of investment during the period from 1987 to 1993.

The variance decompositions confirm these findings about Japan's business fluctuations. Table 4 reports the relative contribution by each shock to the variances of output growth, investment growth, hours worked, and consumption growth in Japan at each forecast horizon $T = 8, 32, \infty$. The neutral technology shock (z^z) explains over 65% of the variance of output growth, and this shock is the dominant source of output fluctuations in Japan. The variance decomposition of investment growth shows that the neutral technology shock makes the largest contribution to investment fluctuations and the external finance premium shock (z^{efp}) makes the second largest one. Then, the sum of the contribution by the two financial shocks, the external finance premium shock and the net worth shock (z^{nw}), is as large as that of the two technology shocks, the neutral one and the investment-specific one (z^{ψ}). As is the case with the U.S., the contribution by the neutral technology shock to fluctuations in hours worked and consumption growth as well as output growth and investment growth are the largest or the second largest, and thus this technology shock is a major source of comovements in these four variables in Japan.

The above historical and variance decompositions demonstrate that the main source of output fluctuations in both Japan and the U.S. is the neutral technology shock, which is in line with the results of previous business cycle studies using general equilibrium models. Also, the financial shocks are at least as important for investment fluctuations as the technology shocks. Particularly, the external finance premium shock is the primary source of investment fluctuations in the U.S., and this shock is a major one in Japan.

4.3 External finance premium and investment boom and bust cycles

The preceding subsection has shown that, in Japan and the U.S., the external finance premium shock plays a crucial role in investment fluctuations, particularly in boom and bust cycles of investment. As Gilchrist, Ortiz, and Zakrajsek (2009) point out, an external finance premium shock represents a shock to the supply of credit that captures changes in the efficiency of the financial intermediation process or a shock to the financial sector that boosts the external finance premium beyond the level warranted by currently available information about the state of the economy and the stance of monetary policy. This subsection thus investigates the background of the investment boom and bust cycles using Kalman smoothed mean estimates and historical decompositions of the external finance premium in Japan and the U.S.

Figure 5 shows the estimates of the external finance premium in the U.S. and two proxies for this premium, the spreads between the federal funds rate and Moody's seasoned Aaa and Baa corporate bond yields, respectively. The shaded areas indicate the NBER recession periods. In this figure, three points are worth noting. First, the estimated premium, which is the spread between the federal funds rate and the estimated borrowing rate in the U.S., strongly correlates with the two proxies. The values of the correlation coefficients during the period from 1987:1Q to 2008:4Q are 0.64 for the Aaa yield and 0.66 for the Baa yield. Second, the external finance premium rose significantly in the recession periods. Last, during the period from 2004 to 2005, the premium declined substantially. Figure 6 presents the historical decomposition of the U.S. external finance premium. This figure shows that the above-mentioned movements in the premium were generated mainly by shocks to this premium. To see the relationship between the external finance premium and the two recent booms in the U.S., the so-called "dot-com bubble" period from 1996 to 2000 and the "housing bubble" period from 2004 to 2007, the plot of the estimated external finance premium and the detrended real borrowing in the U.S. is presented in Figure 7. This figure shows that the detrended real borrowing expanded under the stable external finance premium during the dot-com bubble period, whereas it grew with the sharp decline in the premium during the first half of the housing bubble period (i.e. from 2004 to 2005). This suggests that the credit expansion during the dot-com bubble period was driven by entrepreneurs' credit demand stemming from a progress in information technology. By contrast, the credit growth during the first half of the housing bubble period was caused by financial intermediaries' credit supply reflecting the extension of credit to a wider range of borrowers (Dokko et al., 2009). After the collapse of these two bubbles, the detrended real borrowing increased little in the face of the significant rise in the external finance premium.

We turn next to the case of Japan. Figure 8 presents the estimates of the external finance premium in Japan and two proxies for this premium, the spreads between the overnight call rate and the short- and long-term average interest rates on contracted loans and discounts, respectively. The shaded areas indicate the ESRI recession periods. As is the case with the U.S., the estimated premium (i.e. the spread between the overnight call rate and the estimated borrowing rate in Japan) strongly correlates with the two proxies. The values of the correlation coefficients during the period from 1983:1Q to 1998:4Q are 0.65 for the short-term rate and 0.76 for the long-term rate. During the so-called "asset price bubble" period from 1987 to 1990, the external finance premium declined rapidly. Thereafter, the premium rose until the end of the sample period, 1998:4Q. Figure 9 shows the historical decomposition of Japan's external finance premium. This figure illustrates that such movements in the premium were caused by shocks to this premium. Figure 10 plots the estimated external finance premium and the detrended real borrowing in Japan to see the relationship between the external finance premium and the asset price bubble. In this figure, three points are worth noting. First, as is the case with the first half of the U.S. housing bubble period, the detrended real borrowing expanded substantially with the sharp decline in the external finance premium during the asset price bubble period (from 1987 to 1990). Second, the external finance premium rose and the detrended real borrowing decreased slightly in the recovery period from 1994 to 1996. Last but not least, the detrended real borrowing decreased in the face of the further hike in the premium during the recession period starting from 1997. These three points suggest that the credit expansion during the asset price bubble period was driven by the credit supply of financial intermediaries which were inclined to extend loans aggressively to small- and medium-sized enterprises against real estate collateral as well as real estate-related loans at low interest rates (Okina and Shiratsuka, 2002), and that after the collapse of the bubble, credit decreased due to a balance-sheet problem of financial intermediaries in Japan, which deteriorated further and resulted in a credit contraction during the recession period from 1997.

5 Concluding Remarks

In this paper we have addressed the question as to what is the major source of business fluctuations, financial or technology shocks. To this end, we have incorporated the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999), together with two financial shocks to the external finance premium and to entrepreneurs' net worth, into a DSGE model with stochastic trends in neutral and investment-specific technological changes. This model has been estimated by Bayesian methods with Japanese and the U.S. data that include the relative price of investment and credit growth. Our empirical analysis has shown that, in both Japan and the U.S., neutral technology shocks are the main driving force of output fluctuations and financial shocks are at least as important for investment fluctuations as technology shocks. The analysis has also demonstrated that a sharp decline and a subsequent hike in the external finance premium, caused by shocks to this premium, induced the boom and bust cycles of investment via the financial accelerator mechanism during the late 1980s and 1990s in Japan and since 2004 in the U.S.

Our model presents no explicit theoretical foundation for the external finance premium shock. For this foundation, we need to explicitly consider financial intermediaries' profit maximization problem. Christiano, Motto, and Rostagno (2010), Gerali, Neri, Sessa, and Signoretti (2010), and Hirakata, Sudo, and Ueda (2010) develop a DSGE model in this direction and estimate such a model with the Euro area and the U.S. data. Their models, however, are those for stationary variables, and the data used in their estimation are detrended by a linear trend or by the Hodrick-Prescott filter. Thus, one direction of future research will be to introduce financial intermediaries' optimization problem into our model and to estimate this model with non-detrended data to investigate what the external finance premium shock really is.

Another research direction is found in recent studies such as Christiano, Ilut, Motto, and Rostagno (2010), which emphasize the role of anticipated future technological changes as a major source of boom and bust cycles.[11] Thus, an interesting research question arises as to what is the major source of boom and bust cycles, financial shocks or anticipated future technological changes. We will investigate these topics in future work.

[11] For empirical studies of anticipated future technological changes, see e.g. Beaudry and Portier (2006), Fujiwara, Hirose, and Shintani (2010), Khan and Tsoukalas (2009), and Schmitt-Grohe and Uribe (2008).

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Table 1: Prior and posterior distributions of parameters: U.S.

	Prior distribution			Posterior distribution	
Parameter	Distribution	Mean	S.D.	Mean	90% interval
σ	Gamma	1.500	0.375	1.497	[0.982, 1.995]
θ	Beta	0.700	0.100	0.784	[0.698, 0.876]
χ	Gamma	2.000	0.750	2.654	[1.455, 3.849]
$1/\zeta$	Gamma	4.000	1.500	3.139	[2.128, 4.124]
μ	Gamma	1.000	0.200	0.526	[0.304, 0.743]
ϕ/y	Gamma	0.250	0.125	0.414	[0.300, 0.522]
γ_w	Beta	0.500	0.150	0.412	[0.190, 0.622]
ξ_w	Beta	0.500	0.100	0.690	[0.595, 0.789]
γ_p	Beta	0.500	0.150	0.260	[0.097, 0.416]
ξ_p	Beta	0.500	0.100	0.838	[0.801, 0.874]
ϕ_r	Beta	0.750	0.100	0.701	[0.630, 0.772]
ϕ_π	Gamma	1.500	0.250	1.724	[1.476, 1.976]
ϕ_y	Gamma	0.125	0.050	0.122	[0.078, 0.166]
$\overline{z^*}$	Gamma	0.380	0.100	0.389	[0.277, 0.497]
$\overline{\psi}$	Gamma	0.290	0.100	0.249	[0.138, 0.355]
η	Beta	0.973	0.020	0.980	[0.959, 0.999]
n/k	Beta	0.500	0.070	0.662	[0.573, 0.749]
μ^E	Gamma	0.070	0.020	0.038	[0.020, 0.055]
$\overline{r^E}$	Gamma	1.240	0.050	1.242	[1.158, 1.324]
ρ_b	Beta	0.500	0.200	0.694	[0.554, 0.833]
ρ_g	Beta	0.500	0.200	0.971	[0.948, 0.994]
ρ_w	Beta	0.500	0.200	0.390	[0.204, 0.581]
ρ_p	Beta	0.500	0.200	0.291	[0.092, 0.475]
ρ_r	Beta	0.500	0.200	0.692	[0.599, 0.785]
ρ_ν	Beta	0.500	0.200	0.957	[0.931, 0.983]
ρ_z	Beta	0.500	0.200	0.111	[0.022, 0.193]
ρ_ψ	Beta	0.500	0.200	0.187	[0.059, 0.313]
ρ_{efp}	Beta	0.500	0.200	0.943	[0.910, 0.976]
ρ_{nw}	Beta	0.500	0.200	0.579	[0.396, 0.768]
σ_b	Inv. gamma	0.500	Inf	4.246	[2.689, 5.728]
σ_g	Inv. gamma	0.500	Inf	0.393	[0.346, 0.440]
σ_w	Inv. gamma	0.500	Inf	0.517	[0.394, 0.634]
σ_p	Inv. gamma	0.500	Inf	0.291	[0.217, 0.364]
σ_r	Inv. gamma	0.500	Inf	0.101	[0.088, 0.114]
σ_ν	Inv. gamma	0.500	Inf	0.968	[0.843, 1.090]
σ_z	Inv. gamma	0.500	Inf	1.005	[0.873, 1.138]
σ_ψ	Inv. gamma	0.500	Inf	0.960	[0.826, 1.085]
σ_{efp}	Inv. gamma	0.500	Inf	0.262	[0.202, 0.318]
σ_{nw}	Inv. gamma	0.500	Inf	0.676	[0.454, 0.898]

Note: For the posterior distribution, three chains of 500,000 draws were created using the Metropolis-Hastings algorithm, and the first half of these draws was discarded.

Table 2: Prior and posterior distributions of parameters: Japan.

	Prior distribution			Posterior distribution	
Parameter	Distribution	Mean	S.D.	Mean	90% interval
σ	Gamma	1.000	0.375	1.107	[0.720, 1.474]
θ	Beta	0.700	0.150	0.481	[0.340, 0.620]
χ	Gamma	2.000	0.750	3.857	[2.292, 5.301]
$1/\zeta$	Gamma	4.000	1.500	0.578	[0.368, 0.780]
μ	Gamma	1.000	0.200	0.955	[0.646, 1.253]
ϕ/y	Gamma	0.075	0.013	0.083	[0.060, 0.104]
γ_w	Beta	0.500	0.250	0.311	[0.011, 0.595]
ξ_w	Beta	0.375	0.100	0.477	[0.367, 0.587]
γ_p	Beta	0.500	0.250	0.446	[0.152, 0.729]
ξ_p	Beta	0.375	0.100	0.660	[0.603, 0.718]
ϕ_r	Beta	0.800	0.100	0.577	[0.471, 0.683]
ϕ_π	Gamma	1.700	0.100	1.804	[1.663, 1.946]
ϕ_y	Gamma	0.125	0.050	0.088	[0.053, 0.122]
$\overline{z^*}$	Gamma	0.370	0.100	0.352	[0.214, 0.486]
$\overline{\psi}$	Gamma	0.460	0.100	0.427	[0.294, 0.556]
η	Beta	0.973	0.020	0.967	[0.939, 0.997]
n/k	Beta	0.500	0.070	0.490	[0.392, 0.589]
μ^E	Gamma	0.038	0.019	0.029	[0.015, 0.043]
$\overline{r^E}$	Gamma	1.340	0.050	1.337	[1.254, 1.418]
ρ_b	Beta	0.500	0.200	0.575	[0.344, 0.815]
ρ_g	Beta	0.500	0.200	0.960	[0.926, 0.995]
ρ_w	Beta	0.500	0.200	0.239	[0.046, 0.428]
ρ_p	Beta	0.500	0.200	0.982	[0.966, 0.997]
ρ_r	Beta	0.500	0.200	0.579	[0.449, 0.706]
ρ_ν	Beta	0.500	0.200	0.934	[0.902, 0.965]
ρ_z	Beta	0.500	0.200	0.069	[0.012, 0.125]
ρ_ψ	Beta	0.500	0.200	0.169	[0.052, 0.278]
ρ_{efp}	Beta	0.500	0.200	0.966	[0.940, 0.993]
ρ_{nw}	Beta	0.500	0.200	0.804	[0.682, 0.929]
σ_b	Inv. gamma	0.500	Inf	2.029	[1.353, 2.703]
σ_g	Inv. gamma	0.500	Inf	0.589	[0.509, 0.668]
σ_w	Inv. gamma	0.500	Inf	0.584	[0.462, 0.702]
σ_p	Inv. gamma	0.500	Inf	0.185	[0.115, 0.253]
σ_r	Inv. gamma	0.500	Inf	0.133	[0.113, 0.153]
σ_ν	Inv. gamma	0.500	Inf	1.335	[1.149, 1.520]
σ_z	Inv. gamma	0.500	Inf	1.715	[1.463, 1.949]
σ_ψ	Inv. gamma	0.500	Inf	1.351	[1.167, 1.537]
σ_{efp}	Inv. gamma	0.500	Inf	0.197	[0.156, 0.237]
σ_{nw}	Inv. gamma	0.500	Inf	1.577	[1.043, 2.092]

Note: For the posterior distribution, three chains of 500,000 draws were created using the Metropolis-Hastings algorithm, and the first half of these draws was discarded.

Table 3: Variance decompositions: U.S.

	Output growth			Investment growth		
Shock	$T=8$	$T=32$	$T=\infty$	$T=8$	$T=32$	$T=\infty$
z^b	16.7	16.6	16.6	3.1	4.0	4.1
z^g	15.0	14.5	14.5	0.4	0.4	0.4
z^w	2.4	3.1	3.1	1.6	2.2	2.3
z^p	3.6	3.7	3.7	6.2	5.7	5.7
z^r	4.2	4.3	4.3	6.7	6.3	6.3
z^ν	1.4	1.5	1.5	3.5	3.5	3.5
z^z	40.4	39.1	38.9	13.5	12.2	12.1
z^ψ	2.1	2.2	2.2	7.8	6.6	6.6
z^{efp}	13.0	13.7	14.0	52.3	54.1	54.1
z^{nw}	1.1	1.1	1.2	5.0	4.9	4.9
	Hours worked			**Consumption growth**		
Shock	$T=8$	$T=32$	$T=\infty$	$T=8$	$T=32$	$T=\infty$
z^b	8.6	6.7	5.8	67.0	65.2	64.3
z^g	4.7	6.2	6.4	2.5	2.4	2.4
z^w	12.9	10.2	8.7	2.3	2.5	2.5
z^p	4.2	3.1	2.7	0.8	0.8	0.8
z^r	8.1	5.7	5.0	1.1	1.1	1.1
z^ν	0.5	0.8	1.4	0.1	0.2	0.2
z^z	12.5	14.0	12.1	24.2	22.5	22.1
z^ψ	9.7	17.6	17.9	0.5	0.9	1.1
z^{efp}	35.8	32.7	35.4	1.2	4.0	4.8
z^{nw}	3.0	3.1	4.6	0.2	0.6	0.7

Notes: This table shows the forecast error variance decompositions of output growth, investment growth, hours worked, and consumption growth in the U.S. at each horizon $T = 8, 32, \infty$, based on the mean of the posterior distribution. The infinite horizon decompositions are computed by solving a dynamic Lyapunov equation for the system of log-linearized equilibrium conditions.

Table 4: Variance decompositions: Japan.

	Output growth			Investment growth		
Shock	$T=8$	$T=32$	$T=\infty$	$T=8$	$T=32$	$T=\infty$
z^b	6.4	6.3	6.3	1.6	1.7	1.7
z^g	5.1	5.1	5.1	0.2	0.2	0.2
z^w	1.5	1.6	1.6	2.1	2.1	2.1
z^p	8.6	8.6	8.7	14.2	14.1	14.1
z^r	2.2	2.2	2.2	4.3	4.1	4.1
z^ν	2.5	2.6	2.7	9.0	9.3	9.3
z^z	67.0	66.5	66.4	27.3	26.4	26.4
z^ψ	3.7	3.8	3.8	8.0	7.6	7.6
z^{efp}	2.0	2.1	2.2	20.8	21.2	21.2
z^{nw}	1.0	1.1	1.2	12.5	13.1	13.2
	Hours worked			Consumption growth		
Shock	$T=8$	$T=32$	$T=\infty$	$T=8$	$T=32$	$T=\infty$
z^b	3.8	3.5	3.3	31.5	30.3	30.1
z^g	4.8	7.5	7.8	7.3	7.3	7.3
z^w	8.5	7.5	7.2	1.5	1.5	1.5
z^p	30.8	30.7	30.5	6.5	6.3	6.3
z^r	4.1	3.6	3.5	1.3	1.2	1.2
z^ν	2.0	2.1	2.1	0.4	0.5	0.6
z^z	28.7	25.6	24.6	44.0	42.4	42.1
z^ψ	4.4	5.6	5.6	1.3	1.6	1.7
z^{efp}	8.3	8.3	8.7	3.1	4.1	4.3
z^{nw}	4.6	5.6	6.8	3.1	4.8	5.0

Notes: This table shows the forecast error variance decompositions of output growth, investment growth, hours worked, and consumption growth in Japan at each horizon $T = 8, 32, \infty$, based on the mean of the posterior distribution. The infinite horizon decompositions are computed by solving a dynamic Lyapunov equation for the system of log-linearized equilibrium conditions.

Table 5: Prior and posterior distributions of parameters: U.S., 1985:1Q-2009:4Q.

	Prior distribution			Posterior distribution	
Parameter	Distribution	Mean	S.D.	Mean	90% interval
σ	Gamma	1.500	0.375	1.492	[0.982, 1.993]
θ	Beta	0.700	0.100	0.790	[0.707, 0.874]
χ	Gamma	2.000	0.750	2.218	[1.147, 3.251]
$1/\zeta$	Gamma	4.000	1.500	1.890	[1.138, 2.593]
μ	Gamma	1.000	0.200	0.847	[0.491, 1.193]
ϕ/y	Gamma	0.250	0.125	0.305	[0.200, 0.407]
γ_w	Beta	0.500	0.150	0.402	[0.196, 0.604]
ξ_w	Beta	0.500	0.100	0.759	[0.670, 0.847]
γ_p	Beta	0.500	0.150	0.226	[0.102, 0.350]
ξ_p	Beta	0.500	0.100	0.894	[0.863, 0.928]
ϕ_r	Beta	0.750	0.100	0.715	[0.644, 0.785]
ϕ_π	Gamma	1.500	0.250	1.475	[1.122, 1.799]
ϕ_y	Gamma	0.125	0.050	0.144	[0.087, 0.200]
$\overline{z^*}$	Gamma	0.360	0.100	0.380	[0.267, 0.495]
$\overline{\psi}$	Gamma	0.320	0.100	0.339	[0.205, 0.475]
η	Beta	0.973	0.020	0.942	[0.907, 0.983]
n/k	Beta	0.500	0.070	0.673	[0.590, 0.760]
μ^E	Gamma	0.070	0.020	0.050	[0.026, 0.073]
$\overline{r^E}$	Gamma	1.190	0.050	1.191	[1.106, 1.272]
ρ_b	Beta	0.500	0.200	0.711	[0.577, 0.852]
ρ_g	Beta	0.500	0.200	0.979	[0.962, 0.995]
ρ_w	Beta	0.500	0.200	0.338	[0.149, 0.516]
ρ_p	Beta	0.500	0.200	0.190	[0.057, 0.320]
ρ_r	Beta	0.500	0.200	0.634	[0.539, 0.735]
ρ_ν	Beta	0.500	0.200	0.941	[0.912, 0.969]
ρ_z	Beta	0.500	0.200	0.100	[0.018, 0.179]
ρ_ψ	Beta	0.500	0.200	0.377	[0.239, 0.518]
ρ_{efp}	Beta	0.500	0.200	0.938	[0.905, 0.974]
ρ_{nw}	Beta	0.500	0.200	0.659	[0.509, 0.816]
σ_b	Inv. gamma	0.500	Inf	4.338	[2.657, 5.966]
σ_g	Inv. gamma	0.500	Inf	0.385	[0.340, 0.429]
σ_w	Inv. gamma	0.500	Inf	0.544	[0.422, 0.663]
σ_p	Inv. gamma	0.500	Inf	0.307	[0.246, 0.366]
σ_r	Inv. gamma	0.500	Inf	0.103	[0.090, 0.116]
σ_ν	Inv. gamma	0.500	Inf	1.218	[1.070, 1.366]
σ_z	Inv. gamma	0.500	Inf	1.062	[0.914, 1.208]
σ_ψ	Inv. gamma	0.500	Inf	1.080	[0.946, 1.215]
σ_{efp}	Inv. gamma	0.500	Inf	0.256	[0.206, 0.306]
σ_{nw}	Inv. gamma	0.500	Inf	0.653	[0.438, 0.858]

Note: For the posterior distribution, three chains of 500,000 draws were created using the Metropolis-Hastings algorithm, and the first half of these draws was discarded.

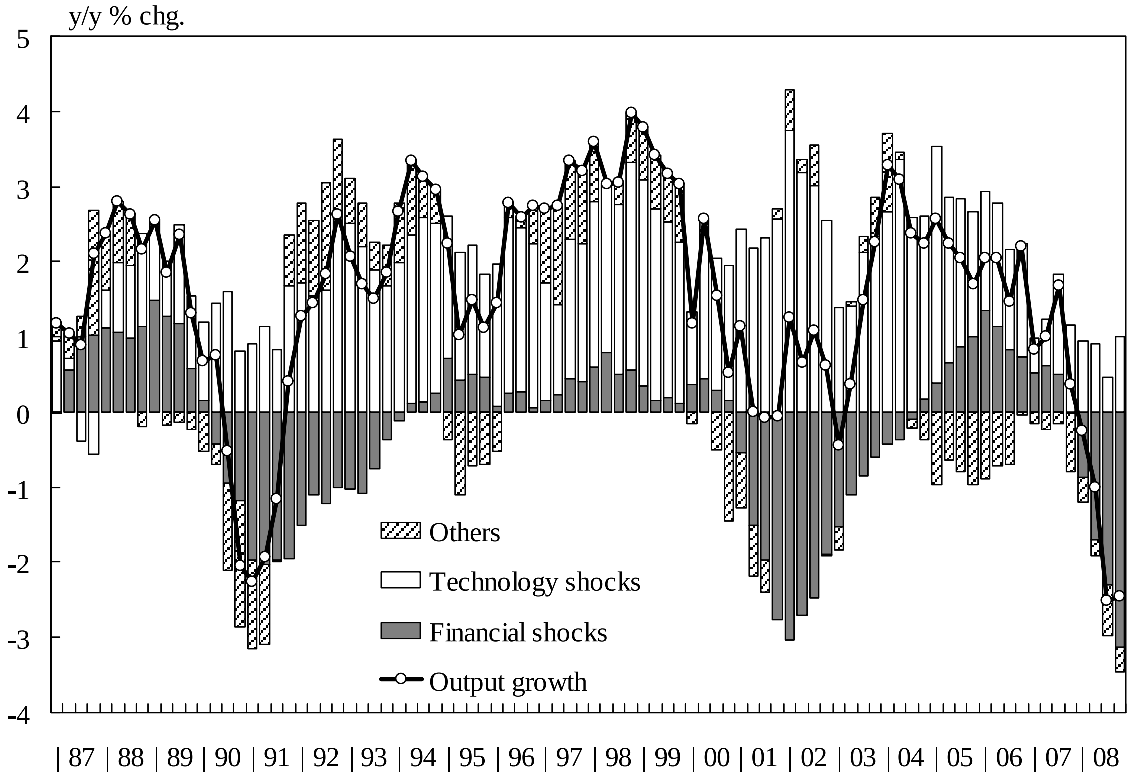

Figure 1: Historical decomposition of the U.S. output growth rate

Note: This figure shows the historical decomposition of the U.S. output growth rate based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

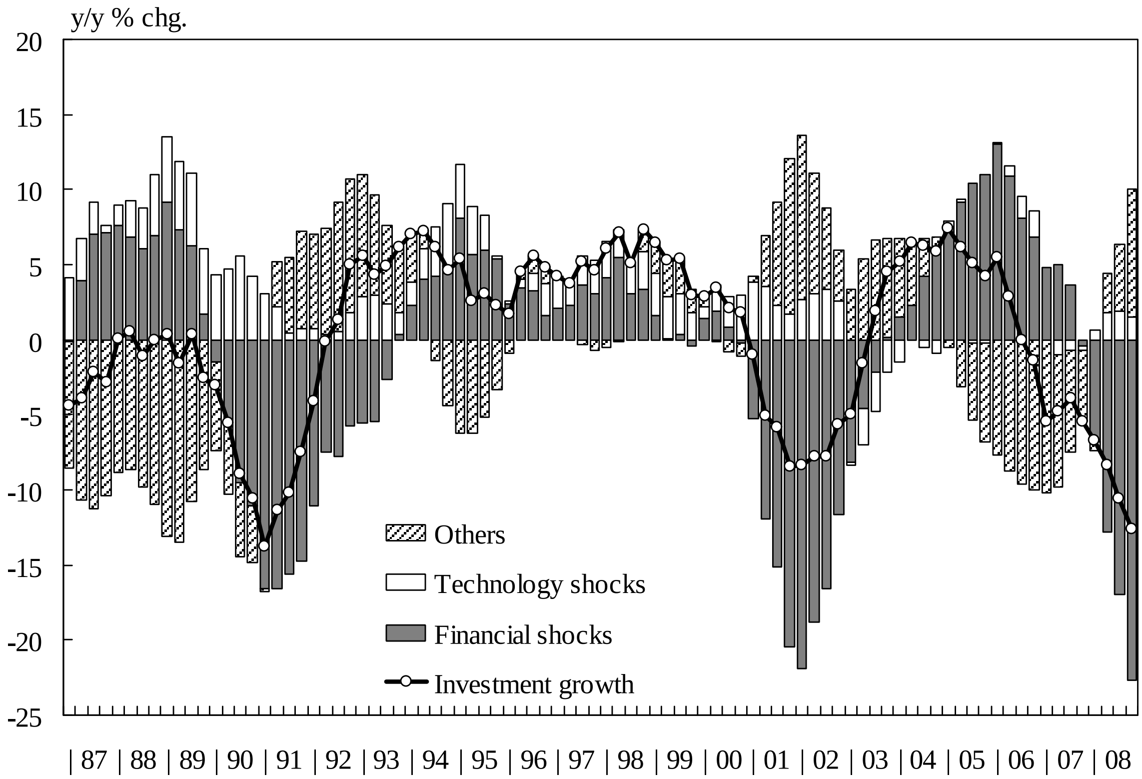

Figure 2: Historical decomposition of the U.S. investment growth rate

Note: This figure shows the historical decomposition of the U.S. investment growth rate based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

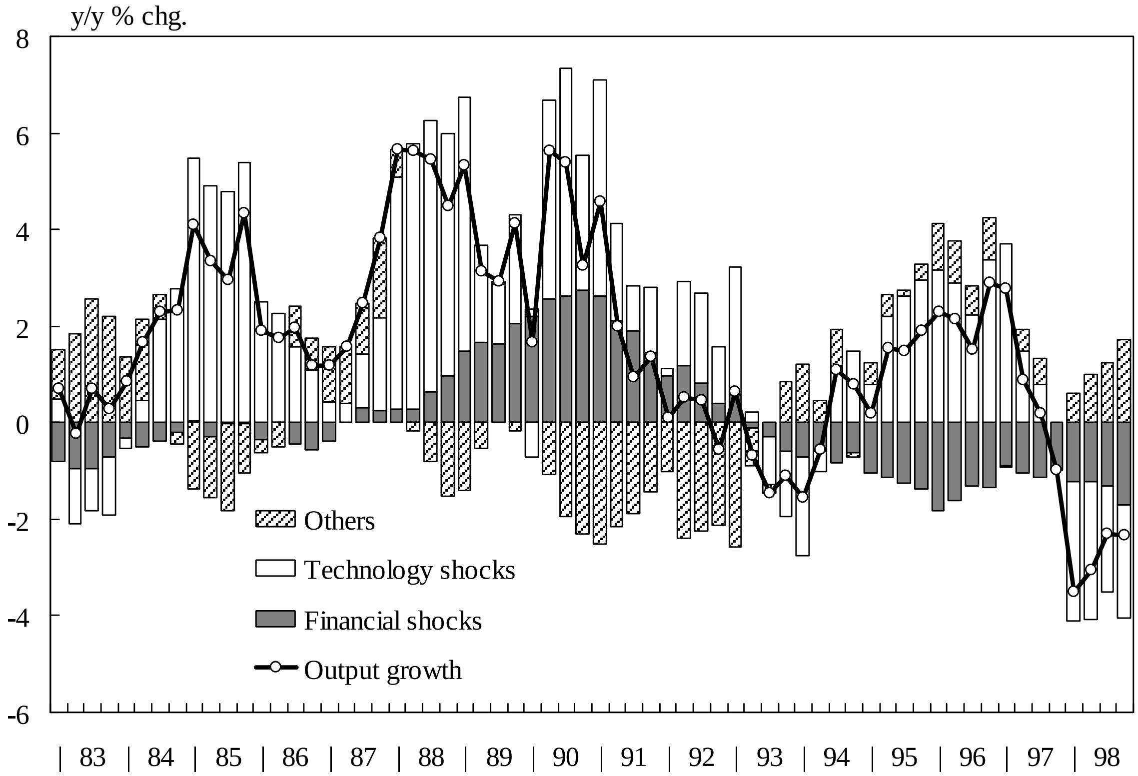

Figure 3: Historical decomposition of Japan's output growth rate

Note: This figure shows the historical decomposition of Japan's output growth rate based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

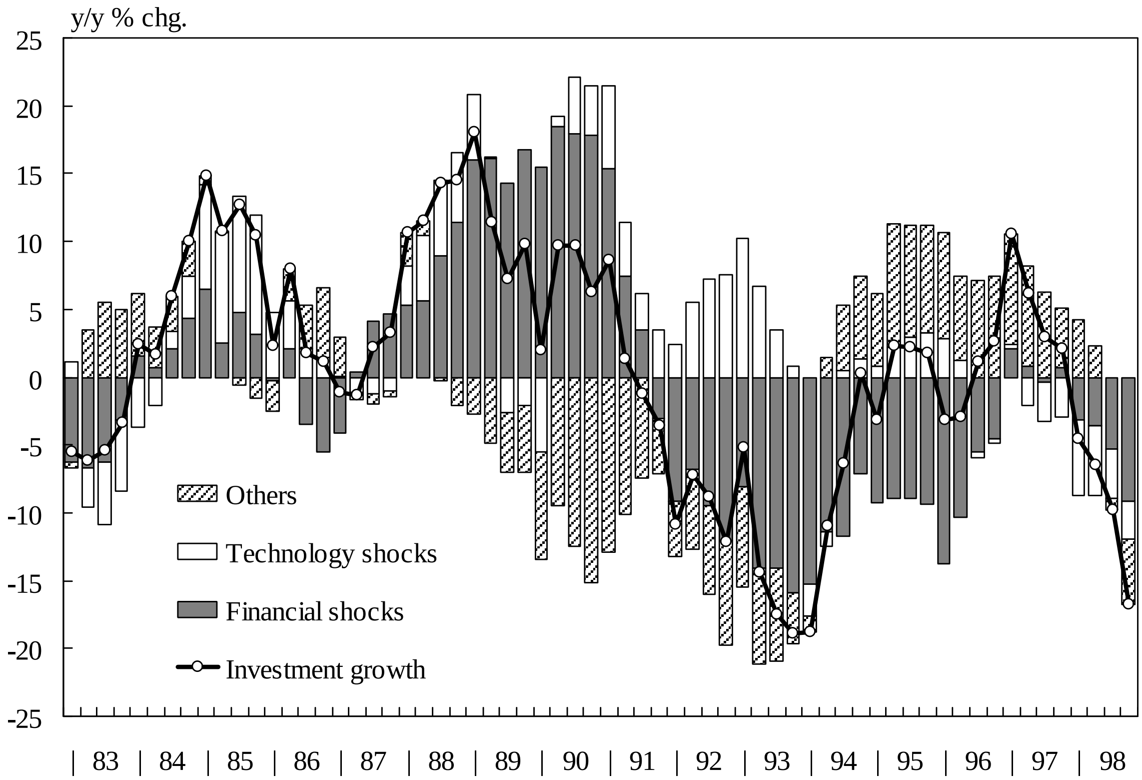

Figure 4: Historical decomposition of Japan's investment growth rate

Note: This figure shows the historical decomposition of Japan's investment growth rate based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

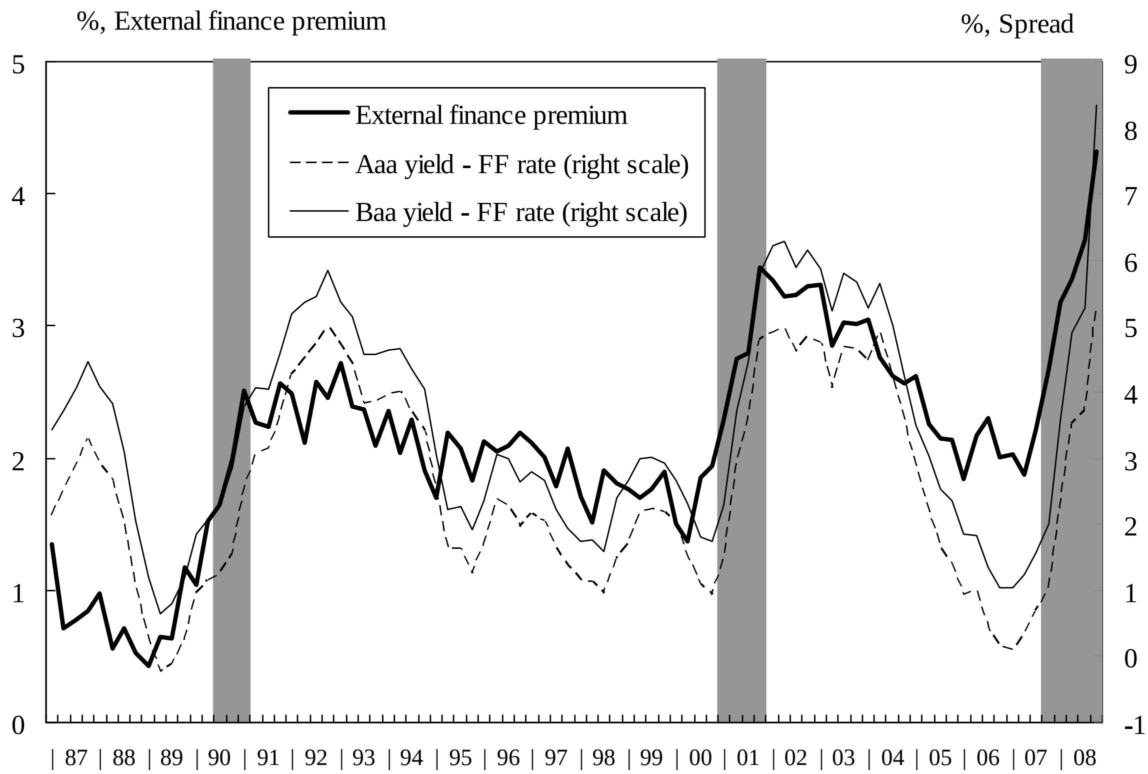

Figure 5: The estimated external finance premium in the U.S.

Notes: This figure shows the Kalman smoothed mean estimates of the external finance premium in the U.S. and two proxies for this premium, the spreads between the federal funds rate and Moody's seasoned Aaa and Baa corporate bond yields, respectively. The shaded areas indicate the NBER recession periods.

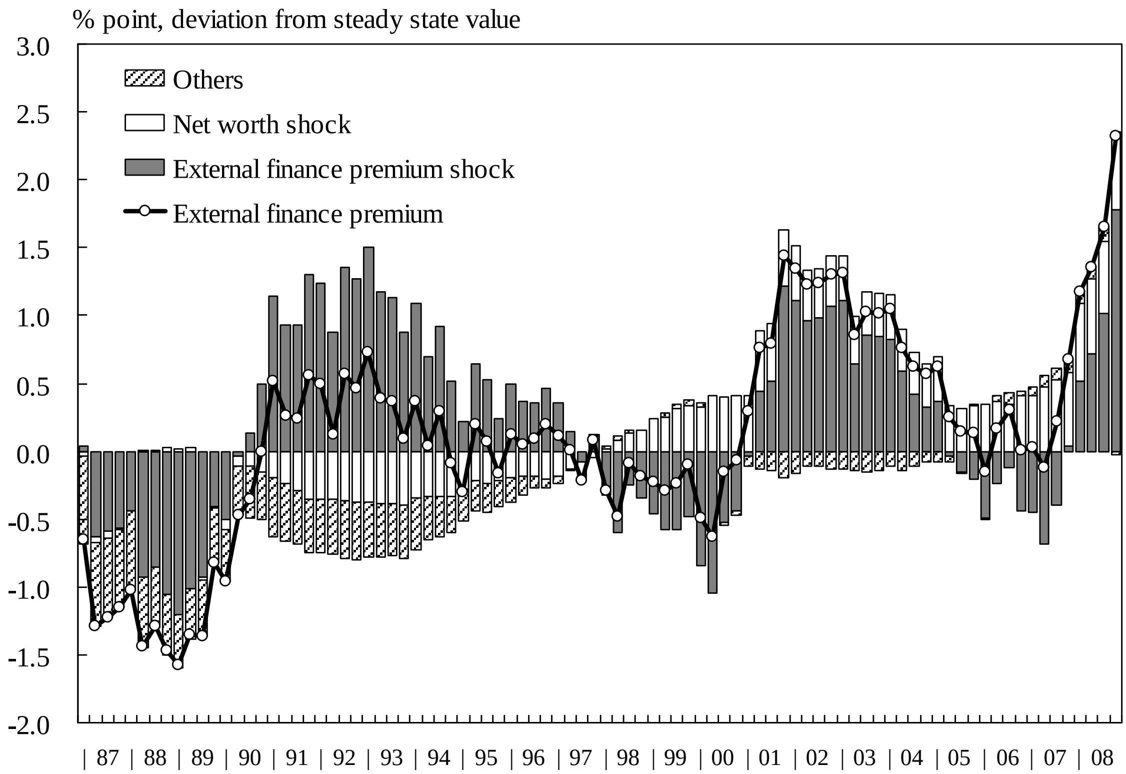

Figure 6: Historical decomposition of the U.S. external finance premium

Note: This figure shows the historical decomposition of the U.S. external finance premium based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

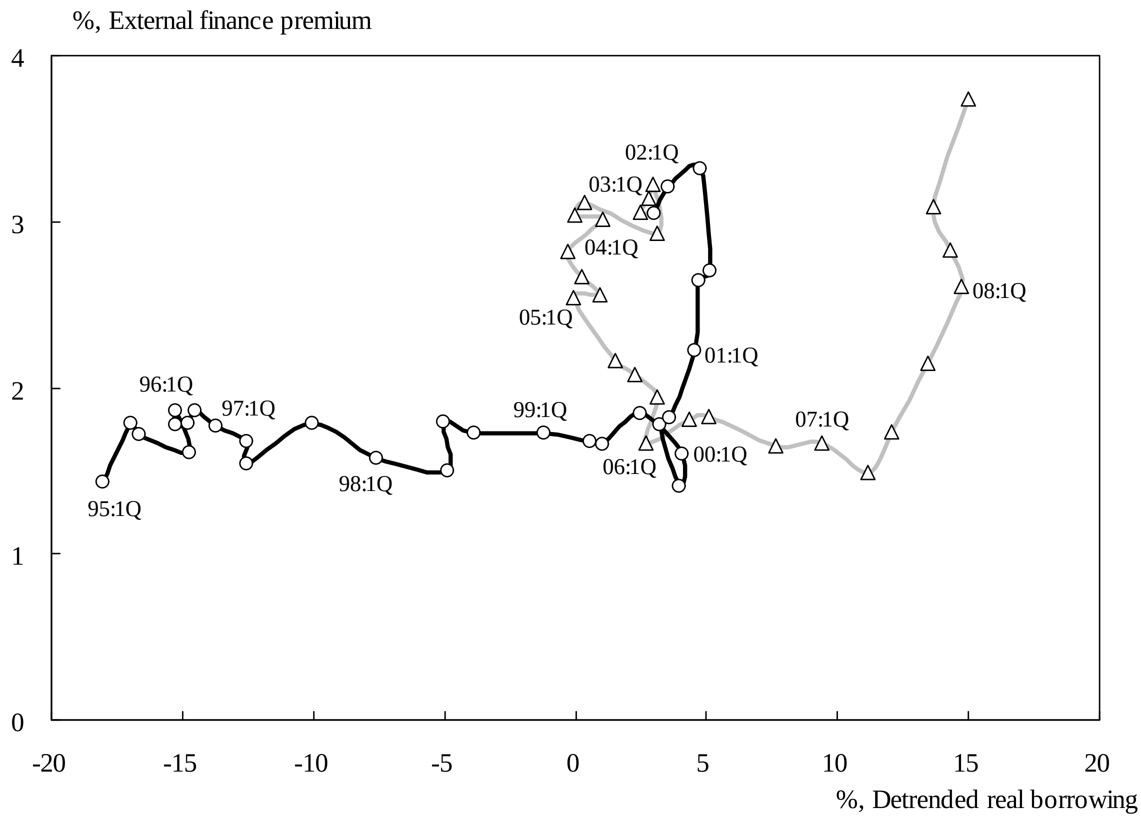

Figure 7: The external finance premium and the detrended real borrowing in the U.S.

Note: This figure shows the Kalman smoothed mean estimates of the external finance premium and the percent deviation of the detrended real borrowing from its average over the period from 1995:1Q to 2008:4Q in the U.S.

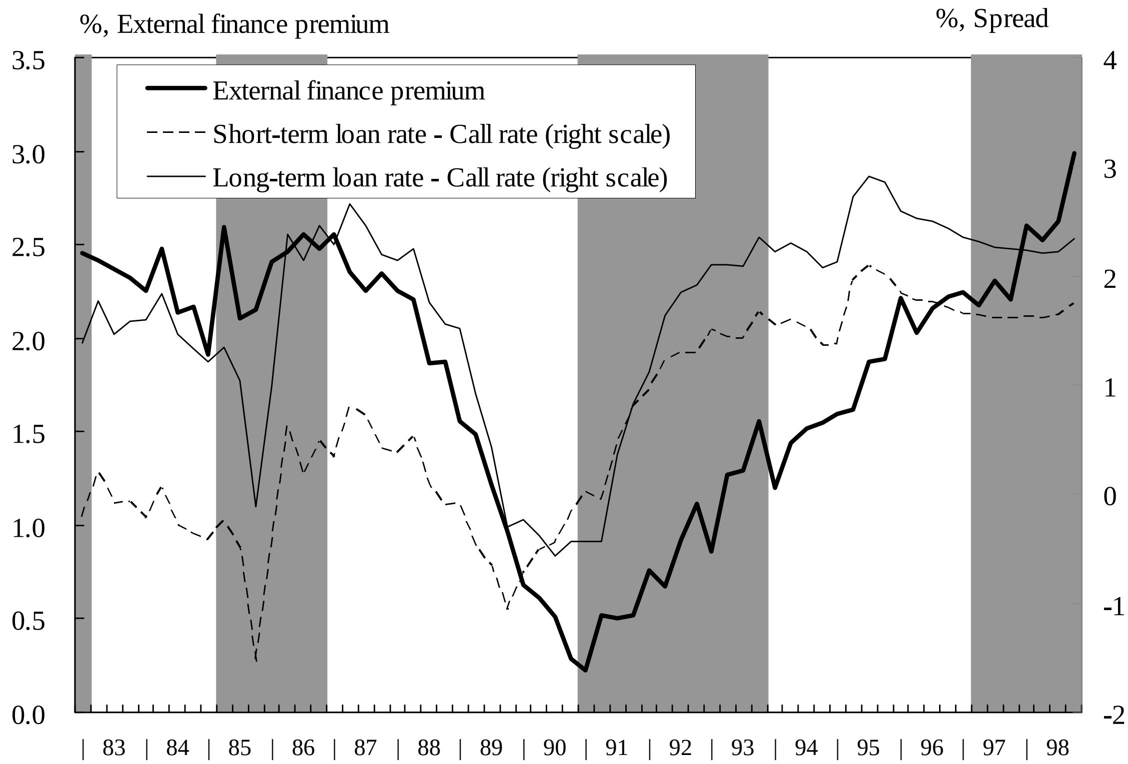

Figure 8: The estimated external finance premium in Japan

Notes: This figure shows the Kalman smoothed mean estimates of the external finance premium in Japan and two proxies for this premium, the spreads between the overnight call rate and the short- and long-term average interest rates on contracted loans and discounts, respectively. The shaded areas indicate the ESRI recession periods.

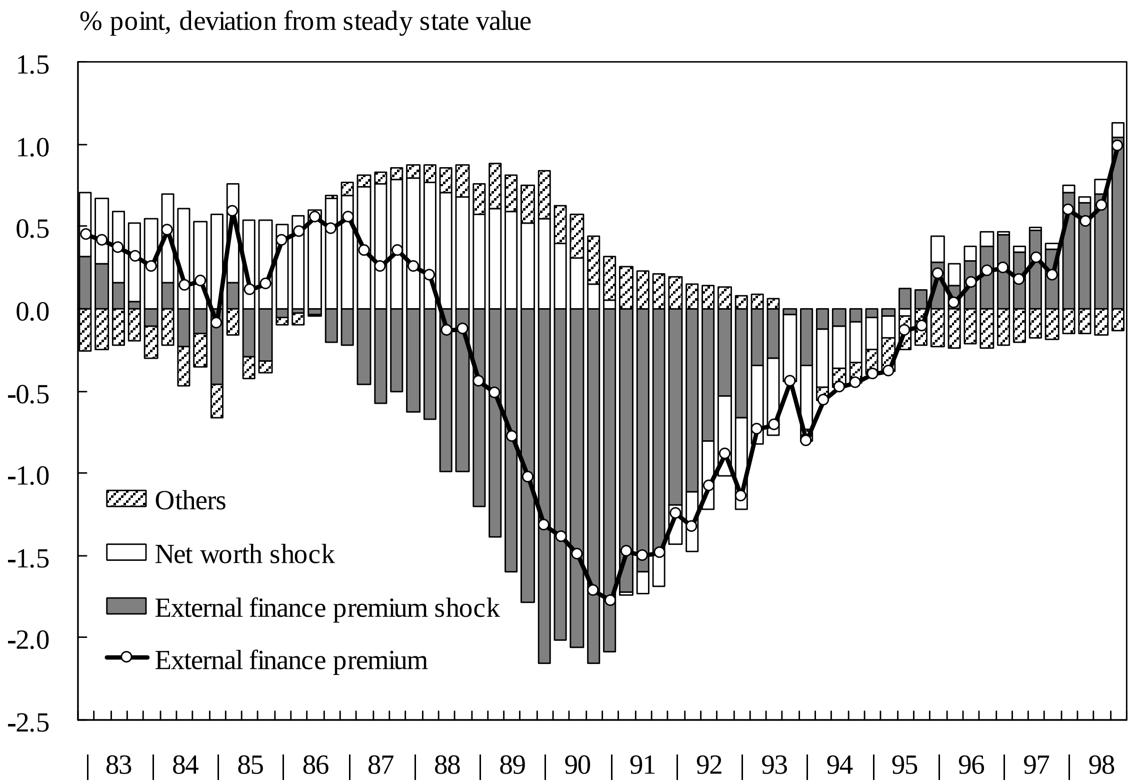

Figure 9: Historical decomposition of Japan's external finance premium

Note: This figure shows the historical decomposition of Japan's external finance premium based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

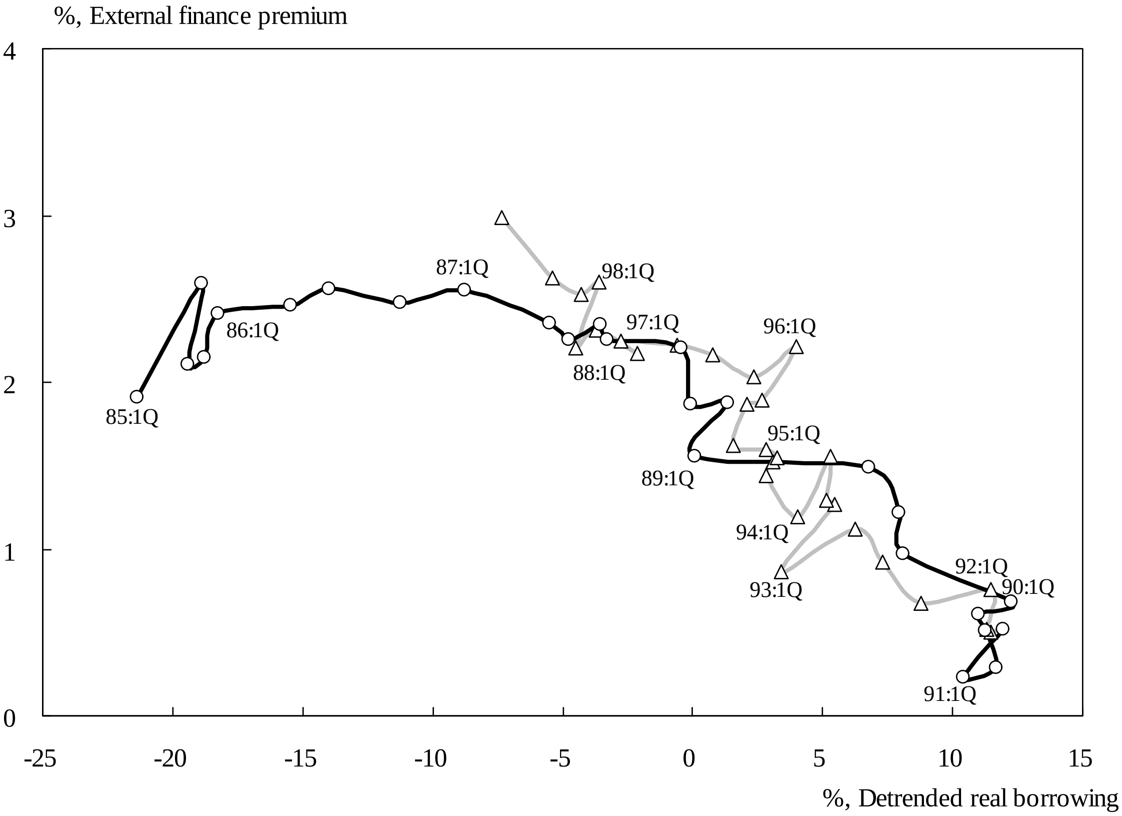

Figure 10: The external finance premium and the detrended real borrowing in Japan

Note: This figure shows the Kalman smoothed mean estimates of the external finance premium and the percent deviation of the detrended real borrowing from its average over the period from 1985:1Q to 1998:4Q in Japan.