Do investment-specific technological changes matter for business fluctuations? Evidence from Japan

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Do Investment-Specific Technological Changes Matter for Business Fluctuations? Evidence from Japan*

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Abstract

The observed decline in the relative price of investment goods to consumption goods in Japan suggests the existence of investment-specific technological (IST) changes. We examine whether IST changes are a major source of business fluctuations in Japan, by estimating a dynamic stochastic general equilibrium model with Bayesian methods. We show that IST changes are less important than neutral technological changes in explaining output fluctuations. We also demonstrate that investment fluctuations are mainly driven by shocks to investment adjustment costs. Such shocks represent variations of costs involved in changing investment spending, such as financial intermediation costs. We then find that the estimated series of the investment adjustment cost shock correlates strongly with the diffusion index of firms' financial position in the *Tankan* (Short-term Economic Survey of Enterprises in Japan). We thus argue that the large decline in investment growth in the early 1990s is due to an increase in investment adjustment costs stemming from firms' tight financial constraint after the collapse of Japan's asset price bubble.

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1 Introduction

What is the main source of business fluctuations? The conventional view in the business cycle literature is that technological changes play a major role in explaining aggregate fluctuations. Particularly, the importance of sector-specific technological changes has been emphasized. Canova *et al.* (1994), for instance, point out that co-trending relationships assumed in business cycle models are often rejected by data. More specifically, Greenwood *et al.* (1997, 2000) and Fisher (2006) focus on the movements in the relative price of investment goods to consumption goods, and demonstrate the crucial importance of investment-specific technological (IST) changes in the U.S. business fluctuations using calibrated dynamic stochastic general equilibrium (DSGE) models and estimated structural vector autoregression (SVAR) models. Motivated by these previous studies' results, Ireland and Schuh (2008) and Justiniano *et al.* (2011) estimate DSGE models to re-examine whether IST changes are critical in explaining the U.S. business cycles.[1] However, Ireland and Schuh find that consumption-specific technological changes are more important than IST changes. Also, Justiniano *et al.* show that the investment efficiency shock proposed by Greenwood *et al.* (1988) is the main driving force of the U.S. aggregate fluctuations rather than IST changes.[2]

In this paper, we address the question of whether IST changes are a major source of business fluctuations in Japan, by estimating a DSGE model with Bayesian methods.[3] In recent studies, Christiano and Fujiwara (2006) suggest that the observed decline in the relative price

[1] Edge *et al.* (2008) develop a more rigorous multi-sector model.

[2] The investment efficiency shock is a shock that affects the transformation of investment goods into productive capital.

[3] For Bayesian estimation of DSGE models of Japan's economy, see Iiboshi *et al.* (2006), Hirose (2008), Sugo and Ueda (2008), Ichiue *et al.* (2008), Fujiwara *et al.* (2008), Kaihatsu and Kurozumi (2010), and Fueki *et al.* (2010). These studies, except the last three, estimate DSGE models for stationary variables using detrended data as in line with Christiano *et al.* (2005), Smets and Wouters (2003), and Levin *et al.* (2006). This approach differs from that of the present paper, since our DSGE model incorporates stochastic trends both in neutral technology and in IST so that we can explicitly examine whether the boom-bust cycle during the late 1980s and the early 1990s in Japan is driven by changes in the trends or by non-permanent shocks.

of investment goods to consumption goods in Japan (see Figure 1) implies the necessity for IST changes in DSGE models of Japan's economy. Braun and Shioji (2007) incorporate IST changes into Hayashi and Prescott's (2002) neoclassical growth model for Japan, and show that the model's prediction of output and investment in the 1990s is higher than the data. However, Braun and Shioji estimate an SVAR model with sign restrictions as in Uhlig (2005) in which the restrictions are derived from DSGE models with IST changes, and conclude that the IST changes are at least as important as neutral technological changes in Japan's business cycles.

We take a different approach from Braun and Shioji (2007). Specifically, we use a Bayesian likelihood approach to estimate a fully specified DSGE model with IST changes and investment adjustment cost shocks. Such cost shocks have been used in recent business cycle studies since Smets and Wouters (2003), and represent variations of costs involved in changing investment spending, such as financial intermediation costs analyzed by Carlstrom and Fuerst (1997).[4]

The present paper has three main findings. First, we find that IST changes are less important than neutral technological changes in explaining output fluctuations in Japan. By investigating historical and variance decompositions of output growth, we show that the IST changes play a minor role or sometimes an offsetting role in the output fluctuations. This is consistent with the result Braun and Shioji (2007) obtain using the calibrated growth model, but it is in stark contrast to their result obtained with the SVAR model.

Second, we find that investment fluctuations in Japan are mainly driven by investment adjustment cost shocks rather than IST changes. Our historical and variance decompositions of investment growth demonstrate that the adjustment cost shock is the main driving force of investment fluctuations and also plays a major role in output fluctuations.

Last but not least, we find that the estimated series of the investment adjustment cost shock correlates strongly with the diffusion index of firms' financial position in the *Tankan* (Short-

[4]The investment adjustment cost shock considered in this paper and the investment efficiency shock studied by Greenwood *et al.* (1988) and Justiniano *et al.* (2010, 2011) capture almost the same wedge in an equilibrium condition for investment spending. We have confirmed that our results hold even when the investment efficiency shock is introduced in our model instead of the investment adjustment cost shock.

term Economic Survey of Enterprises in Japan).[5] This suggests that the estimated shocks can be considered as a measure for firms' financial constraint regarding investment spending. We thus argue that the large decline in investment growth in the early 1990s is due to an increase in investment adjustment costs stemming from firms' tight financial constraint after the collapse of Japan's asset price bubble. This interpretation may be in stark contrast with the view of Hayashi and Prescott (2002), who point out that the dysfunction of Japan's banking system during the 1990s did not constrain firms' financing for investment. However, our interpretation is in line with the so-called "credit crunch" hypothesis, which suggests that the tight financial condition constrained investment and hence depressed output.

The remainder of the paper proceeds as follows. Section 2 describes a DSGE model with IST changes and investment adjustment cost shocks. Section 3 presents data and strategy for estimating the model. Section 4 explains empirical results. Finally, Section 5 concludes.

2 The log-linearized DSGE model

We develop a DSGE model along the lines of recent business cycle studies such as Christiano *et al.* (2005), Smets and Wouters (2003), and Levin *et al.* (2006). In the model, we consider balanced growth as in Erceg *et al.* (2006) and Smets and Wouters (2007) and incorporate IST changes as in Justiniano *et al.* (2011). We also allow for stochastic trends in neutral technological changes and in IST changes, since there seems to be at least one break in the growth rates of GDP and investment in Japan around 1991 as Sugo and Ueda (2008) point out. Further, we suppose monopolistic competition in the investment-good sector so that the associated price markup generates a wedge between the IST level and the relative price of investment goods to consumption goods.

In the rest of this section, we describe the log-linearized equilibrium conditions represented

[5] For the U.S. economy, Justiniano *et al.* (2011) obtain a similar result that there is a strong correlation between their estimated series of investment efficiency shocks and a credit spread measured as the difference between the returns on high-yield and AAA corporate bonds.

in terms of stationary variables detrended by the levels of neutral technology and IST.[6] All hatted variables denote the log-deviations from steady-state values associated with the capital utilization rate of one. In the model economy there are a continuum of households, four types of firms, and a central bank. We describe each agent's decisions in turn.

2.1 Households

We begin with households' decisions. Each household purchases consumption goods and one-period riskless bonds and supplies one kind of differentiated labor services to intermediate-good firms under monopolistic competition.

In the presence of complete insurance markets, all households purchase the same levels of consumption goods and bonds. Hence, optimality conditions for the utility maximization with respect to consumption and bond-holdings yield

$$\begin{aligned} \hat{\lambda}_t = & -\frac{1}{1-\theta\pi/r^n}\left\{\frac{\sigma}{1-\theta/z^*}\left(\hat{c}_t - \frac{\theta}{z^*}\left(\hat{c}_{t-1} - z_t^*\right)\right) - z_t^b\right\} \\ & + \frac{\theta\pi/r^n}{1-\theta\pi/r^n}\left\{\frac{\sigma}{1-\theta/z^*}\left(E_t\hat{c}_{t+1} + E_t z_{t+1}^* - \frac{\theta}{z^*}\hat{c}_t\right) - E_t z_{t+1}^b\right\}, \end{aligned} \tag{1}$$

$$0 = E_t\hat{\lambda}_{t+1} - \hat{\lambda}_t - \sigma E_t z_{t+1}^* + \hat{r}_t^n - E_t\hat{\pi}_{t+1}. \tag{2}$$

Here, $\hat{c}_t$ is consumption, $\hat{\lambda}_t$ is the marginal utility of consumption, $\hat{r}_t^n$ is the nominal interest rate, $\hat{\pi}_t$ is the inflation rate, z_t^b is an intertemporal preference shock, and $z_t^* = z_t^z + \alpha/(1-\alpha)z_t^\psi$ is a composite technology shock, where z_t^z, z_t^ψ are shocks to the rates of neutral technological changes and IST changes and $\alpha \in (0,1)$ is the capital elasticity of output in intermediate-good firms' Cobb-Douglas production functions. The parameter $\theta \in (0,1)$ is the degree of habit persistence in consumption preferences, $\sigma > 0$ is the degree of relative risk aversion, r^n is the gross steady-state nominal interest rate, π is the gross steady-state inflation rate, and $z^* = z\psi^{\alpha/(1-\alpha)}$ is the gross steady-state balanced growth rate, where z, ψ are the gross rates of neutral technological changes and IST changes at the steady state. Throughout the paper, the subjective discount factor β is substituted out of log-linearized equilibrium conditions using

[6] See the working-paper version of this paper (Hirose and Kurozumi, 2010) for details of the decisions faced by agents in the model economy as well as the equilibrium conditions.

the steady-state condition $\beta = (z^*)^\sigma \pi / r^n$.

In the face of intermediate-good firms' demand for differentiated labor services, wages are determined on a staggered basis à la Calvo (1983) so as to minimize labor disutility. As for the specification of the labor disutility, we follow Erceg *et al.* (2006) to ensure the existence of the balanced growth path for the model economy.[7] In each period, a fraction $1 - \xi_w \in (0, 1)$ of wages is re-optimized, while the remaining fraction ξ_w is set by indexation to the steady-state balanced growth rate z^* as well as a weighted average of past inflation $\hat{\pi}_{t-1}$ and steady-state inflation π. Combining labor-disutility-minimizing conditions for re-optimized wages and the CES aggregator of wages generates

$$\begin{aligned} \hat{w}_t = \hat{w}_{t-1} - \hat{\pi}_t + \gamma_w \hat{\pi}_{t-1} - z_t^* + \frac{z^* \pi}{r^n} \left(E_t \hat{w}_{t+1} - \hat{w}_t + E_t \hat{\pi}_{t+1} - \gamma_w \hat{\pi}_t + E_t z_{t+1}^* \right) \\ + \frac{(1 - \xi_w)(1 - \xi_w z^* \pi / r^n)}{\xi_w \{1 + \chi(1 + \lambda^w)/\lambda^w\}} \left(\chi \hat{l}_t - \hat{\lambda}_t - \hat{w}_t + z_t^b \right) + z_t^w, \end{aligned} \tag{3}$$

where $\hat{w}_t$ is the real wage, $\hat{l}_t$ is labor, z_t^w is a composite labor shock relevant to the labor disutility and the wage markup, $\gamma_w \in [0, 1]$ is the weight of wage indexation to past inflation relative to steady-state inflation, $\chi > 0$ is the inverse of the elasticity of labor supply, and $\lambda^w > 0$ is the steady-state wage markup.

2.2 Firms

We turn next to firms' decisions. There are a continuum of intermediate-good-producing firms, a representative consumption-good-producing firm, a continuum of investment-good-producing firms, and a representative capital-service-providing firm.

2.2.1 Intermediate-good firms

Each intermediate-good firm produces one kind of differentiated goods by choosing a pair of capital and labor services so as to minimize production cost subject to a Cobb-Douglas production function with the capital elasticity of output $\alpha \in (0, 1)$ and a fixed cost of production.

Combining optimality conditions for the cost minimization with respect to capital and labor services shows that real marginal cost $\hat{mc}_t$ is identical among intermediate-good firms

[7] See the working-paper version (Hirose and Kurozumi, 2010) for details of the labor disutility specification.

and satisfies

$$\hat{mc}_t = (1-\alpha)\hat{w}_t + \alpha \hat{r}_t^k, \tag{4}$$

where $\hat{r}_t^k$ is the real rental price of capital. Also, combining the cost-minimizing conditions and aggregating the resulting equations over intermediate-good firms show that the capital-labor ratio, $(\hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi) - \hat{l}_t$, is identical among intermediate-good firms and satisfies

$$(\hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi) - \hat{l}_t = \hat{w}_t - \hat{r}_t^k, \tag{5}$$

where $\hat{k}_t$ is capital and $\hat{u}_t$ is the utilization rate of capital. Moreover, aggregating the Cobb-Douglas production functions over intermediate-good firms generates

$$\hat{y}_t = \left(1 + \frac{\phi}{y}\right)\left\{(1-\alpha)\,\hat{l}_t + \alpha\left(\hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi\right)\right\}, \tag{6}$$

where $\phi/y > 0$ is the steady-state output ratio of the production fixed cost.

Facing the consumption-good firm's demand, each intermediate-good firm sets the price of its differentiated product on a staggered basis à la Calvo (1983) so as to maximize profit. In each period, a fraction $1-\xi_p \in (0,1)$ of intermediate-good firms re-optimizes prices, while the remaining fraction ξ_p indexes prices to a weighted average of past inflation $\hat{\pi}_{t-1}$ and steady-state inflation π. Combining profit-maximizing conditions for re-optimized prices and the CES aggregator of prices generates

$$\hat{\pi}_t = \gamma_p \hat{\pi}_{t-1} + \frac{z^*\pi}{r^n}\left(E_t \hat{\pi}_{t+1} - \gamma_p \hat{\pi}_t\right) + \frac{(1-\xi_p)(1-\xi_p z^* \pi / r^n)}{\xi_p}\hat{mc}_t + z_t^p, \tag{7}$$

where z_t^p is a shock to the consumption-good price markup and $\gamma_p \in [0,1]$ is the weight of price indexation to past inflation relative to steady-state inflation.

2.2.2 Consumption-good firm

The consumption-good firm produces homogeneous goods by choosing a combination of intermediate goods so as to minimize production cost subject to a CES production technology.

The consumption-good market clearing condition yields

$$\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{i}{y}\hat{\imath}_t + z_t^g, \tag{8}$$

where $\hat{y}_t$ is output, $\hat{\imath}_t$ is investment, z_t^g is an expenditure shock, and $c/y, i/y \in (0,1)$ are the steady-state output shares of consumption and investment.

2.2.3 Investment-good firms

Each investment-good firm 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 IST. The inverse of the IST level, $1/\Psi_t$, turns out to be real marginal cost of producing each investment good. Hence, the marginal cost is identical among investment-good firms. The log-level of IST follows the stochastic process: $\log \Psi_t = \log \psi + \log \Psi_{t-1} + z_t^{\psi}$.

Facing the capital-service firm's demand, each investment-good firm sets the price of its product so as to maximize profit. The optimality condition for the profit maximization shows that the price of each investment good is the nominal marginal cost plus the price markup. Then, the change rate of the relative price of investment goods to consumption goods, $\hat{r}_t^i$, satisfies[8]

$$\hat{r}_t^i = -z_t^{\psi} + z_t^{\nu} - z_{t-1}^{\nu}, \tag{9}$$

where z_t^{ν} is a shock to the investment-good price markup.

2.2.4 Capital-service firm

The capital-service firm owns the entire stock of capital at the beginning of each period, and makes an investment to accumulate capital. As in Greenwood *et al.* (1988), it is assumed that a higher utilization rate of capital leads to a higher depreciation rate of capital. Then, the capital accumulation equation yields

$$\hat{k}_t = \frac{1-\delta - r^n \psi/\pi}{z^* \psi}\,\hat{u}_t + \frac{1-\delta}{z^*\psi}\left(\hat{k}_{t-1} - z_t^* - z_t^{\psi}\right) + \left(1 - \frac{1-\delta}{z^*\psi}\right)\hat{\imath}_t, \tag{10}$$

[8] Note that when the investment-good markets are perfectly competitive as in Justiniano *et al.* (2011) and Braun and Shioji (2007), we have $z_t^{\nu} = 0$ in each period t, and hence (9) becomes $\hat{r}_t^i = -z_t^{\psi}$. Hence, there is one-to-one correspodence between the change rate of the relative price of investment goods and the IST shock. In contrast to this restrictive specification, our model supposes the monopolistically competitive markets with the time-varying elasticity of substitution between investment goods. This yields the time-varying price markup, which serves as a wedge between the change rate of the relative price and the IST shock, as shown in (9).

where $\delta \in (0,1)$ is the steady-state capital depreciation rate.

The capital-service firm rents utilization-adjusted capital to intermediate-good firms. The optimality conditions for the profit maximization with respect to investment, the utilization rate, and capital yield

$$z_t^{\nu} = \hat{q}_t - \frac{1}{\zeta}\left(\hat{\imath}_t - \hat{\imath}_{t-1} + z_t^* + z_t^{\psi} + z_t^i\right) + \frac{z^*\pi}{\zeta r^n}\left(E_t\hat{\imath}_{t+1} - \hat{\imath}_t + E_t z_{t+1}^* + E_t z_{t+1}^{\psi} + E_t z_{t+1}^i\right), \quad (11)$$

$$\hat{r}_t^k = \hat{q}_t + \frac{1}{\mu}\hat{u}_t, \quad (12)$$

$$\hat{q}_t = E_t\hat{\lambda}_{t+1} - \hat{\lambda}_t - \sigma E_t z_{t+1}^* - E_t z_{t+1}^{\psi} + \left(1 - \frac{\pi(1-\delta)}{r^n\psi}\right) E_t\hat{r}_{t+1}^k + \frac{\pi(1-\delta)}{r^n\psi} E_t\hat{q}_{t+1}, \quad (13)$$

where $\hat{q}_t$ is the real price of capital, z_t^i is a shock to the investment adjustment cost, $\zeta > 0$ is the inverse of the elasticity of the investment adjustment cost, and $\mu > 0$ is the inverse of the steady-state elasticity of the utilization-rate adjustment cost.

2.3 Central bank and exogenous shock processes

Last, we present the central bank's decisions and exogenous shock processes. The bank conducts monetary policy by adjusting the nominal interest rate according to the Taylor (1993) type rule

$$\hat{r}_t^n = \phi_r \hat{r}_{t-1}^n + (1-\phi_r)\left\{\phi_\pi \sum_{j=0}^{3} \frac{\hat{\pi}_{t-j}}{4} + \phi_y(\hat{y}_t - \hat{y}_t^*)\right\} + z_t^r, \quad (14)$$

where $\phi_r \in [0,1)$ is the degree of interest rate smoothing, $\phi_\pi, \phi_y \geq 0$ are the degrees of policy responses to the annual inflation rate $\sum_{j=0}^{3} \hat{\pi}_{t-j}/4$ and the output gap $\hat{y}_t - \hat{y}_t^*$, and z_t^r is a monetary policy shock. The output gap is given by

$$\hat{y}_t - \hat{y}_t^* = \left(1 + \frac{\phi}{y}\right)\left\{(1-\alpha)\,\hat{l}_t + \alpha\left(\hat{u}_t + \hat{k}_{t-1}\right)\right\}. \quad (15)$$

This specification is close to the one estimated by the Bank of Japan (Hara *et al.*, 2006), which is included in our dataset for estimation.

Each exogenous shock follows the univariate stationary first-order autoregressive process:

$$z_t^x = \rho_x z_{t-1}^x + \varepsilon_t^x, \quad (16)$$

for $x \in \{b, i, g, w, p, r, \nu, z, \psi\}$, where $\rho_x \in [0,1)$ is the autoregressive coefficient and ε_t^x is the white noise with zero mean and variance σ_x^2.

3 Data and estimation strategy

The model presented in the preceding section is estimated using Bayesian methods. In what follows, we first describe the data used for estimation, and next explain the estimation strategy regarding prior distributions of parameters and identification issues.

3.1 Data

We use nine quarterly Japanese time series as observable variables: Y_t, C_t, I_t, W_t, l_t, P_t, r_t^n, Y_t/Y_t^*, P_t^i/P_t. The first seven series follow from Sugo and Ueda (2008): Y_t is per capita real GDP, C_t is per capita real consumption, I_t is per capita real investment, W_t is the real wage, l_t is hours worked, P_t is the CPI, and r_t^n is the overnight call rate.[9] Unlike Sugo and Ueda, these data are not detrended, and the real series of GDP and consumption are constructed by dividing the nominal series with the CPI in order to be consistent with the corresponding model variables. For the output gap Y_t/Y_t^*, we use the Bank of Japan's estimates (Hara *et al.*, 2006). The remaining one data is the relative price of investment P_t^i/P_t, for which we divide the investment deflator by the CPI. Then, the observation equations are given by

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

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 quarterly inflation rate is chosen at $\overline{\pi} = 1/4$.

[9] For details of these seven time series, see Sugo and Ueda (2008).

As is similar to previous studies on estimated DSGE models of Japan's economy, the sample period is from 1981:1Q to 1998:4Q. The end of the sample is determined so as to exclude the period of the zero nominal interest rate policy, since our estimation strategy is not able to take into account the non-linearity in monetary policy rules due to the zero lower bounds on nominal interest rates.[10]

3.2 Estimation strategy

We estimate most parameters of the model but some are fixed to avoid an identification issue. As in Sugo and Ueda (2008), we set the steady-state depreciation rate at $\delta = 0.06$, the capital elasticity of output at $\alpha = 0.37$, and the steady-state wage markup at $\lambda^w = 0.2$. The steady-state output shares of consumption and investment, $c/y, i/y$, are set at the sample mean.

The prior distributions of parameters to be estimated are shown in the second to fourth columns of Table 1. The priors of parameters that describe the private-sector behavior (i.e., $\sigma, \theta, \chi, 1/\zeta, \mu, \phi/y, \gamma_w, \xi_w, \gamma_p, \xi_p$) are the same as those of Sugo and Ueda (2008) and the priors of the monetary policy rule's parameters (i.e., ϕ_r, ϕ_π, ϕ_y) are the same as those of Iiboshi *et al.* (2006), since the private-sector part of our model is close to that of Sugo and Ueda and the policy rule of our model is close to that of Iiboshi *et al.* The priors of the steady-state growth rates of the composite technology and IST (i.e., $\overline{z^*}, \overline{\psi}$) are set to be the Gamma distribution with the standard deviation of 0.2 and the mean based on the sample mean of $100\Delta \log Y_t$ and $100\Delta \log \left(P_t^i/P_t\right)$. For parameters regarding shocks, we choose fairly wide prior distributions. The priors of the autoregressive coefficients $\rho_x, x \in \{b, i, g, w, p, r, \nu, z, \psi\}$ are set to be the Beta distribution with the mean of 0.5 and the standard deviation of 0.2, and the priors of the white noises' standard deviations $\sigma_x, x \in \{b, i, g, w, p, r, \nu, z, \psi\}$ are set to be the Inverse Gamma distribution with the mean of 0.5 and the standard deviation of an infinity.

As in recent studies taking Bayesian likelihood approaches to estimate DSGE models, we use the Kalman filter to evaluate the likelihood function of the system of log-linearized equilibrium

[10] In Section 4.5, the model is re-estimated in the extended sample from 1981:1Q to 2010:3Q to examine whether the results obtained with the baseline estimation hold for the extended sample.

conditions and apply the Metropolis-Hastings algorithm to generate draws from the posterior distribution of model parameters.[11] Based on these draws, we make inference on the parameters and obtain the Kalman smoothed estimates of unobservables and the historical and variance decompositions of the model variables.

Before proceeding to the empirical results, it is worth mentioning the identifiability of the three structural shocks that affect the process of capital accumulation: the IST shock z_t^{ψ}, the investment-good price markup shock z_t^{ν}, and the investment adjustment cost shock z_t^{i}. As noted in footnote 8, if the investment-good markets are perfectly competitive, the evolution of the IST shock z_t^{ψ} is fully determined by the data on the relative price of investment goods. Thus, our model introduces the monopolistic competition and the time-varying substitution elasticity in the investment-good markets to generate the price markup shock, which serves as a wedge between the IST shock and the change rate of the relative price of investment goods in (9). The IST shock appears in the nine equilibrium conditions (1)–(3), (5), (6), (9)–(13) because the IST shock is one component of the composite technology shock z_t^*. Consequently, the evolution of the IST shock is determined in the presence of the markup shock so as to improve the overall fit of the model to all the nine time series. This implies that, given the data on the relative price of investment and the series of the IST shock, the series of the markup shock is determined as a residual in the equilibrium condition (9). Similarly, given the data on investment and the series of the IST shock, the markup shock, and the composite technology shock, the series of the investment adjustment cost shock is determined as a residual in the equilibrium condition (11). Therefore, it is possible to identify the three structural shocks.

4 Empirical results

We now present the empirical results. We first illustrate the estimates of parameters and then discuss the historical and variance decompositions of business fluctuations.

[11] For the ensuing analysis, 200,000 draws were generated and the first half of them was discarded. We adjusted the scale factor for the jumping distribution in the Metropolis-Hastings algorithm so that the acceptance rate of 25% was obtained. Brooks and Gelman's (1998) measure was used to check the convergence of parameters.

4.1 Parameter estimates

The posterior mean of each parameter and its 90% posterior interval are reported in the fifth to sixth columns of Table 1. Our posterior estimates of the structural parameters are similar to those in Sugo and Ueda (2008) and Iiboshi *et al.* (2006). The estimates of the risk aversion, the consumption habit persistence, and the inverse elasticity of labor supply are respectively $\sigma = 1.52$, $\theta = 0.44$, and $\chi = 4.42$, which are in line with the estimates by previous studies using DSGE models. For the parameters regarding firms' activities, we have the estimates of $1/\zeta = 7.12$, $\mu = 2.08$, and $\phi/y = 0.09$. These estimates are quite similar to those in Sugo and Ueda. The parameters regarding wage and price rigidities are estimated reasonably: $\gamma_w = 0.32$, $\xi_w = 0.52$, $\gamma_p = 0.63$, $\xi_p = 0.66$. The weights of wage and price indexation are one-third and two-thirds, respectively, and the average frequencies of wage and price re-optimization are two quarters and three quarters, respectively. The posterior mean of interest rate smoothing ($\phi_r = 0.65$) is a mild one and the estimate of the policy response to inflation ($\phi_\pi = 1.68$) is much larger than that of the policy response to the output gap ($\phi_y = 0.08$). The steady-state growth rates of the composite technology and IST are estimated at $\overline{z^*} = 0.39$ and $\overline{\psi} = 0.56$.

As for the shock parameters, the estimated shocks to the rates of neutral technological changes and IST changes are not persistent ($\rho_z = 0.07, \rho_\psi = 0.08$). This is because the log-levels of neutral technology and IST have unit roots. The expenditure shock is persistent ($\rho_g = 0.87$). Although the persistence of the investment adjustment cost shock is not high ($\rho_i = 0.54$), the magnitude of its innovations is fairly large ($\sigma_i = 4.78$). The shocks to intermediate-good and investment-good price markups exhibit quite high persistence ($\rho_p = 0.97, \rho_\nu = 0.99$) whereas the shock to the wage markup is not persistent ($\rho_w = 0.22$).

4.2 Historical and variance decompositions

We next investigate whether IST changes are of crucial importance in explaining Japan's business fluctuations. We begin with historical decompositions of the growth rates of output and investment based on the smoothed mean estimates of the structural shocks. Such decompositions identify the contribution of the shocks to the growth rates in each period.

Figure 2 shows the historical decomposition of the output growth rate. In this figure, we can see that neutral technological changes are the main driving force of output growth and are much more important than IST changes. We can also see that investment adjustment cost shocks play a crucial role in explaining output fluctuations. Particularly, the shocks contribute to the boom-bust cycle of output from the late 1980s to the early 1990s. The IST changes, however, play a minor role or sometimes an offsetting role in explaining output fluctuations.

The historical decomposition of the investment growth rate is shown in Figure 3. This figure illustrates that investment fluctuations are mainly driven by investment adjustment cost shocks rather than IST changes. Particularly, the boom-bust cycle of investment from the late 1980s to the early 1990s is for the most part explained by the adjustment cost shocks. This result is similar to that of Justiniano *et al.* (2011), who estimate a similar model for the U.S. economy. Justiniano *et al.* show that the investment efficiency shock proposed by Greenwood *et al.* (1988), which captures almost the same wedge in an investment equilibrium condition as the investment adjustment cost shocks in our model, is the main driving force of aggregate fluctuations rather than IST shocks.

These findings are confirmed by the variance decompositions as well. Table 2 reports the relative contribution of each shock to the variances of the growth rates of output, investment and consumption and to the variance of the inflation rate over each forecast horizon of $T = 8, 32, \infty$. In this table, we can see that the neutral technology shock (z_t^z) is the main driving force of fluctuations in output and consumption. This shock accounts for about a half of these fluctuations. By contrast, the contribution of the IST shock (z_t^ψ) is marginal for all the variables, even for investment. We can also see that investment fluctuations are mainly driven by the investment adjustment cost shock (z_t^i). This shock accounts for most of the investment fluctuations.[12]

[12]It is worth noting that the variance decompositions miss out the contributions of the steady-state rates of neutral technological changes and IST changes. By contrast, the historical decompositions presented above take into account these contributions.

4.3 Comparison with Braun and Shioji (2007)

In the previous literature, Braun and Shioji (2007) have evaluated the role of IST changes in Japan's business cycles using two approaches. In the first approach, Braun and Shioji incorporate IST changes into Hayashi and Prescott's (2002) neoclassical growth model for Japan, and demonstrate that the model's prediction of output and investment in the 1990s is higher than the actual data. Our historical decompositions exhibit a similar result in that IST shocks positively contribute to the growth rates of output and investment throughout the sample period, particularly in the early 1990s. This is because the relative price of investment goods continued to decline during the period, as can be seen in Figure 1. Consequently, both our model and that of Braun and Shioji predict that IST changes should boost investment and output growth. Our contribution is that the finding about the positive contribution of IST changes to Japan's business cycles in the 1990s is robust even if we introduce the monopolistic competition in the investment-good markets instead of the perfect competition assumed in Braun and Shioji.

In the second approach, Braun and Shioji (2007) estimate an SVAR model in which as in Uhlig (2005) the sign restrictions are derived from implications that are common to DSGE models with IST changes. Braun and Shioji then find that IST changes are at least as important as neutral technological changes in output and investment fluctuations in Japan. This is in stark contrast with our result that IST changes are less important than neutral technological changes. The difference between our result and that of Braun and Shioji is ascribed to whether other disturbances than IST changes are taken into account in equilibrium conditions for investment spending. Our model contains not only IST changes but also investment adjustment cost shocks whereas Braun and Shioji's SVAR model does not consider the latter shocks. As a consequence, our estimation results show that the investment adjustment cost shocks play a much more important role in explaining business fluctuations than IST changes. This suggests that Braun and Shioji's SVAR model might over-estimate the role of IST changes due to the missing investment adjustment cost shocks. To examine this issue, we estimate our model without the adjustment cost shocks.[13] Figures 4 and 5 show the historical decompositions of the growth rates of output and investment in the estimated model without the investment adjustment cost shocks. These figures illustrate that IST changes frequently contribute to output and investment growth in the same direction and play an important role in the aggregate fluctuations. These are consistent with the results Braun and Shioji obtain with their SVAR model. Therefore, the inclusion of the investment adjustment cost shock in our model distinguishes our results from those obtained by Braun and Shioji's SVAR model.

4.4 Investment adjustment cost shock and firms' financial constraint

The historical and variance decompositions have shown that the investment adjustment cost shock is the main driving force of investment fluctuations in Japan. This poses the question of what is the interpretation of the estimated series of the adjustment cost shock. In the model, this shock represents variations of costs associated with changing investment spending, such as financial intermediation costs. On the basis of a similar model to ours estimated for the U.S. economy, Justiniano *et al.* (2011) show that there is a strong correlation between their estimated series of investment efficiency shocks and a credit spread measured as the difference between the returns on high-yield and AAA corporate bonds. Justiniano *et al.* then conclude that the efficiency shock can be interpreted as a fundamental disturbance to the functioning of the financial sector. We thus investigate the estimated series of the investment adjustment cost shock from the perspective of financial intermediation.

Among a numerous number of time series that reflect financial conditions in Japan, Figure 6 plots the Financial Position Diffusion Index (all industries, all enterprises) in the *Tankan*, Short-term Economic Survey of Enterprises in Japan, and the smoothed mean estimates of the investment adjustment cost shock z_t^i. In this figure, we can see that the index of firms' financial position and the estimated series of the investment adjustment cost shock are highly correlated (correlation coefficient: 0.59). This suggests that the estimated shock can be considered as

[13] The exclusion of the investment adjustment cost shock from our model requires to exclude one data series from our dataset in order to avoid stochastic singularity in the estimation. We exclude the data on the output gap, since Braun and Shioji (2007) do not use this data.

a measure for firms' financial constraint regarding investment spending. Therefore, we argue that the large decline in Japan's investment growth in the early 1990s is due to firms' tight financial constraint stemming from the crisis in Japan's banking and financial sectors after the collapse of the asset price bubble. This interpretation may be in stark contrast with the view of Hayashi and Prescott (2002), who indicate with data from various sources that although bank lending declined during 1990s, firms still found other sources of investment finance. However, our interpretation is in line with the so-called "credit crunch" hypothesis, which suggests that a decrease in the amount a firm can borrow constrained investment and hence depressed output.

4.5 Extended sample

In our baseline estimation, the end of the sample is determined so as to exclude the period of the zero nominal interest rate policy because our estimation strategy is not able to take into account the effect of zero lower bounds on nominal interest rates. Yet it is still interesting to investigate whether the results obtained with the baseline estimation are altered by including recent data in the estimation, even if we run the risk of ignoring the binding nominal interest rates.[14] For this purpose, the model is re-estimated in the extended sample from 1981:1Q to 2010:3Q. The estimation strategy is the same as that for the baseline one.

Each parameter's posterior mean and 90% posterior interval in the extended sample is reported in the last two columns of Table 1. Most of the parameter estimates are in line with the baseline estimates, but some are different. The inverse elasticity of the utilization-rate adjustment cost ($\mu = 4.41$) is twice as large as that in the baseline estimation. The weights of wage and price indexation ($\gamma_w = 0.16$, $\gamma_p = 0.31$) are half of those in the baseline estimation, implying that wage and inflation dynamics are less persistent in recent periods.

Figures 7 and 8 show the historical decompositions of the output and investment growth rates. These figures are very similar to Figures 2 and 3 in the baseline estimation, regardless of the several changes in the parameter estimates. Therefore, the results obtained with the

[14] The authors would like to thank the editors and an anonymous referee for their suggestions on the robustness analysis of the model with the extended sample presented in this subsection.

baseline estimation still hold for the extended sample. That is, output fluctuations are mainly driven by neutral technological changes rather than IST changes, and investment fluctuations are explained mostly by investment adjustment cost shocks. Moreover, our interpretation of the investment adjustment cost shock survives, as shown in Figure 9. From this figure, we can observe that the correlation between the index of firms' financial position and the estimated series of the investment adjustment cost shock is still high (correlation coefficient: 0.61), and that these two series almost perfectly comove in the aftermath of the recent financial turmoil in 2008.

5 Concluding remarks

In this paper we have estimated a DSGE model with IST changes and investment adjustment cost shocks by Bayesian methods in order to examine whether the IST changes are a major source of business fluctuations in Japan. Our estimation results show that the IST changes are less important than neutral technological changes in explaining output fluctuations in Japan. This finding is in stark contrast with that of Braun and Shioji (2007), who estimate an SVAR model to reach the conclusion that IST changes are at least as important as neutral technological changes. We also demonstrate that investment fluctuations are mainly driven by the investment adjustment cost shock, which represents variations of costs involved in changing investment spending, such as financial intermediation costs. Further, we find that the estimated series of investment adjustment cost shock correlates strongly with the diffusion index of firms' financial position in the *Tankan*. We thus argue that the large decline in investment growth in the early 1990s is due to an increase in investment adjustment costs reflecting firms' tight financial constraint after the collapse of Japan's asset price bubble. This view may be in stark contrast with that of Hayashi and Prescott (2002), who indicate that firms were not constrained from financing investment at that time, but it is in line with the credit crunch hypothesis, which suggests that the tight financial condition constrained investment and hence depressed output.

In our model, the financial mechanism generating the estimated investment adjustment cost shock is a black box. To make it clear, we need to introduce financial market imperfection into the model along the lines of Bernanke *et al.* (1999) and Carlstrom and Fuerst (1997). Specifically, financial intermediation needs to be explicitly incorporated (e.g., Christiano *et al.*, 2010; Gilchrist *et al.*, 2009; Meh and Moran, 2010; Hirakata *et al.*, 2010; Kaihatsu and Kurozumi, 2010). Such an extension allows us to structurally understand the relationship between financial intermediation costs and investment fluctuations. We leave this issue for future research.

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Table 1: Prior and posterior distributions of parameters.

	Prior distribution			Posterior distribution			
				Baseline		Extended sample	
Parameter	Distribution	Mean	S.D.	Mean	90% interval	Mean	90% interval
σ	Gamma	1.000	0.375	1.522	[0.956, 2.083]	1.547	[1.045, 2.057]
θ	Beta	0.700	0.150	0.444	[0.295, 0.592]	0.508	[0.408, 0.601]
χ	Gamma	2.000	0.750	4.415	[2.718, 5.971]	5.489	[3.909, 6.994]
$1/\zeta$	Gamma	4.000	1.500	7.118	[4.052, 10.240]	9.949	[6.433, 13.363]
μ	Gamma	1.000	1.000	2.078	[0.950, 3.163]	4.411	[2.467, 6.283]
ϕ/y	Gamma	0.075	0.013	0.091	[0.066, 0.115]	0.112	[0.083, 0.139]
γ_w	Beta	0.500	0.250	0.324	[0.018, 0.607]	0.159	[0.002, 0.313]
ξ_w	Beta	0.375	0.100	0.522	[0.422, 0.627]	0.567	[0.480, 0.650]
γ_p	Beta	0.500	0.250	0.631	[0.371, 0.941]	0.310	[0.069, 0.547]
ξ_p	Beta	0.375	0.100	0.655	[0.596, 0.718]	0.715	[0.647, 0.780]
ϕ_r	Beta	0.800	0.100	0.654	[0.560, 0.749]	0.794	[0.746, 0.843]
ϕ_π	Gamma	1.700	0.100	1.683	[1.544, 1.821]	1.694	[1.547, 1.839]
ϕ_y	Gamma	0.125	0.050	0.079	[0.050, 0.104]	0.065	[0.044, 0.088]
$\overline{z^*}$	Gamma	0.370	0.200	0.388	[0.176, 0.586]	0.165	[0.000, 0.304]
$\overline{\psi}$	Gamma	0.460	0.200	0.558	[0.336, 0.766]	0.486	[0.285, 0.669]
ρ_b	Beta	0.500	0.200	0.740	[0.555, 0.922]	0.910	[0.833, 0.977]
ρ_i	Beta	0.500	0.200	0.540	[0.401, 0.685]	0.461	[0.351, 0.577]
ρ_g	Beta	0.500	0.200	0.868	[0.738, 0.987]	0.945	[0.899, 0.993]
ρ_w	Beta	0.500	0.200	0.218	[0.039, 0.388]	0.124	[0.020, 0.222]
ρ_p	Beta	0.500	0.200	0.974	[0.954, 0.995]	0.933	[0.877, 0.986]
ρ_r	Beta	0.500	0.200	0.490	[0.335, 0.647]	0.320	[0.182, 0.456]
ρ_ν	Beta	0.500	0.200	0.985	[0.972, 0.997]	0.993	[0.988, 0.999]
ρ_z	Beta	0.500	0.200	0.067	[0.012, 0.120]	0.032	[0.004, 0.060]
ρ_ψ	Beta	0.500	0.200	0.079	[0.010, 0.142]	0.097	[0.016, 0.170]
σ_b	Inv. gamma	0.500	Inf	3.139	[2.068, 4.164]	4.996	[3.249, 6.780]
σ_i	Inv. gamma	0.500	Inf	4.777	[3.725, 5.723]	4.147	[3.568, 4.717]
σ_g	Inv. gamma	0.500	Inf	0.445	[0.381, 0.506]	0.454	[0.403, 0.506]
σ_w	Inv. gamma	0.500	Inf	0.531	[0.425, 0.645]	0.477	[0.406, 0.546]
σ_p	Inv. gamma	0.500	Inf	0.199	[0.124, 0.273]	0.152	[0.100, 0.207]
σ_r	Inv. gamma	0.500	Inf	0.129	[0.110, 0.147]	0.098	[0.087, 0.109]
σ_ν	Inv. gamma	0.500	Inf	1.307	[1.118, 1.486]	1.380	[1.209, 1.546]
σ_z	Inv. gamma	0.500	Inf	1.557	[1.324, 1.777]	1.632	[1.440, 1.830]
σ_ψ	Inv. gamma	0.500	Inf	1.358	[1.166, 1.548]	1.375	[1.216, 1.533]

Notes: The table summarizes the prior and posterior distributions of the parameters. The prior mean for $\overline{z^*}$ and $\overline{\psi}$ in the extended sample is 0.19 and 0.37, respectively.

Table 2: Variance decompositions

Forecast horizon	$T = 8$	$T = 32$	$T = \infty$	$T = 8$	$T = 32$	$T = \infty$
	Output growth			Investment growth		
z_t^b	11.9	11.8	11.8	0.6	0.7	0.7
z_t^i	12.8	13.1	13.1	82.8	82.9	82.7
z_t^g	6.6	6.6	6.6	0.1	0.1	0.1
z_t^w	0.5	0.5	0.5	0.2	0.3	0.3
z_t^p	5.0	5.0	5.1	3.9	3.9	4.0
z_t^r	0.5	0.5	0.5	0.1	0.1	0.1
z_t^ν	1.7	1.7	1.8	3.7	3.7	3.8
z_t^z	56.7	56.3	56.2	4.2	4.0	4.0
z_t^ψ	4.5	4.6	4.6	4.5	4.4	4.4
	Consumption growth			Inflation		
z_t^b	40.4	40.3	40.1	9.5	6.4	4.2
z_t^i	0.6	0.8	0.9	1.9	10.1	7.6
z_t^g	0.9	0.9	0.9	0.9	0.9	0.7
z_t^w	0.9	0.9	0.9	8.6	4.9	3.2
z_t^p	8.2	8.2	8.2	49.7	41.0	36.0
z_t^r	1.1	1.1	1.1	3.3	1.9	1.2
z_t^ν	1.3	1.4	1.5	5.0	13.1	32.5
z_t^z	43.6	43.2	43.1	12.5	9.3	6.1
z_t^ψ	3.0	3.2	3.2	8.6	12.5	8.6

Notes: The table shows the posterior mode estimates of forecast error variance decompositions of the output growth rate, the investment growth rate, the consumption growth rate, and the inflation rate for each forecast horizon. The infinite horizon decompositions are computed by solving a dynamic Lyapunov equation for the system of log-linearized equilibrium conditions.

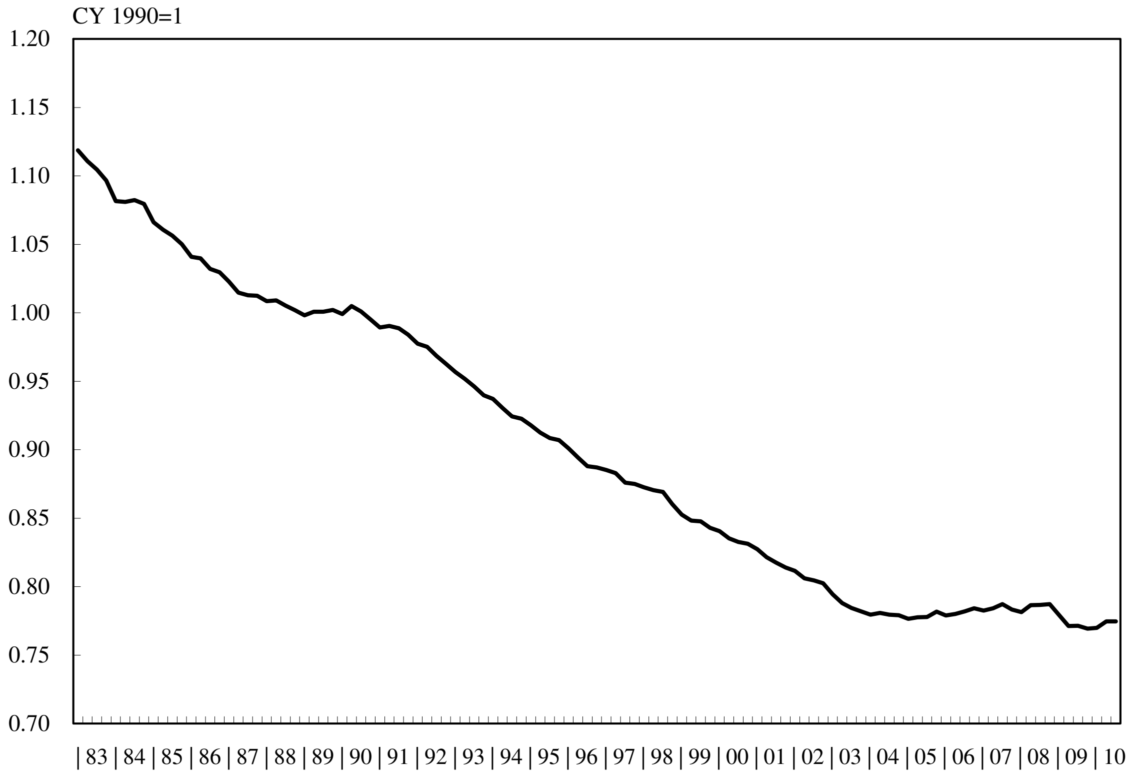

Figure 1: Relative price of investment goods in Japan

Note: The figure shows the relative price of investment goods in terms of the investment deflator divided by the consumer price index.

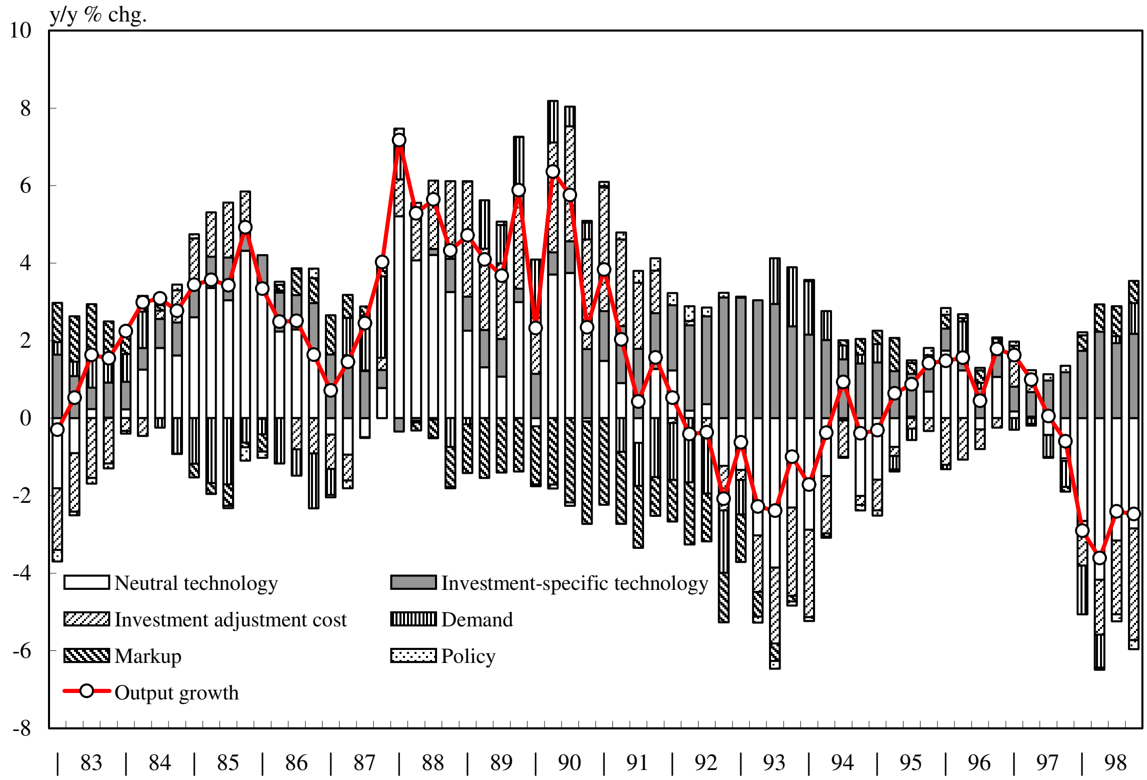

Figure 2: Historical decomposition of output growth

Notes: The figure shows the historical decomposition of the output growth rate evaluated at the posterior mean parameters. The markup shocks include z_t^w, z_t^p and z_t^ν, and the demand shocks include z_t^b and z_t^g.

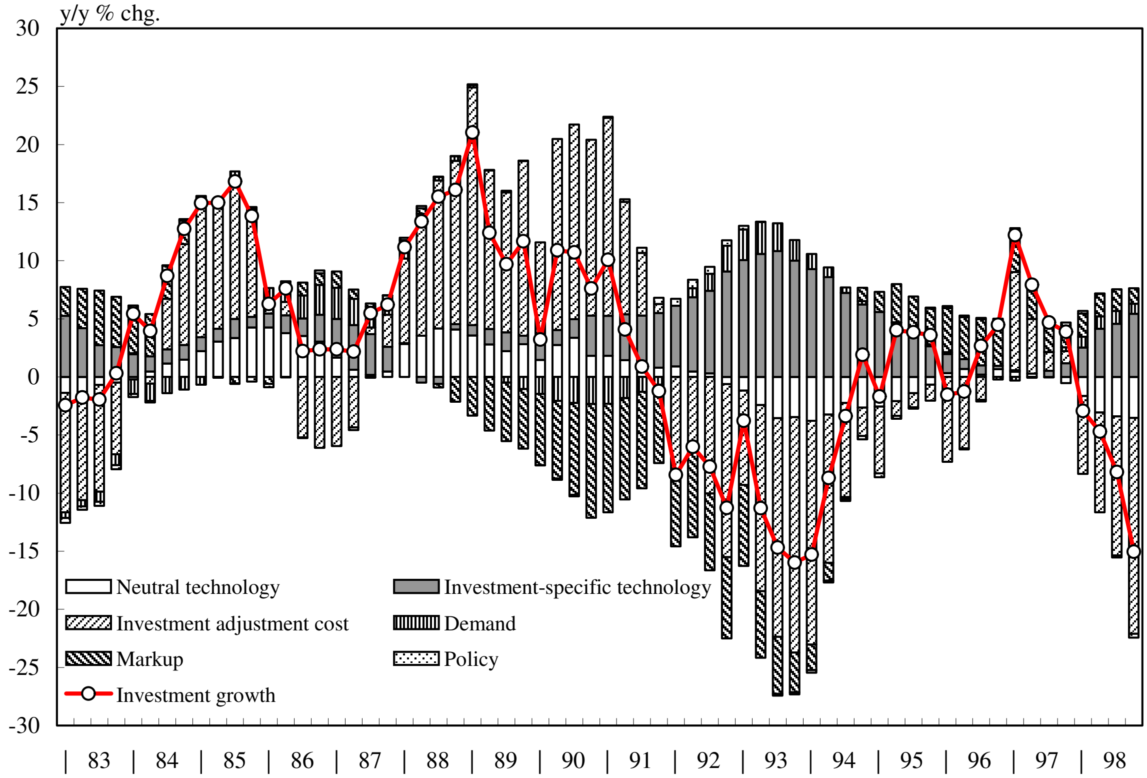

Figure 3: Historical decomposition of investment growth

Notes: The figure shows the historical decomposition of the investment growth rate evaluated at the posterior mean parameters. The markup shocks include z_t^w, z_t^p and z_t^ν, and the demand shocks include z_t^b and z_t^g.

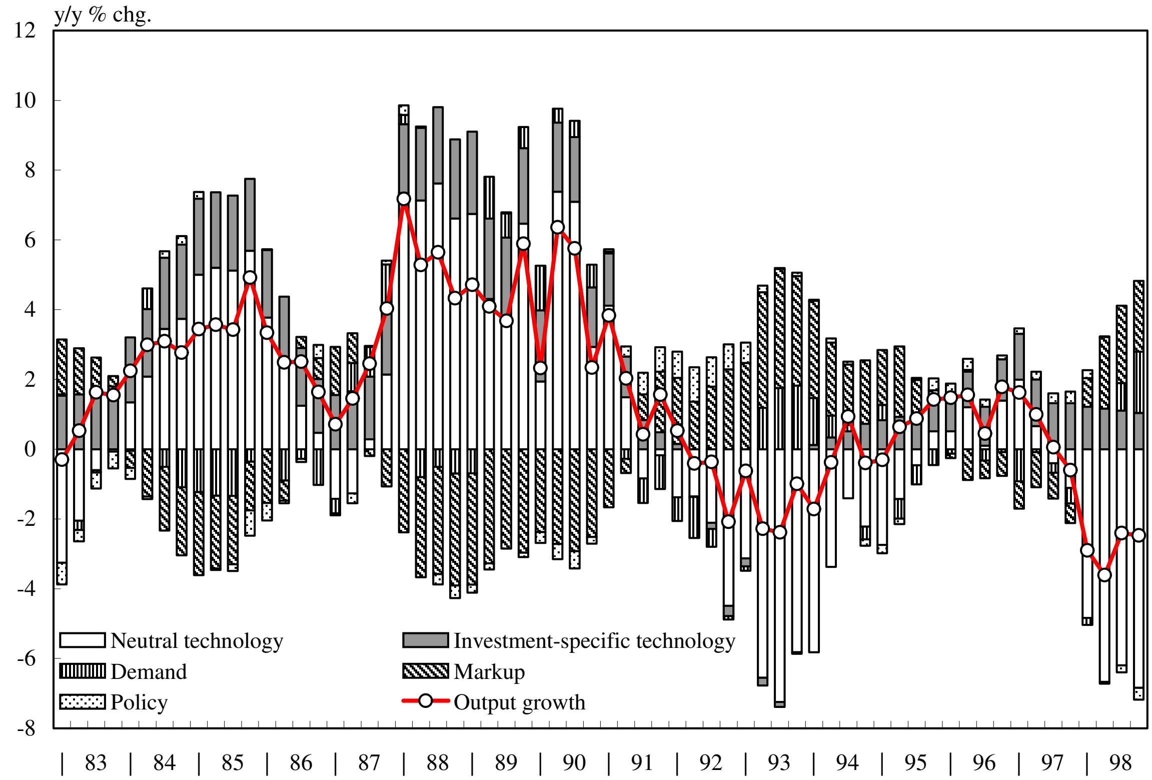

Figure 4: Historical decomposition of output growth: the model without investment adjustment cost shocks

Notes: The figure shows the historical decomposition of the output growth rate evaluated at the posterior mean parameters in the estimated model without investment adjustment cost shocks. The markup shocks include z_t^w, z_t^p and z_t^ν, and the demand shocks include z_t^b and z_t^g.

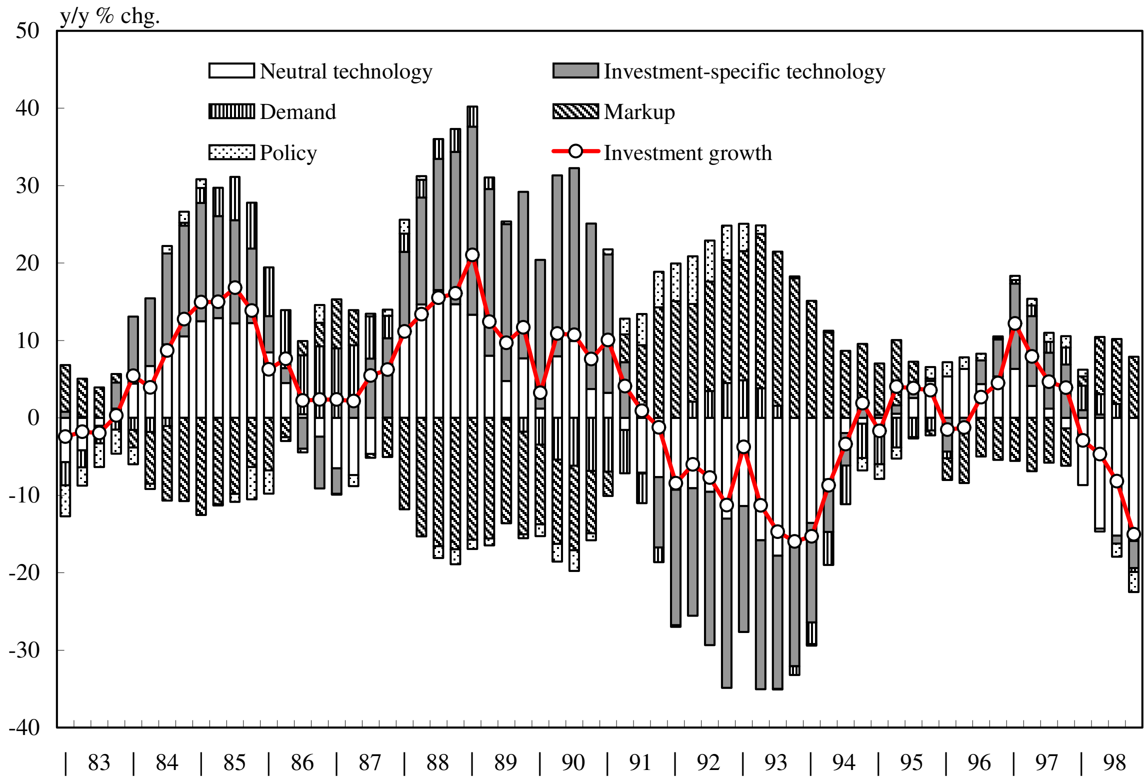

Figure 5: Historical decomposition of investment growth: the model without investment adjustment cost shocks

Notes: The figure shows the historical decomposition of the investment growth rate evaluated at the posterior mean parameters in the estimated model without investment adjustment cost shocks. The markup shocks include z_t^w, z_t^p and z_t^ν, and the demand shocks include z_t^b and z_t^g.

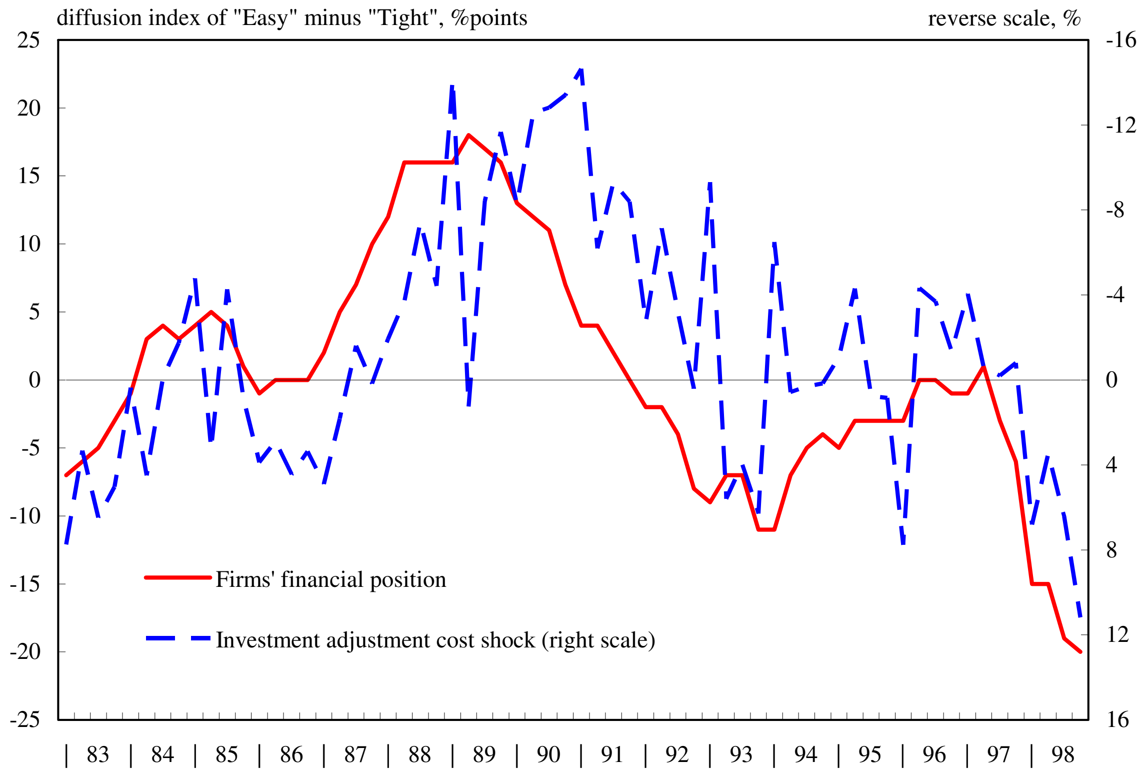

Figure 6: Investment adjustment cost shock and firms' financial position

Note: The figure compares the diffusion index of firms' financial position in the *Tankan*, Short-term Economic Survey of Enterprises in Japan, and the smoothed estimates of the investment adjustment cost shock z_t^i evaluated at the posterior mean.

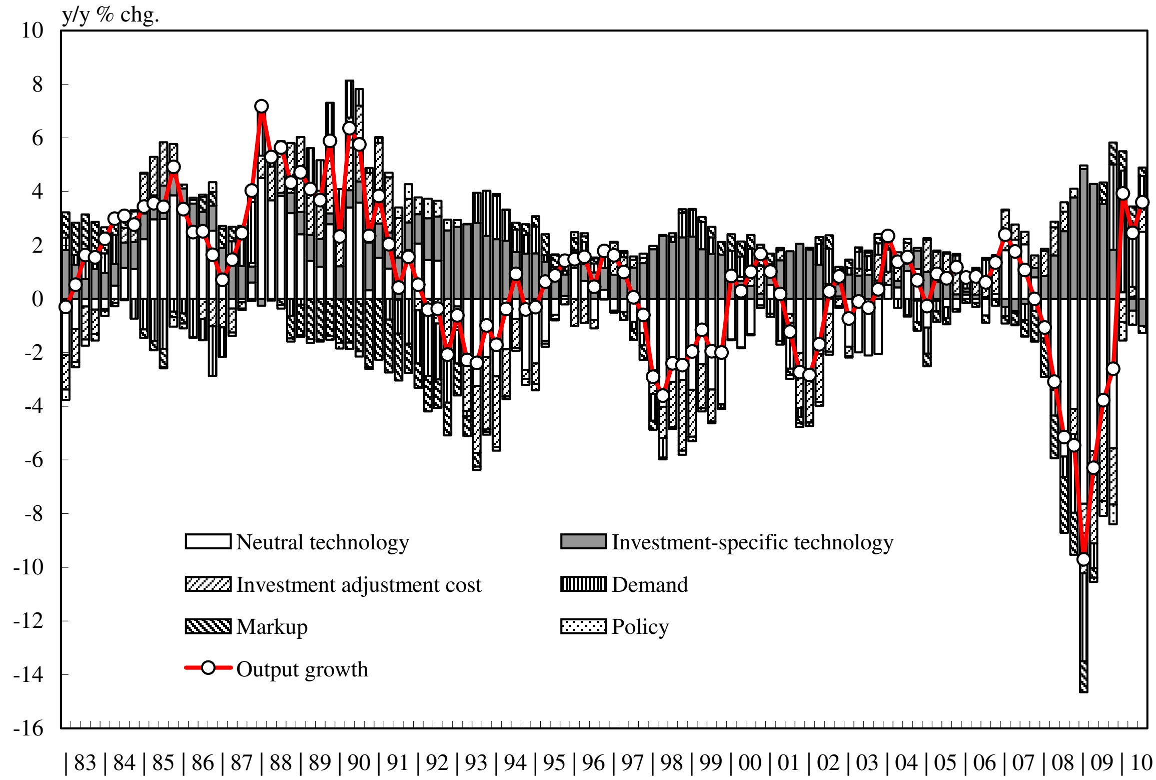

Figure 7: Historical decomposition of output growth: the extended sample

Notes: The figure shows the historical decomposition of the output growth rate evaluated at the posterior mean parameters in the model estimated in the extended sample. The markup shocks include z_t^w, z_t^p and z_t^ν, and the demand shocks include z_t^b and z_t^g.

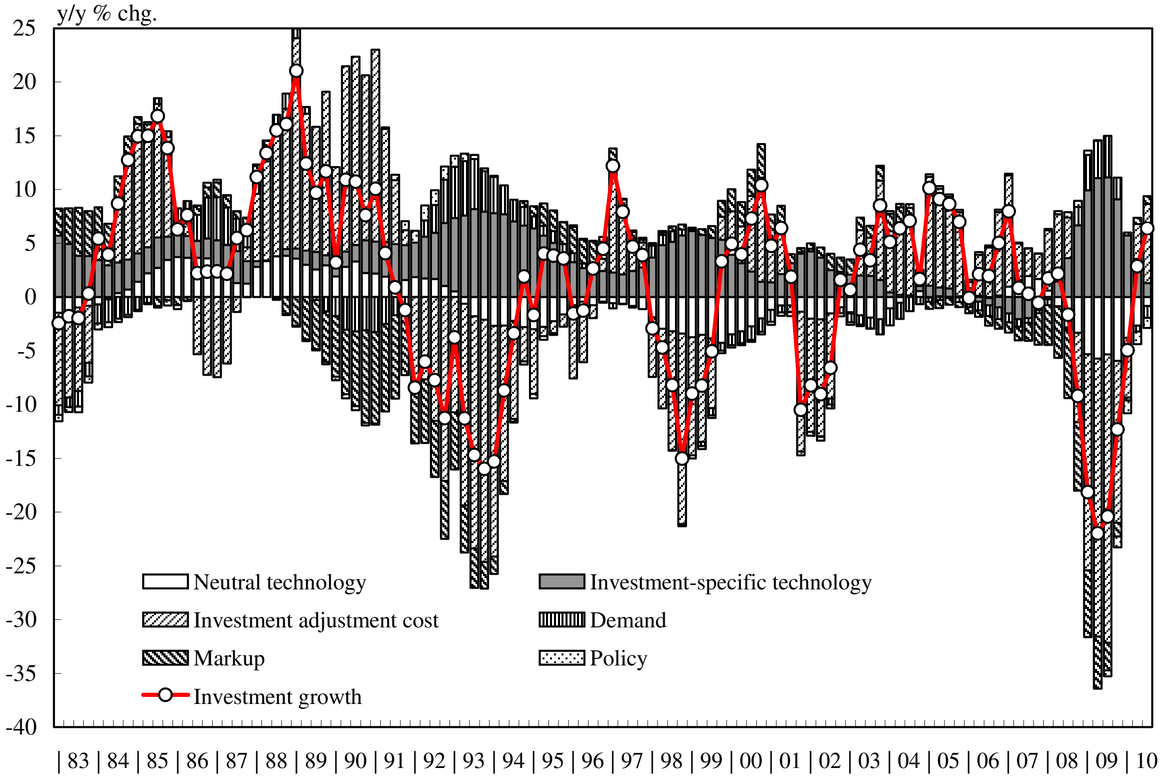

Figure 8: Historical decomposition of investment growth: the extended sample

Notes: The figure shows the historical decomposition of the investment growth rate evaluated at the posterior mean parameters in the model estimated in the extended sample. The markup shocks include z_t^w, z_t^p and z_t^ν, and the demand shocks include z_t^b and z_t^g.

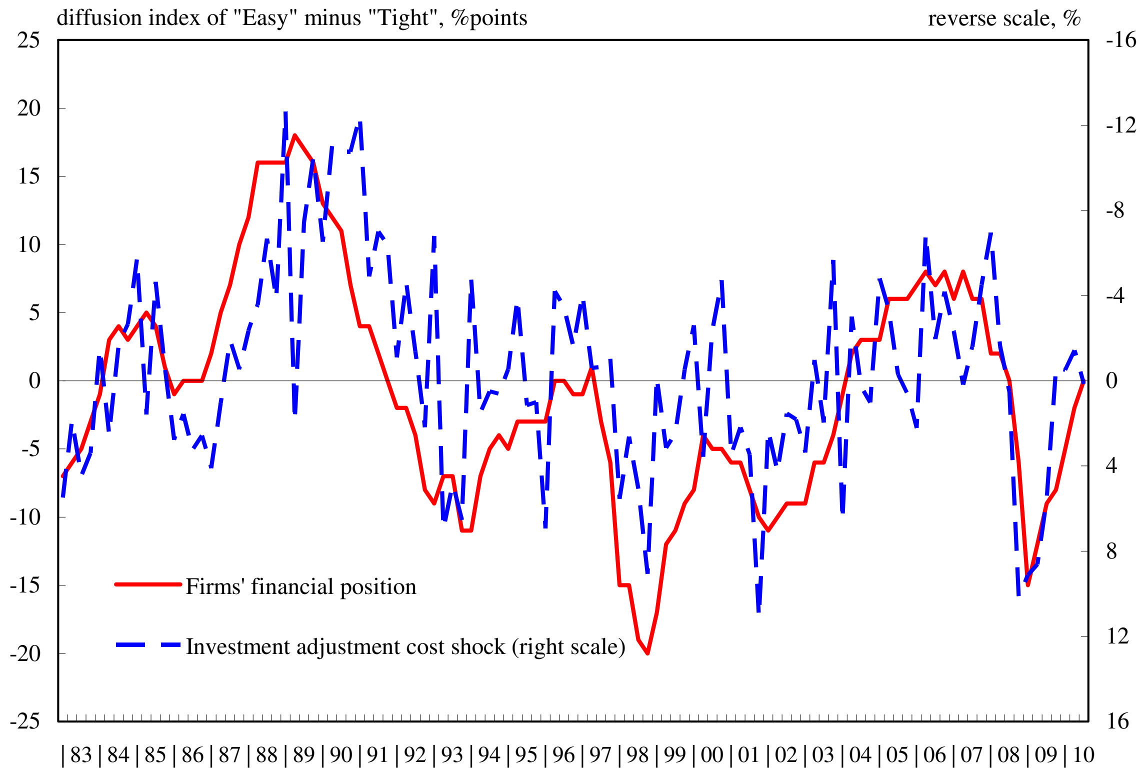

Figure 9: Investment adjustment cost shock and firms' financial position: the extended sample

Note: The figure compares the diffusion index of firms' financial position in the *Tankan*, Short-term Economic Survey of Enterprises in Japan, and the smoothed estimates of the investment adjustment cost shock z_t^i evaluated at the posterior mean in the model estimated in the extended sample.