Estimating a DSGE Model for Japan: Evaluating and Modifying a CEE/SW/LOWW Model*

Tomohiro Sugo† and Kozo Ueda‡

November 13, 2006

Abstract

We estimate a middle-scale DSGE model of the Japanese economy following Christiano, Eichenbaum and Evans (2005), Smets and Wouters (2003) and Levin et al. (2005). By using actual capital utilization data and modifying the formalization of utilization following Greenwood et al. (1988), this paper succeeds in incorporating a negative correlation between capital utilization and rental costs to explain actual capital utilization rates. We find that Japanese business cycles are driven largely by an investment adjustment cost shock in the short run while a productivity shock is a dominant driving force in the long run. We also find a hump-shaped and persistent behavior of inflation rates in response to a monetary policy shock, which CEE doubt about.

JEL Classification: E22, E32, E52
Keywords: DSGE model, monetary policy, capital utilization, Japan

1 Introduction

This paper constructs a middle-scale dynamic stochastic general equilibrium (hereafter DSGE) model, and estimates it with Japanese data. Our analysis can provide a useful benchmark for central bankers to conduct monetary policy. The reason is threefold. Firstly, as an advantage of DSGE models over unstructured models (e.g. VAR or old-Keynesian), we can correctly evaluate the effect of policy changes on the economy. A policy change alters people's behavior, but since unstructured models are built on one regime, they cannot assess the effect of the policy change (Lucas critique). In contrast, DSGE models are based on micro-foundations, and depict people's rational and forward-looking behavior with deep parameters which are not affected by policy changes. Therefore, DSGE models can avoid the Lucas critique, and enable us to correctly evaluate the effect of monetary policy changes on the economy.

Secondly, our model is middle-scale. One kind of DSGE models which have been widely used for monetary policy analysis is very small one. It consists only of three equations, namely, an IS curve, a Phillips curve, and a monetary policy reaction function. It thus neglects some important

*We would like to thank Toni Braun, Ippei Fujiwara, Michel Juillard, Koichiro Kamada, Hideo Hayakawa, Takuji Kawamoto, Andrew Levin, Kenji Nishizaki, Hiroshi Ugai, Toshiaki Watanabe, John Williams, Noah Williams, Raf Wouters, and Tomoo Yoshida. The views expressed here are those of the authors and do not reflect those of the Bank of Japan.

†Monetary Affairs Department, Bank of Japan (E-mail: tomohiro.sugou@boj.or.jp)

‡Corresponding author. Monetary Affairs Department, Bank of Japan (E-mail: kouzou.ueda@boj.or.jp)

factors, such as capital stocks and staggered wages, which must have a great influence on the macroeconomy. Such a small-scaled model seems to be too simplified to describe the actual economy well. On the other hand, our middle-scale model can incorporate the above factors while keeping micro-foundations. Its theoretical foundation is largely based on a seminal paper by Christiano, Eichenbaum and Evans (2005) (hereafter CEE), who take account of not only typical three equations, but also staggered wages and price setting with partial indexation, the adjustment costs of capital investment, habit formation in consumption, variable capital utilization, and smoothed monetary policy. This improvement enables us to investigate the situation of the actual economy and the effect of monetary policy in more detail. In contrast to small DSGE models, there exist large-scale models, too (e.g. BOJ's JEM (Fujiwara et al. 2005), FRB/US model (Brayton and Tinsley 1996), BOE's BEQM (Harrison et al. 2005)). It is true that these models can incorporate more factors than ours, such as a difference between intermediate and final goods, but a drawback is that they tend to lack micro-foundations, which leads to the Lucas critique and to a difficulty for us to explain underlying mechanisms. Moreover, they are rather too big and too complex, so it is not easy for us to cope with the models.

Thirdly, we estimate deep parameters in our model. Almost all of the large-scale DSGE models rely on calibrated parameters. If the parameters are not correctly assessed, the subsequent analyses provide wrong implications. In contrast, thanks to estimation, we can more correctly analyze the effect of monetary policy. Furthermore, we can examine the characteristics of the Japanese economy, such as the value of deep parameters and the driving forces of business cycles.

To estimate the middle-scale DSGE model, we employ a Bayesian method. Smets and Wouters (2003) (hereafter SW) is the first attempt to estimate the middle-scale DSGE model with Bayesian techniques. They apply the model to the Euro economy, and argue that estimated parameters are more or less consistent with microeconometric findings and that their middle-scale DSGE model has almost as good power of explaining the actual economy as VAR. Their result was later confirmed by Onatski and Williams (2004) (hereafter OW). Levin, Onatski, Williams and Williams (2005) (hereafter LOWW) slightly modify their model and estimate it for the U.S. economy. In terms of the application to Japanese economy, Iiboshi, Nishiyama and Watanabe (2006) (hereafter INW) already exist prior to our paper. However, considering these above properties of the model, it looks extremely important for Japanese central bankers to understand the middle-scale DSGE models and to use them. This paper aims to construct and estimate the middle-scale DSGE model so that it can describe the Japanese economy well, and to provide a useful benchmark for central bankers to conduct monetary policy.

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When we build the middle-scale DSGE model, we make some modifications from CEE/SW/LOWW. Although these studies seem to succeed in explaining the actual economy very well, we find that there are still unresolved problems relating to capital utilization rates. In SW and others, this variable is treated as unobservable, and inferred with the Kalman filter. Figure 1 shows the inferred movement of capital utilization rates. However, there exists a statistics of capital utilization rates although it is limited only to manufacturing firms in Japan. We find that the two utilization rates are very different in terms of their movements and their amplitude.

Since we have the data of capital utilization rates, it is quite natural to estimate the model by using this. This, in turn, generates another problem. The CEE/SW/LOWW model requires that capital utilization rates should be positively correlated with capital rental costs. As is

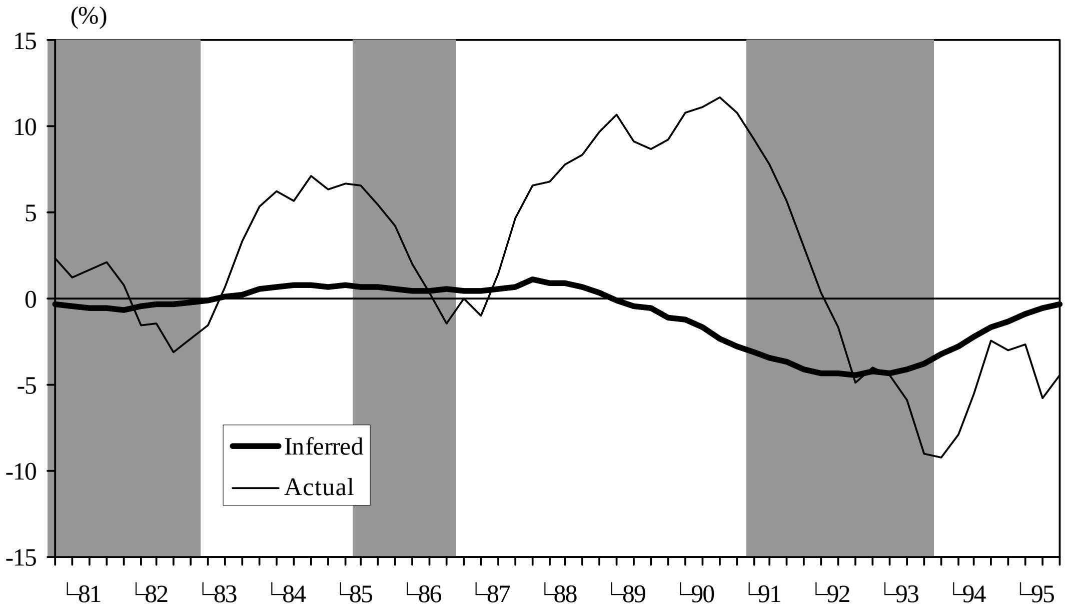

Figure 1: Actual and inferred capital utilization rates. Shaded areas represent recessions.

shown in Figure 2, however, we find that these two variables are negatively correlated. The logic runs as follows. High capital utilization reduces the marginal product of effective capital (including capital utilization), which in turn, lowers capital rental costs, but the CEE model cannot explain this fact. Therefore, we need to modify the model to incorporate the negative correlation between capital utilization and rental rates of capital.

To modify the model of capital utilization, we follow Greenwood et al. (1988). We assume that the adjustment costs of capital utilization are not additional expenditure on goods but accelerating the depreciation speed of capital. This assumption makes utilization rates depend not only upon rental costs positively but also upon the value of capital negatively. By applying this assumption to our highly persistent DSGE model, we succeed in incorporating the negative correlation between rental costs and utilization rates.

The rest of the paper is organized as follows. Section 2 presents the benchmark model following CEE/SW/LOWW. In Section 3, we present estimation results: estimated parameters and the movement of capital utilization rates. We also investigate the business cycles in Japan. Section 4 compares our model with those of CEE/SW/LOWW from the viewpoint of the effect of monetary policy shocks. Section 5 concludes the paper.

2 Model

This section introduces a DSGE model for our estimation. This model largely follows those of CEE/SW/LOWW. In addition to sound micro-foundations, it incorporates several distinct features in order to match the actual economy, in particular, staggered wage and price setting with partial indexation, the adjustment costs of capital investment, habit formation in consumption, variable capital utilization, and smoothed monetary policy.

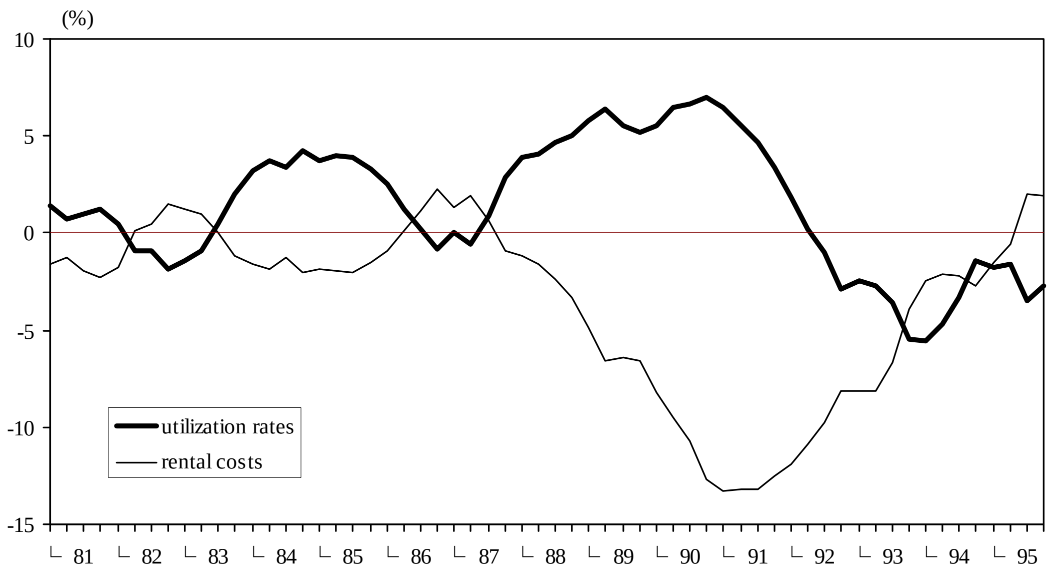

Figure 2: Utilization rates and rental costs

2.1 Model Setup

Household Preferences A household h maximizes the presented value of one's present and future utility:

$$\Xi_t(h) = E_t \sum_{j=0}^{\infty} \beta_{t+j}^j V_{t+j}(h), \tag{2.1}$$

where a subjective discount factor is given by $\beta_{t+j}^j = \prod_{s=0}^j \beta_{t+s}$, and $\beta_t = \beta Z_t^b$. A stochastic variation in preference is represented by Z_t^b whose mean is one. Furthermore, we assume that the logarithm of this disturbance obeys an AR(1) process. The utility function V_t is separable between consumption and leisure as

$$V_t = \frac{(C_t(h) - \theta C_{t-1}(h))^{1-\sigma}}{1-\sigma} - \frac{Z_t^L (L_t(h))^{1+\chi}}{1+\chi}, \tag{2.2}$$

where the first term represents consumption habit, which yields more persistence in the economy[1]. The parameters σ, θ, and χ respectively denote the inverse of the intertemporal elasticity of substitution of consumption, the magnitude of habit ($0 \leq \theta < 1$), and the inverse of the elasticity of hours worked with respect to real wages. $C_t(h)$ and $L_t(h)$ represent aggregated consumption and labor supply. Z_t^L is a stochastic variation in labor supply disutility, which follows an AR(1) process.

The household h's budget constraint is given by

$$\begin{aligned} & \frac{B_{t-1}(h)}{P_t} + W_t(h)L_t(h) + R_t^k U_t(h) K_{t-1}(h) + \Pi_t(h) \\ \geq \;& C_t(h) + I_t(h) + b_t \frac{B_t(h)}{P_t}. \end{aligned} \tag{2.3}$$

[1]Following LOWW, we assume "internal habit persistence," in which the lagged value of individual consumption serves as the reference value for each individual household.

The left and right hand side of the equation shows the household h's income and expenditure, respectively. The variable $B_t(h)$ denotes h's bond holdings, and b_t is their present-valued price. P_t and $W_t(h)$ respectively stand for aggregate price index and the real wage which the household h receives. R_t^k is the return on capital and $U_t(h)$ is a capital utilization rate. $\Pi_t(h)$ denotes the transfer of firms' profits to the household h. $K_t(h)$ and $I_t(h)$ denote the household h's capital stock and capital investment.

Capital Utilization and Accumulation While CEE/SW/LOWW assume that the adjustment costs of capital utilization are used for additional goods spending[2], our paper follows Greenwood et al. (1988) and assumes that high capital utilization leads to faster depreciation of capital. In particular, we assume that capital depreciation rates depend on capital utilization rates:

$$\delta(U_t(h)) = \delta\Psi(Z_t^U U_t(h)). \tag{2.4}$$

A higher capital utilization rate leads to higher depreciation of capital:

$$\Psi(X) = 1 + \mu\frac{X^{1+\psi^{-1}} - 1}{1 + \psi^{-1}}. \tag{2.5}$$

The parameter ψ is the inverse of the elasticity of capital utilization costs[3]. Z_t^U is a stochastic variation in the adjustment costs of capital utilization, which follows an AR(1) process[4]. In a steady state, a utilization rate is one, which implies that a capital depreciation rate is equal to δ.

Capital is used for producing goods, and cannot be accumulated or disposed instantaneously because of adjustment costs. Capital $K_t(h)$ evolves as

$$K_t(h) = \{1 - \delta(U_t(h))\}K_{t-1}(h) + \left\{1 - \zeta^{-1}\left(\frac{Z_t^I I_t(h)}{I_{t-1}(h)} - 1\right)^2\right\} I_t(h). \tag{2.6}$$

Z_t^I is a stochastic variation in the adjustment costs of investment, which follows an AR(1) process. $1/\zeta$ represents the magnitude of investment adjustment costs.

Production and Prices

Final Goods Sector A final goods sector is perfectly competitive. The final good Y is produced by bundling the differentiated intermediate goods $Y(j)$ as

$$Y_t = \left[\int_0^1 (Y_t(j))^{\frac{1}{1+\lambda_{p,t}}} dj\right]^{1+\lambda_{p,t}}. \tag{2.7}$$

We assume that price markup $\lambda_{p,t}$ has an i.i.d. disturbance. This equation implies that the aggregate price index is given by

$$P_t = \left[\int_0^1 (P_t(j))^{-\frac{1}{\lambda_{p,t}}} dj\right]^{-\lambda_{p,t}}. \tag{2.8}$$

[2] See Appendix A.2.

[3] We share the same functional form, $\Psi(X)$ as SW and LOWW, but the meaning of the parameter ψ differs.

[4] Unlike SW and LOWW, we use the actual data of capital utilization rates for estimation. To this end, we introduce an adjustment cost shock of capital utilization. In common with other shocks, this shock comes from a structure of the model.

Intermediate Goods Producers Intermediate goods are differentiated, and their producers face monopolistic competition. Production technology exhibits an increasing return to scale because of fixed costs Φ :

$$Y_t(j) = A_t(\widetilde{K_t}(j))^{\alpha} L_t(j)^{1-\alpha} - \Phi. \tag{2.9}$$

Productivity is given by $A_t = Z_t^A A$, where Z_t^A obeys an AR(1) process. $\widetilde{K_t}$ denotes an effective capital stock embedding capital utilization, and a parameter α is a capital share.

We assume that there is Calvo-type price stickiness. All the producers cannot optimize their prices at every period, and the probability that they cannot reset their prices is ξ_p ($0 < \xi_p < 1$). The average duration that prices are not optimized for thus becomes $1/(1-\xi_p)$. We also assume that even the firms which cannot revise their prices optimally can change their prices to some degree by means of indexation to the past inflation rate. The degree is given by a parameter γ_p ($0 \leq \gamma_p < 1$). This assumption yields the persistence of an inflation rate as well as of a price level.

The firms' cost-minimization condition is given by

$$\frac{W_t L_t}{R_t^k U_t K_{t-1}} = \frac{1-\alpha}{\alpha}. \tag{2.10}$$

Labor Supply and Wages In a similar way to price stickiness, this paper models wage stickiness. We assume that households supply their differentiated labor in a monopolistic competitive manner as in Erceg, Henderson, and Levin (2000). We define the elasticity of substitution between different types of labor as $\lambda_{w,t}$, which has the disturbance of i.i.d. A household h can optimize one's wage with a constant probability $1 - \xi_w$ ($0 < \xi_w < 1$), and even the households who cannot reset their wages optimally can adjust their wages by indexing them to the past inflation rate. The degree is given by γ_w ($0 \leq \gamma_w < 1$).

Market Clearing Condition A goods market is cleared as

$$Y_t = C_t + G_t + I_t, \tag{2.11}$$

where G_t stands for external demand such as government expenditure. Its variation in logarithm follows an AR(1) process.

Monetary Policy Rule In a monetary policy rule, a short-term nominal interest rate depends not only on the past inflation rate and output gap but also on their changes. Furthermore, it has a smoothing effect in that a lagged nominal interest rate also affects the current nominal interest rate. Denoting *nominal* interest rates as r_t, we write the monetary policy rule as

$$\begin{aligned} r_t \;\; = \;\; & r_i r_{t-1} + (1-r_i)\overline{\pi}_t + r_\pi(\pi_{t-1} - \overline{\pi}_t) + r_y(y_{t-1} - y^*_{t-1}) \\ & + r_{\Delta\pi}(\pi_t - \pi_{t-1}) + r_{\Delta y}((y_t - y^*_t) - (y_{t-1} - y^*_{t-1})) + \eta^r_t. \end{aligned} \tag{2.12}$$

π_t, y_t, and y^*_t represent an inflation rate, output, and natural output[5], respectively[6]. $\overline{\pi}_t$ and η^r_t are monetary policy shocks, that is, target inflation rate and an interest rate shock, respectively.

[5] As will be discussed later, natural output is defined as the level of output that would prevail under flexible price and wages in the absence of the three "cost push" shocks, namely, price markup shock, wage markup shock, and external finance premium shock.

[6] This policy rule is slightly modified from SW and LOWW where not only $\overline{\pi}_t$ but also $\overline{\pi}_t + r_\pi(\pi_{t-1} - \overline{\pi}_t) + r_y(y_{t-1} - y^*_{t-1})$ is multiplied by $1 - r_i$. Our modification enables $r_i \geq 1$ as well as $r_i < 1$ to satisfy a Blanchard-Kahn condition for plausible parameter values of r_π and r_y.

We assume that, while the interest rate shock is i.i.d., the target inflation rate follows an AR(1) process.

2.2 Log-Linearized Model

2.2.1 Real Economy

From the above setup, we can derive a log-linearized form. We write logarithmic deviations from steady states with lower-case letters, except that r_t and π_t represent deviations in levels. As to persistent shocks Z_t^x, $x = \{a, b, g, i, l, u\}$, we denote their logarithmic deviations as ϵ_t^x. Temporary i.i.d. shocks are denoted as η_t^z, $z = \{p, q, r, w\}$ or v_t^x, $x = \{a, b, g, i, l, u\}$.

Households' consumption with habit is written as

$$\begin{aligned} c_t \quad = \quad & E_t \frac{1}{1+\theta+\beta\theta^2} \left\{ \theta c_{t-1} + (1+\beta\theta^2+\beta\theta) c_{t+1} - \beta\theta c_{t+2} \right. \\ & \left. - \frac{1-\theta}{\sigma} \left((1-\beta\theta)(r_t - \pi_{t+1}) - \epsilon_t^b + (1+\beta\theta)\epsilon_{t+1}^b - \beta\theta\epsilon_{t+2}^b \right) \right\}. \end{aligned} \tag{2.13}$$

The value of capital is written as

$$q_t = -(r_t - E_t\pi_{t+1}) + \frac{1}{1-\delta+\overline{R^k}} \left\{ (1-\delta) E_t q_{t+1} + \overline{R^k} E_t r_{t+1}^k \right\} + \eta_t^q. \tag{2.14}$$

$\overline{R^k}$ stands for the equilibrium real rate of return on capital. The present value of capital is equal to the present discounted value of capital and rental revenues at the next period deducted by the opportunity cost. η_t^q is something like an "external finance premium" shock, which represents a stochastic variation in the expected rate of return on physical capital.

Investment becomes[7]

$$i_t = \frac{1}{1+\beta} E_t \left(i_{t-1} + \beta i_{t+1} + \zeta q_t + \beta \epsilon_{t+1}^i - \epsilon_t^i \right). \tag{2.15}$$

Capital accumulation is given by

$$k_t = (1-\delta) k_{t-1} + \delta i_t - \overline{R^k}(u_t + \epsilon_t^u). \tag{2.16}$$

The higher capital utilization rate, the more capital is depreciated. Thus, capital is less accumulated.

Capital utilization is described as

$$u_t = \psi(r_t^k - q_t - \epsilon_t^u) - \epsilon_t^u. \tag{2.17}$$

A higher rental cost leads to high capital utilization because households can receive higher revenues by increasing capital utilization and by renting more effective capital to firms. On the other hand, a higher q discourages capital utilization. The intuition behind this is simple. A higher q makes the future capital more valuable, but high capital utilization accelerates the speed of capital depreciation. This, in turn, discourages capital utilization.

Labor demand is given by

$$l_t = -w_t + r_t^k + u_t + k_{t-1}. \tag{2.18}$$

[7] This equation corrects a slight error in LOWW regarding the investment adjustment cost shock.

A market clearing condition is

$$y_t = c_y c_t + g_y \epsilon_t^g + \delta k_y i_t, \tag{2.19}$$

where c_y and g_y represent the share of consumption and external demand relative to output.

A firm's production function is

$$y_t = \phi \left[\epsilon_t^a + \alpha(u_t + k_{t-1}) + (1-\alpha) l_t \right]. \tag{2.20}$$

Real wages are

$$\begin{aligned} w_t &= \frac{1}{1+\beta} E_t \left\{ \beta w_{t+1} + w_{t-1} + \beta \pi_{t+1} - (1+\beta\gamma_w)\pi_t + \gamma_w \pi_{t-1} \right. \\ & \quad - \frac{\lambda_w (1-\beta\xi_w)(1-\xi_w)}{(\lambda_w + (1+\lambda_w)\chi)\xi_w} \left(w_t - \chi l_t - \epsilon_t^l + \frac{\beta\theta}{1-\beta\theta}(\epsilon_t^b - \epsilon_{t+1}^b) - \eta_t^w \right. \\ & \quad \left. \left. - \frac{\sigma}{(1-\theta)(1-\beta\theta)} ((1+\beta\theta^2)c_t - \theta c_{t-1} - \beta\theta c_{t+1}) \right) \right\}, \end{aligned} \tag{2.21}$$

where η_t^w is a wage markup shock.

Inflation dynamics is

$$\begin{aligned} \pi_t &= \frac{1}{1+\beta\gamma_p} \left\{ \beta E_t \pi_{t+1} + \gamma_p \pi_{t-1} \right. \\ & \quad \left. + \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p} (w_t + \alpha(l_t - u_t - k_{t-1}) - \epsilon_t^a + \eta_t^p) \right\}, \end{aligned} \tag{2.22}$$

where η_t^p is a price markup shock.

A monetary policy rule is

$$\begin{aligned} r_t &= r_i r_{t-1} + (1-r_i)\overline{\pi}_t + r_\pi(\pi_{t-1} - \overline{\pi}_t) + r_y(y_{t-1} - y_{t-1}^*) \\ & \quad + r_{\Delta\pi}(\pi_t - \pi_{t-1}) + r_{\Delta y}((y_t - y_t^*) - (y_{t-1} - y_{t-1}^*)) + \eta_t^r. \end{aligned} \tag{2.23}$$

This model includes 11 persistent and temporary shocks. Persistent shocks are

$$\epsilon_t^x = \rho_x \epsilon_{t-1}^x + \nu_t^x \tag{2.24}$$

$$\overline{\pi}_t = \rho_\pi \overline{\pi}_{t-1} + \nu_t^\pi, \tag{2.25}$$

where $x = \{a, b, g, i, l, u\}$.

ν_t^x, η_t^p, η_t^q, η_t^r,and η_t^w are i.i.d. shocks with mean zero and variance σ_x^2, σ_p^2, σ_q^2, σ_r^2, and σ_w^2.

2.2.2 Frictionless Economy

We formalize a monetary policy rule which responds to an output gap as the deviation of actual output from natural output. In order to justify this formalization, we may need to answer the following two questions.

The first question is as to what is natural output. It is conventional to define natural output as the one in a frictionless economy. Following SW/LOWW, this paper further assumes that, in the frictionless economy, prices and wages are perfectly flexible, and that there are no cost push shocks, namely, the price markup shock η_t^p, the wage markup shock η_t^w, and the external finance premium shock η_t^q. Therefore, the allocation of the frictionless economy consists of ten equations and ten variables, $\{c_t^*, i_t^*, y_t^*, w_t^*, l_t^*, u_t^*, q_t^*, r_t^*, r_t^{k*}, k_t^*\}$, where the asterisk superscript denotes the frictionless economy value of the variable.

The next question is as to why central banks stabilize this output gap. Without nominal rigidity and the cost push shocks, an economy could immediately converge to a desirable level. However, their presence prevents automatic price adjustment by a market, which results in inefficient resource allocation. Therefore, from a social welfare perspective, the difference between actual and natural output, that is, an output gap, should not be large, and this is why central banks respond to the output gap. It is here worth noting that the frictionless economy is assumed to have real rigidity (such as habit formation) as well as real shocks (such as households' preference shock) because economic fluctuations caused by the real disturbances represent an economy's fundamental variations and do not yield inefficient resource allocation. Central banks thus should not try to control real disturbances.

Note that this output gap is very different from the widely-used gap which is defined as the deviation of demand from supply capacity. It is the latter gap which many economists including central bankers pay great attention to, so it may be better for us to use the latter gap in order to match reality. This paper, however, will not do this in order to focus on central banks' normative point of view.

The full model consists of Eq. (2.13)-(2.25) and equations that describe the log-linearized equations for the frictionless-economy allocation.

3 Model Estimation

3.1 Preliminary Setting

When we estimate the Japanese economy, we fix a certain parameters following Fujiwara et al. (2005) who calibrate the model to match the data. As for the parameters that are not given by Fujiwara et al. (2005), we follow LOWW. We set a capital share $\alpha = 0.37$, a discount rate $\beta = 0.995$, a steady-state capital depreciation rate $\delta = 0.06$, the output share of consumption $c_y = 0.6$, the output share of government expenditure $g_y = 0.2$, price and wage markup $\lambda_p = \lambda_w = 0.2$, and the real rate of return on capital $\overline{R^k} = 1/\beta - (1 - \delta)$.

We estimate the model using quarterly Japanese data over the period from 1981:1Q to 1995:4Q. The data set consists of eight variables: real GDP, real consumption, real investment, hours worked, real wages, capital utilization rates, inflation rates and overnight call rates. Appendix A.1 explains the detail of the data. A notable difference from a strand of previous literature is that we use the actual data of capital utilization rates. This is mainly because, as was shown in Figure 1, the utilization rates which are inferred in their methods are inconsistent with actual ones. Since we have relatively reliable actual data series of capital utilization rates, we explicitly treat this as an observable variable. However, to be fair, we must admit that available data are the utilization rates only of manufacturing firms.

All the variables are detrended or demeaned over the period from 1981:1Q to 2006:2Q, although we estimate the model over the period from 1981:1Q to 1995:4Q. This end period corresponds to when an overnight call rate fell to 0.5%. We choose this period because we suppose that, around then, people became aware of the zero lower bound on nominal interest rates. The start period is chosen because, since then, inflation rates have been stable and low. Although it is possible to include the data before 1980 for estimation, it is hard to know how different an implicit target inflation rate by the Bank of Japan from the current one, so we set the start period 1981:1Q, and regard the implicit target inflation rate as constant over

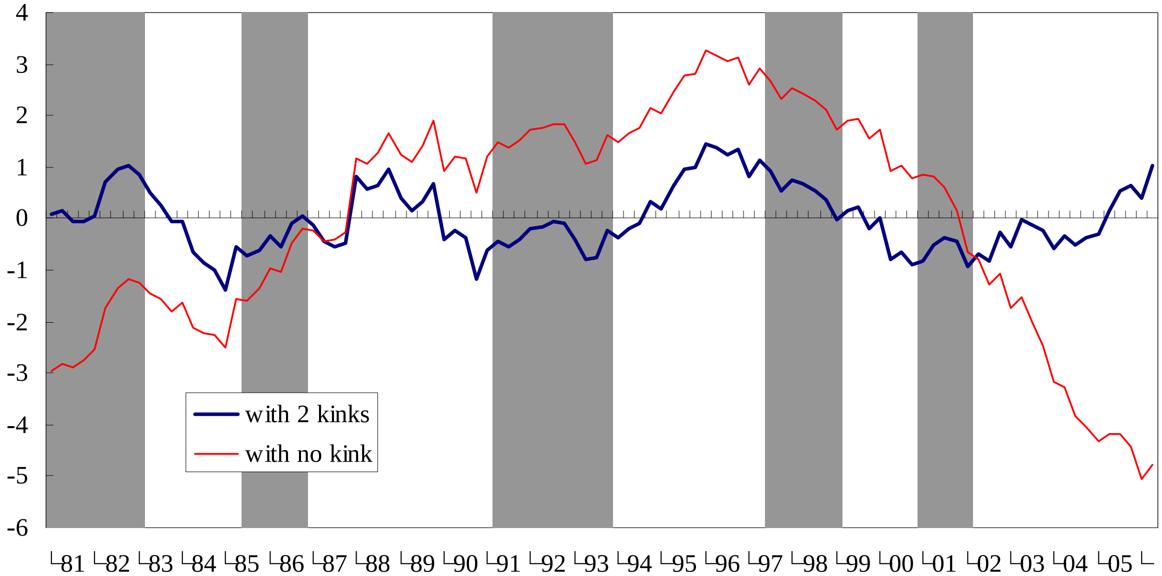

Figure 3: Real wage data detrended with and without kinks

estimation periods. This paper detrends four real variables, i.e. GDP, consumption, investment and real wages, with kinked linear trends. For all the other variables, this paper simply takes the demean of them[8,9]. The timings of trend breaks in real variables are assumed to be in 1991:2Q and 2001:1Q a priori[10]. An underlying idea behind this is that there were structural changes; the former corresponds to approximately when the asset price bubble burst and the economy suffered from long-lasting depression; and the latter corresponds to approximately when there was an significant shift from full-time employment to part-time[11]. We admit that our choice of these kinks are rather ad-hoc. It would be better for us to use a statistics test whether these structural changes will be rejected or not. Nevertheless, it is worth noting that, even if we assume only one kink in 1991:2Q, parameter estimates hardly change. For comparison, Figure 3 demonstrates real wage data that are detrended with and without kinks.

[8]In SW and LOWW, most of variables are lilnearly detrended with no kink. INW detrend data with Hodrick-Prescott filter.

[9]Another point of detrending is that we use independent different trends for the real variables. Although this method is widely accepted, there has been a criticism against an inconsistency with the balanced growth path of these variables. One possible remedy may be to introduce investment-specific technology (Greenwood, Hercowitz and Krussel (1997, 2000)). Doing so allows for a different trend with respect to investment and output. However, even such a remedy is not satisfactory enough, because this does not allow for other important trends such as a structural change in a labor share. For this reason, we simply detrend data with independent trends.

[10]Both of trend breaks are when the Japanese economy entered recessions as were officially determined.

[11]There are some evidences which suggest a structural change in a labor market around 2001. Kuroda and Yamamoto (2005) argue that the downward rigidity of wages disappeared from 1998 on. With the amendment of the Worker Dispatching Law in 1999 and 2004, dispatched workers were allowed to work in wider industries. Looking at the trends before and after the latter break, we see an increase in the slope of all the variables except for real wages. These changes imply that a reduction in wages induced an economic recovery, and that the economic recovery did not cause an increase in wages.

3.2 Methods

Our estimation methodology is similar to that of SW and LOWW[12,13]. We use Dynare which is a convenient tool to conduct Bayesian estimation. The Dynare toolbox derives the reduced-form representation of the DSGE model and automatically provides stability and eigenvalue analysis. In addition, it enables us to conduct a Bayesian estimation. The details of the prior distributions used in this paper are given in Table 2. For the choice of the prior distributions, we mostly follow the previous literature, SW and LOWW[14]. As to a utilization adjustment cost parameter ψ, because the model of capital utilization is different, we cannot use the same prior distribution. However, in both of the models, the effect of capital rental costs on utilization rates becomes the same ψ. We therefore use a little wider but not greatly different prior distribution for ψ with the mean of one and the standard deviation of one. For the persistence of capital utilization shock, ρ_u, we impose the same persistence as that of other shocks. For the standard deviation of capital utilization shock, σ_u, we choose the value from rough grid-search so that it maximizes the value of the likelihood function. Given the prior distributions, Dynare calculates the posterior distributions using a Metropolis-Hastings Markov chain Monte Carlo (MCMC) algorithm. We sample two separate chains for 500,000 periods each, discarding the first 250,000 periods. Using potential scale reduction statistics developed by Brooks and Gelman (1998), we confirm that convergence for all the parameters is achieved.

3.3 Results: Estimated Parameters

Figures 15 to 18 show the prior and posterior distribution of parameters, and Table 3 reports the posterior means and 90% intervals for the parameters. We would like to make comments on several important parameters[15].

Regarding inflation dynamics, the Calvo price-setting parameter ξ_p is 0.88, which implies that an average contract duration of price setting is about eight quarters. This duration is longer than that obtained in micro-based estimation (Bils and Klenow (2004), Dhyne et al. (2005), Saita et al. (2006))[16]. The Calvo wage-setting parameter ξ_w is 0.52, which suggests

[12] In estimating the model, we omit the shock η_t^q. This is because this shock is not derived from the structure of the model while other shocks are derived from the structure. We note that omitting the shock hardly changes our results demonstrated below.

[13] Following SW/LOWW, we normalize the stochastic shocks in the estimation procedure. This implies that in the case of the consumption preference, government spending, investment, and the two markup shocks, the estimated standard deviation does not correspond to the standard deviation of the corresponding shocks in Eq. (2.13) to (2.23).

[14] All the variances of the shocks are assumed to be distributed as an inverted Gamma distribution with a degree of freedom equal to one. For the parameter of fixed costs, we impose narrow prior distribution referring to Basu (1996), Basu and Fernald (1997) and LOWW.

[15] Although both are the estimation of the Japanese economy, we find some different estimated results from INW. The reasons are as follows. As is discussed above, INW do not use the actual data of capital utilization. The model of capital utilization is different from ours and the same as that of CEE/SW/LOWW. Second, the method of data detrend is also different. INW use Hodrick-Prescott (HP) filter for all the variables. However, using HP filter is subject to criticism because of arbitrariness and of the danger of underevaluating the cyclical movement (e.g. see McCallum (2000)). Furthermore, detrending both nominal interest rates and inflation rates are problematic because this implies that they continue to increase or decrease in the future. Thirdly, INW use GDP deflator instead of CPI as the data of inflation rates. Fourthly, they do not take account of the effect of *jitan*, a statutory decrease in hours worked in the late 1980's and the early 1990's. *Jitan* affects a structural path of hours worked and real wages, so it is important to carefully detrend these data. For these reasons, we must be careful in comparing our results with INW even though both are applied to the Japanese economy.

[16] It is widely known from before that macro-based estimation tends to report higher probability of not changing prices than micro-based estimation. This long duration may reflect the underlying specification of the real marginal

that the average contract duration is about two quarters. This wage flexibility looks a little too high considering that our wage data do not include bonus which is normally paid twice a year and that, as is known as *base-up* or *shunto*, salary is normally reviewed in April annually. Nevertheless, this result is consistent with Yoshikawa (1992), which argues that Japanese wages were far more flexible than Europe and the U.S.

As to other structural parameters, the parameter for intertemporal substitution of consumption, $1/\sigma$, is about 0.8. This value lies between 0.5 and 1, which is widely seen in estimation and calibration in macroeconomic models. The parameter for labor supply substitution, $1/\chi$, is about 0.5, which is close to those of SW and LOWW. The parameter for investment adjustment costs, $1/\zeta$, is about 6, which is larger than that of LOWW, 2, but very close to that of SW, 7. The parameter for habit persistence of consumption, θ, is about 0.1, which is very small compared to those in SW/LOWW/INW[17]. Finally, the parameter for capital utilization adjustment costs, ψ, is about 2. Since our model is different from those of SW/LOWW/INW in the setup of capital utilization, direct comparison might be misleading, but our value is lower than that of SW, higher than that of LOWW, and one order higher than that of INW[18].

Regarding monetary policy parameters, the coefficient on lagged interest rates in a monetary policy rule, r_i, is 0.84. This implies that monetary policy has a very high inertia[19]. Both of the coefficients on the output gap and on its change are positive and significant, and larger than those of SW and LOWW. The persistent parameter, ρ_π, is estimated as 0.97. This implies that the time for the target inflation to converge half the way to equilibrium is roughly six years.

3.4 Movement of Capital Utilization Rates

Figure 4 compares the movement of estimated utilization rates with that of actual ones. This figure looks much better than Figure 1 which is based on the CEE/SW/LOWW model. We find that our model well explains a sizable decline in utilization rates in the early 1990's and a recovery in 1994-5. As Eq. (2.17) suggests, our model does not require a strictly positive correlation between capital rental costs and utilization rates, which was the case in Figure 2. This helps to improve the goodness of fit. We admit, however, that the goodness of fit in the early 1980's is not so good. We will discuss possible reasons and remedies in our conclusion.

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costs. SW point out that while individual households' marginal costs of supplying labor are upward-sloping, the marginal cost curve in the intermediate goods sector is the same for all firms. For a given elasticity of prices to real marginal cost, this will tend to bias upward the estimate of Calvo price stickiness. Firm-specific investment, for example, may well help decrease the estimate of ξ_p (Woodford 2003). Another reason is related to an inflation indexation parameter γ_p estimated as high as $\gamma_p = 0.8$. Through indexation, firms can adjust their prices in a rather flexible manner although such price setting is not optimal. Furthermore, the micro-based estimation seem to evaluate a price revision frequency including such non-optimal indexation. The third reason is that this paper uses CPI. Final goods prices which correspond to CPI tend to be more sticky than intermediate and investment goods. Koga and Nishizaki (2005) compare the results by using GDP deflator with those by using CPI, and find higher price flexibility when they use GDP deflator.

[17] Such a discrepancy may be due to our and LOWW's assumption of "internal habit preference" as opposed to that of SW and INW's "external habit preference." In fact, the estimated value by LOWW is 0.3, which is the closest to ours.

[18] However, this value is far lower than that calibrated in CEE, that is, 100.

[19] A high inertia of monetary policy is observed in Japanese previous literature, too. For instance, Oda and Nagahata (2005) report 0.8, and INW report 0.7 although their specification is different from ours in the definition of output gaps, in sample periods, and in that they do not include the term of target inflation and a change of inflation and a change of an output gap.

Figure 4: Actual and estimated utilization rates. Shaded areas represent recessions.

3.5 Driving Force of Japanese Business Cycles

In this subsection we investigate the following question: What is the driving force of the Japanese business cycles?

Figure 5 depicts the impulse responses of endogenous variables to the productivity shocks until ten years after the shocks (The rest of the impulse responses will be shown later). A horizontal axis represents time in a quarterly scale, and a vertical axis represents percent-scale deviation from equilibrium[20]. The magnitude of each shock is estimated one standard error. Due to the parameter uncertainty which is evaluated from posterior distribution of parameters, impulse responses have a certain band. Lines in these figures demonstrate the responses by ten percentile.

When there is a positive productivity shock, hours worked and inflation rates decrease. The logic runs as follows: An increase in productivity requires less work to produce the same amount of goods, so hours worked decrease. The productivity shock also increases the marginal product of labor, and in turn, decreases the real marginal costs. Thus, inflation rates decrease. Such responses are very important in considering whether the productivity shock is the main driving force of economic fluctuations. If so, an economic expansion should see a decrease in hours worked and inflation rates. However, this is not observed in reality. Therefore, we might better to argue that economic fluctuations are affected mainly by other shocks such as demand or nominal shocks (see Gali (1999)).

Tables 4 and 5 demonstrate the variance decomposition which represents the contribution of each shock to the forecast error variance of the endogenous variables at horizons of 1, 4, 10, and 30 quarters.

We find that a productivity shock has not a small impact, but the effect of monetary policy

[20] Inflation and interest rates are not annual but quarterly.

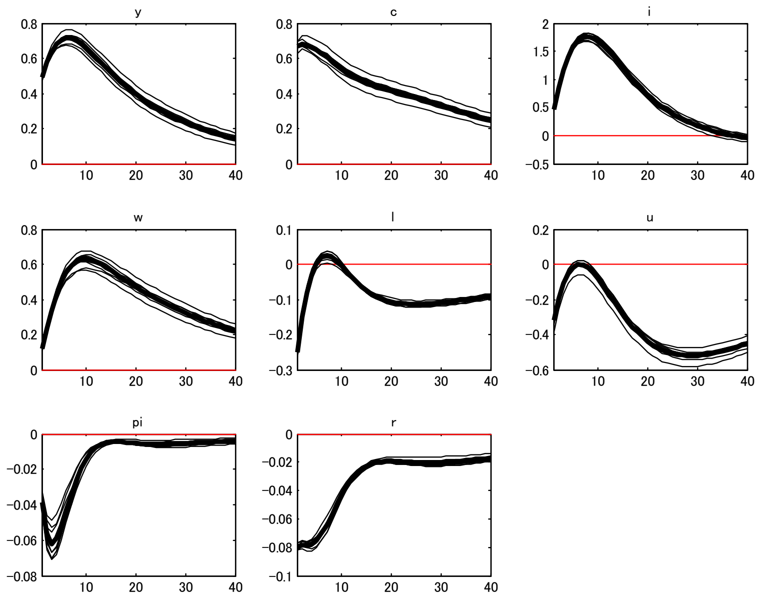

Figure 5: Impulse responses to a productivity shock

shocks is far smaller[21]. Regarding hours worked, the contribution of demand shocks, in particular an investment adjustment cost shock and an external demand shock, looks significantly large while that of preference shocks is very small[22]. In $T = 1$ and 4, the investment adjustment cost shock affects investment and output variations to a large extent. These results imply that, in a short horizon, an increase in output and hours worked which is usually observed in economic booms is caused mainly by the investment adjustment cost shock rather than a productivity innovation and a change in households' preference[23]. In the long run, however, a productivity shock is a dominant driving force.

4 Effect of Monetary Policy Shocks

To explain the hump-shaped and persistent inflation behavior in response to a contracting monetary policy shock, CEE advocate that capital utilization costs should be treated not as capital depreciation but as additional spending on goods. Their assumption plays a role in ensuring that, caused by contracting monetary policy, capital utilization rates fall, which makes a modest fall in the rental rate of capital. They also point out that if the cost of capital utilization is modeled as a higher capital depreciation rate, then contracting monetary policy raises capital utilization rates.

CEE's point can be confirmed in Figure 6, the impulse response of utilization rates to a

[21]This calculates only the contribution of monetary policy *shocks* as a deviation from a specific policy reaction function, so this result does not mean that monetary policy itself has few impacts.

[22]Some people regard preference and labor disutility shocks as demand shocks because they enter households' utility and affects consumption. Unlike their views, we follow that of SW, and interprets preference, investment adjustment cost, and external demand shocks as demand shocks.

[23]Focusing on the determinants of the nominal side of the economy, that is, nominal interest rates and inflation, we find that variations are mainly driven by a target inflation shock. Besides, a productivity shock and a price markup shock also affect inflation to a large extent.

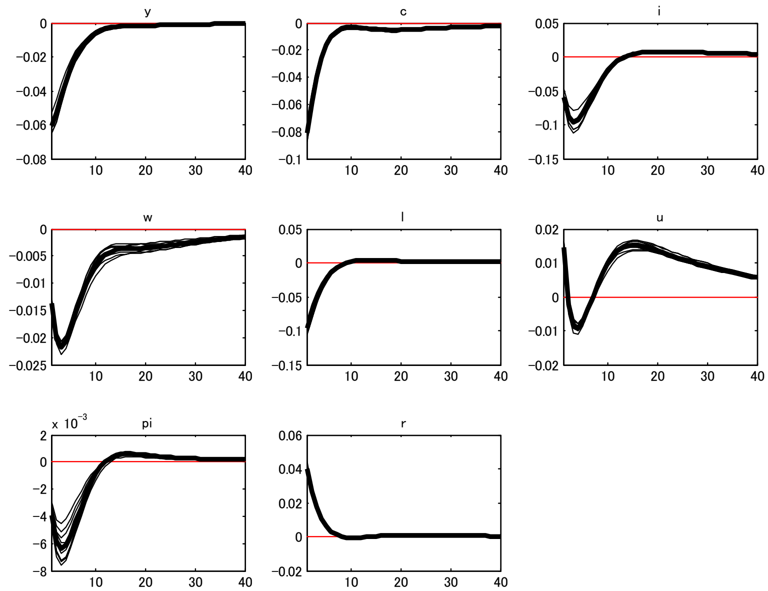

Figure 6: Impulse responses to an interest rate shock

tightening monetary policy shock. In our model, short-run policy tightening given by η^r increases utilization rates on impact, while it decreases utilization rates in CEE/SW/LOWW. Notice that in SW, policy tightening decreases rental costs of capital, r_t^k, decreases capital utilization. In addition to this effect, in our model, policy tightening decreases the value of capital, q_t, since real interest rates increase. As can be seen from Eq. (2.17), this effect encourages capital utilization because households do not need to care much about the depreciation of capital. Which effect dominates the other depends on the deep parameters of the model. Figure 6 shows that, on impact, the utilization rate increases since the latter effect dominates the former.

The capital utilization rates, however, quickly drop and become negative afterwards. This makes a decline in real marginal costs mild, which helps yield the hump-shaped behavior of inflation in response to an contractionary monetary policy. CEE seem to suspect that, with our model following Greenwood et al. (1988), Q has a far dominant effect on utilization rates over rental costs, and that policy tightening leads to an increase in capital utilization for a certain periods. However, this argument is largely subject to parameter values, in particular, that of investment adjustment costs. Figure 7 demonstrates the impulse responses of four variables to the same policy shock for three different parameter values of investment adjustment costs. If the adjustment cost is small, i.e. $\zeta^{-1} = 0.01$, then capital can become volatile, and the deviation of Q from its equilibrium value becomes negligible. The effect of rental costs dominates that of Q, which makes the response close to that in the CEE model. On the other hand, if adjustment costs are large, i.e. $\zeta^{-1} = 100$, then it becomes important for households to take account of the future capital stock and thus the value of Q. This amplifies the effect of Q on capital utilization rates. Hence, policy tightening leads to an increase in utilization rates for longer periods after the shock. This is probably the case that CEE are concerned with. Even with such a high value of adjustment costs, however, capital utilization rates fall to negative in a couple of quarters after the policy shock. Qualitatively, what CEE point out is true, but quantitatively, it does not seem to be a serious matter when we consider the impulse response of utilization rates and inflation to a monetary policy shock.

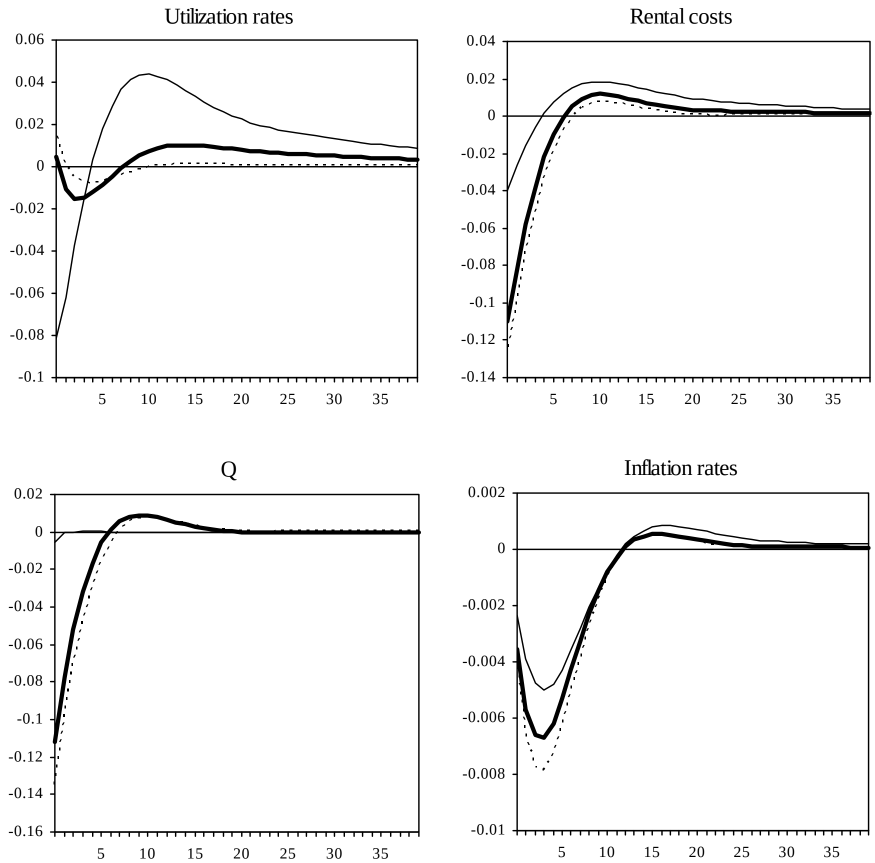

Figure 7: Impulse responses to an interest rate shock for different parameters of investment adjustment costs. Solid thick lines represent a baseline case. Solid thin and broken lines represent the case of $\zeta^{-1} = 0.01$ and $\zeta^{-1} = 100$ respectively.

Moreover, the point of CEE becomes far less convincing when we check the impulse response to a target inflation shock. As Figure 8 demonstrates, a positive policy shock $\overline{\pi}$, or policy accommodating, increases utilization rates even on impact[24]. Such an effect is perfectly in line with that in the CEE model. Moreover, according to variance decomposition, the effect of the target inflation shock is much larger than that of the i.i.d interest rate shock, so it looks more sensible to focus on the effect of the target inflation shock.

For these reasons, inflation exhibits hump-shaped and persistent responses caused by the two monetary policy shocks. Admitting that such responses are also caused by inflation indexation, we feel very confident in using the model of Greenwood et al. instead of CEE/SW/LOWW.

5 Concluding Remarks

This paper applies the middle-scale DSGE model to the Japanese economy. It employes the estimation with Bayesian techniques, and obtains plausible results relating to structural and

[24]Despite accommodating policy, nominal interest rates increase. This is because, in proportion to a rise in medium-term target inflation, there is a rise in the level of medium-run equilibrium nominal interest rates. Real interest rates fall, however, which increases consumption and investment.

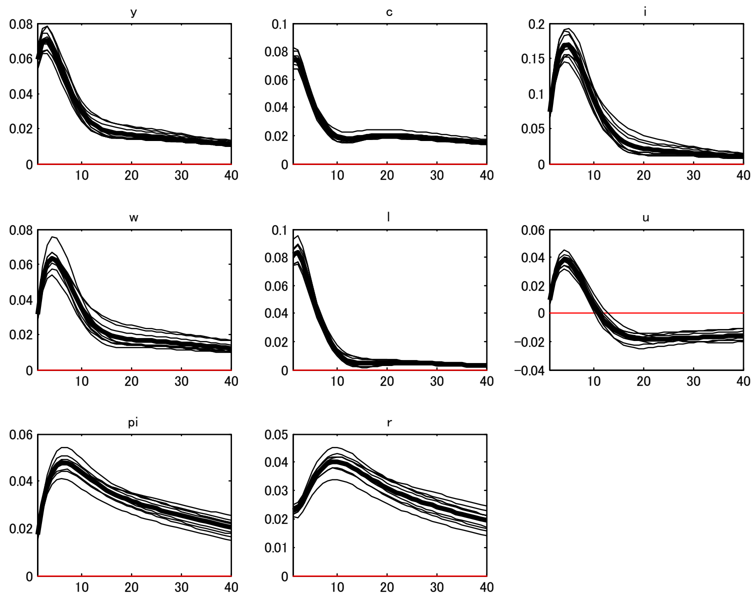

Figure 8: Impulse responses to a target inflation shock

policy parameters, impulse responses, variance decomposition, and the movement of capital utilization rates.

In applying the same method as SW and LOWW, we encounter problems such that the movement of capital utilization rates is inconsistent with actual ones. This paper thus has made mainly two modifications. Firstly, we use actual capital utilization rate data for estimation. Secondly, we modify the CEE/SW/LOWW model with respect to capital utilization rates following Greenwood et al. (1988). In short, we assume that the cost of capital utilization is not to cause additional expenditure on goods but to accelerate capital depreciation. This enables us to incorporates negative correlation between capital utilization rates and rental costs of capital and to make the movement of estimated capital utilization rates almost in line with actual ones.

For the future task, however, the goodness of fit of the estimation needs to be improved[25]. As was mentioned in Section 3.4, estimated capital utilization rates do not quite coincides with actual ones. As a possible reason for this, we suspect that, in our model, the adjustment of wages and labor is far slower than that of capital. This makes rental costs, or the relative productivity of capital over labor, highly dependent upon effective capital. This may make rental costs look negatively correlated with utilization rates.

One main approach to this task is to incorporate the movement of wages and labor into the model, such as to introduce a model of effective labor. If wage and labor were more volatile and procyclical, then the productivity growth would become less pro-cyclical. A concrete way is, for example, to incorporate labor hoarding or overhead labor[26]. Another and more promising remedy is probably to incorporate unemployment. Widely-accepted DSGE models are based on the model of full-employment, and neglect the existence of an involuntary labor slack. This

[25]The other anomalies we have found in this study are (1) high pro-cyclicality of productivity growth rates, (2) the unexplained movement of the output gap in some periods, (3) not strong relationship between real marginal costs and inflation rates. See Appendix A.3 for detail.

[26]See Rotemberg and Woodford (1999) for related discussion. Such a modification can be done rather easily, but according to our bold trial, the estimate of the degree of effective labor becomes unrealistically high.

is truly an important factor which we should not overlook. Some economists have challenged the difficult task of combining unemployment with the Real Business Cycle or New-Keynesian models[27]. Incorporating the real side costs as opposed to monetary frictions will certainly open up our understanding about macroeconomics and help construct a better macroeconomic model.

Finally, up to now, we have not discussed the issue on optimal monetary policy. Appendix A.4 attempts to make the first step for this study by investigating how social welfare is characterized in our middle-scale DSGE model. We expect that this investigation helps us consider what central banks should stabilize.

A Appendix

A.1 Data Description

This appendix explains our dataset. Our data range from 1981:1Q and 2006:2Q. But for our baseline estimation, the data range from 1981:1Q to 1995:4Q. We use eight variables: real GDP, real consumption, real investment, hours worked, real wages, capital utilization rates, inflation rates and overnight call rates. Their sources are summarized in Table 1. All the variables are detrended or demeaned (see Section 3.1 for detailed discussion), and represented as the logarithm deviation in a percent scale. Except for call rates, all the variables are seasonally adjusted. Inflation and call rates are described in a quarterly basis.

Regarding hours worked and real wages, we adjust the effect of *jitan*, a decrease in statutory workdays. However, we must admit that it is impossible to perfectly adjust this effect because we cannot accurately tell how much and when *jitan* influenced hours worked. It took place gradually from 1988:1Q to 1993:4Q, and then from 1997:2Q to 1998:4Q; and the extent of *jitan* varied across firms. We therefore take an approximation by assuming that hours worked per workday remained unchanged due to *jitan*. Thanks to this assumption, we may use the series of 'total hours worked' divided by 'workdays' as hours worked. Both of the data are available. Furthermore, we assume that monthly salary remained unchanged due to *jitan*. Then, we use the series of 'monthly salary' divided by hours worked and by price index (CPI) as real wages. Another point to make concerning hours worked is that we do not include the number of workers. We do this following LOWW. This treatment can be further justified by Braun et al. (2006), who points out that, compared with the U.S., Japan's business cycles are largely caused by the fluctuations of intensive margins.

Capital utilization rates are available only for those of manufacturing firms. However, the manufacturing firms account only for twenty percent of GDP, and non-manufacturing firms may adjust capital utilization rates to a less extent than manufacturing firms. Hence, simply using released statistics may result in over-estimating the effect of capital utilization. Therefore, very boldly, this paper multiplies 0.6 with our available series by assuming that a half of non-manufacturing firms have the same utilization rates as manufacturing firms and that the other firms keep utilization rates constant[28].

[27] For example, see Merz (1995), Walsh (2005), and Blanchard and Gali (2006).

[28] Actually, there is an alternative way to use Hara et al. (2006). They calculate the utilization rates of both manufacturing and non-manufacturing firms from some other statistics. However, we adopt the former way because we want to use raw data as much as possible. Moreover, estimating our model with the alternative way hardly changes our result.

A.2 Model in CEE/SW/LOWW

Unlike this paper, the adjustment cost of capital utilization in CEE/SW/LOWW is assumed to be incurred by households. Note also that the functional form of adjustment costs of capital utilization is given by

$$\Psi(Z_t^U U_t(h)) = \mu \frac{\{Z_t^U U_t(h)\}^{1+\psi^{-1}} - 1}{1+\psi^{-1}}.$$

The budget constraint of households is given by

$$\begin{aligned} & \frac{B_{t-1}(h)}{P_t} + W_t(h)L_t(h) + R_t^k U_t(h)K_{t-1}(h) + \Pi_t(h) \\ \geq \quad & \Psi(Z_t^U U_t(h))K_{t-1} + C_t(h) + I_t(h) + b_t \frac{B_t(h)}{P_t}. \end{aligned} \tag{A.1}$$

The first term in the right hand side is a new term represents additional demand for goods due to capital utilization. The market clearing condition is transformed into

$$Y_t = C_t + G_t + I_t + \Psi(Z_t^U U_t(h))K_{t-1}. \tag{A.2}$$

A depreciation rate of capital becomes constant as

$$\delta(U_t(h)) = \delta. \tag{A.3}$$

With this setup, we can obtain the following log-linearized equations:

$$k_t = (1-\delta)k_{t-1} + \delta i_t \tag{A.4}$$

$$u_t = \psi r_t^k - \epsilon_t^u \tag{A.5}$$

$$y_t = c_y c_t + g_y \epsilon_t^g + \delta k_y i_t + \overline{R^k} k_y (u_t + \epsilon_t^u), \tag{A.6}$$

and the other equations are the same as before. For the following discussion, we also write down the labor demand function:

$$l_t = -w_t + r_t^k + u_t + k_{t-1}. \tag{A.7}$$

Let us firstly present results when we estimate the above CEE/SW/LOWW model of capital utilization rates without using the actual data of the capital utilization rates. In doing so, we omit the adjustment cost shock of capital utilization, ϵ_t^u, from the above equations. Table 6 demonstrates the posterior distribution of parameters which is estimated from 1981:1Q to 1995:4Q by sampling two separate chains for 300,000 periods. There are very few differences from those of our baseline model, but we find a big decrease in the parameter of capital utilization adjustment costs, ψ. Of course, we have to note that the definition of the parameter is different between two models but that the impact of rental costs on capital utilization rates is both given by this same parameter ψ.

Another distinct contrast from our method is the movement of inferred utilization rates. As was shown in Figure 1, inferred utilization rates look hugely different from actual ones. Of course, we do not take the utilization rate data at face value because their statistics are limited only in manufacturing firms. However, the inferred utilization rates move far less strongly than actual ones.

Motivated by the dissatisfaction with the above result, the next attempt is to use the actual capital utilization rate data while maintaining the CEE/SW/LOWW model. Since we add one observed variable, we include and estimate the adjustment cost shock of capital utilization.

In doing so, we notice that the model cannot be well estimated. Simply stated, this is because estimated rental costs are highly negatively correlated with capital utilization rates (see Figure 2) while, in the CEE model, they should be positively correlated. In order to understand this in detail, let us examine what happens in this model. The law of motion with respect to capital has no shock component, so the movement of capital is completely determined by actual investment movement except for its initial value. Therefore, in Eq. (A.7), rental costs become virtually the only unobserved or unknown variable, and are determined from this equation. Observed wages and hours worked are stable, and a large variation in this equation comes from that in utilization rates. Rental costs thus have almost negative correlation with utilization rates as was shown in Figure 2. To put it differently, rental costs are the relative profitability from using capital to using labor, and this value becomes smaller as capital is more utilized. However, this negative correlation between utilization rates and rental costs contradicts with Eq. (A.5) that requires positive correlation[29]. For this reason, the alternative model cannot be well estimated once we use the data of capital utilization rates.

On the other hand, in our model, Eq. (A.5) is altered to Eq. (2.17). Since there is an additional term of the value of capital Q, the model no longer requires strong positive correlation between utilization rates and rental costs.

A.3 Movement of Unobservable Variables

One of the merits of estimating the model, compared with calibration, is that we can see how the economy behaved in the past. We can calculate the movement of various shocks and other unobservable variables such as an output gap. Unobservable variables can be estimated through Kalman filter.

In order to examine the structural parameters and the validity of our DSGE model, it is nearly sufficient for us to estimate the model with the sample from 1981:1Q to 1995:4Q, but it tells no information as to what happened after 1996:1Q. We thus attempt to estimate the model with the full sample until 2006:2Q, but in principle, it is impossible for us to accurately estimate the model with the zero lower bound on nominal interest rates by maintaining a linearized model. We therefore infer the movement of various variables over the period from 1981:1Q to 2006:2Q in the following rather crude way. In the full sample from 1981:1Q to 2006:2Q, nominal interest rates are bounded at near zero in additional periods, so the model is no longer linear. However, we continue to use the same log-linearized model and to use the demeaned data of nominal interest rates. The only treatment we made for non-linearity is to make structural parameters estimated over the period from 1981:1Q to 1995:4Q fixed. Then, with the same procedure, we estimate all the remaining parameters, i.e. policy parameters, shock persistence parameters, and standard deviation of shocks, for the full sample. We admit that such a method is rough, and that it can cause a bias for policy parameters and policy shocks. In particular, because of the zero lower bound, policy shocks may tend to be estimated as being tighter. Of course, it may not be because policy parameters are estimated differently so that it absorbs this bias, but in such a case, policy parameters appear to be estimated wrongly[30]. For this reason, it would be fair to interpret the following results with sensible caution.

Supply Side Figure 9 and 10 demonstrate the movements of supply-side variables. Productivity is calculated as a sum of a productivity shock and a trend of output. Note that this is not

[29] This contradiction is squeezed into a utilization adjustment cost shock, which results in extremely strong comovement with actual utilization rates.

[30] In fact, a policy inertia coefficient increases from 0.84 to 0.93.

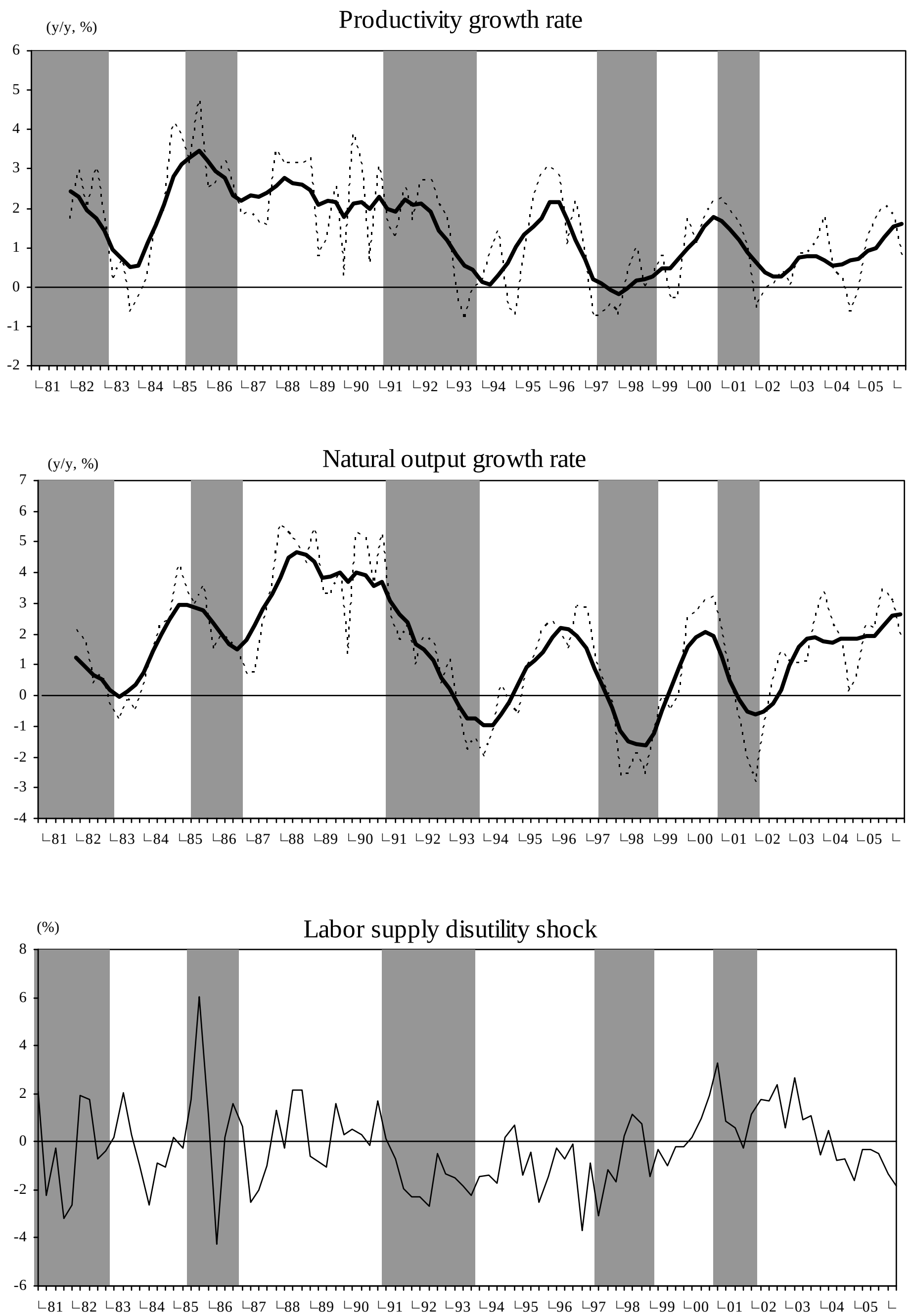

Figure 9: Supply side variables (1). Solid lines in the top two figures indicate the two-year moving averages of the dotted line.

a perfectly right way because we detrend output, consumption and investment with independent different trends. It is rather approximation. We find that productivity growth rates do not look so pro-cyclical, which is partly caused by our use of actual capital utilization rate data. The productivity growth rate, however, still remains pro-cyclical. There were drastic declines three times: in 1993 (after asset price bubble burst), 1997-98 (a credit crunch) and 2001-02 (IT bubble burst). We thus suspect that the productivity shock still accounts for some cyclical factors which cannot be attributed to capital utilization. We notice that the productivity growth has been falling gradually throughout the period from 1981 to 2006. The natural output is the output which would be achieved if prices and wages were perfectly flexible[31]. In principle, this natural output excludes price and wage markup shocks, but includes other demand shocks, e.g. preference or investment adjustment cost shocks. Since the latter demand shocks affect the real side of the economy to a great extent, the natural output growth appears to be more volatile than the productivity growth. This results in small volatility in an output gap. The natural output growth experienced a decline in the 1990's, but it seems to have recovered after 2002. The labor disutility shock is higher in the late 1980's during the asset price bubble era and in 2000-03. This implies that households did not want to work much, which produced an upward pressure in wages. On the other hand, in recent few years, the shock declined, which implied households' more willingness to work and a downward pressure in wages. The capital stock increased from 1986 to the beginning of the 1990's. Capital remained excessive almost throughout the 1990's, but in the late 1990's, its over-accumulation was cleared, and around 2003, the capital stock turned to increase. Rental costs show negative correlation with the capital stock. This is because, as capital increases, the marginal product of effective capital decreases, and the value of capital becomes lower. Regarding the movement of the capital utilization adjustment cost shock, its increase suggests that, provided the same utilization rate, capital is more quickly depreciated. This, in turn, causes a decline in a capital utilization rate, which is consistent with the historical episode in 2001.

Demand Side Figure 11 shows the movements of demand-side variables. An external demand shock is equal to the residual of output from consumption and investment, so it includes government expenditure and net export. This shock exhibits a constant decrease since 2001, which is consistent with an actual decline in government spending. Preference and investment adjustment cost shocks respectively caused to decrease demand for consumption and investment in the early 1990's (asset price bubble burst), in 1997-8 (a consumption tax hike and a credit crunch) and in 2001 (IT bubble burst). In particular, the latter shock seems to be largely caused by the heavy burden of non-performing loans. However, around from 2002, it is said that firms became free from this burden, and investment demand seems to have significantly increased. The value of capital or Tobin's Q shows a rather opposite movement to the actual investment; Q was lower in 1980's than in 1990's while investment was more active in the former period. This results from the real interest rate, which affects Q negatively. Although the monetary authority kept accommodating policy in the 1990's and 2000's and this resulted in increase in Q, there was no significant recovery of investment in the 1990's because of the investment adjustment cost shock which captures the burden of nonperforming loans.

Output gap Figure 12 shows an output gap. Notice that this output gap is equal to the deviation of actual output from the natural output level in the frictionless economy, so it represents

[31] In the same way as the productivity growth rate, when calculating its growth rate, we add the trend of output.

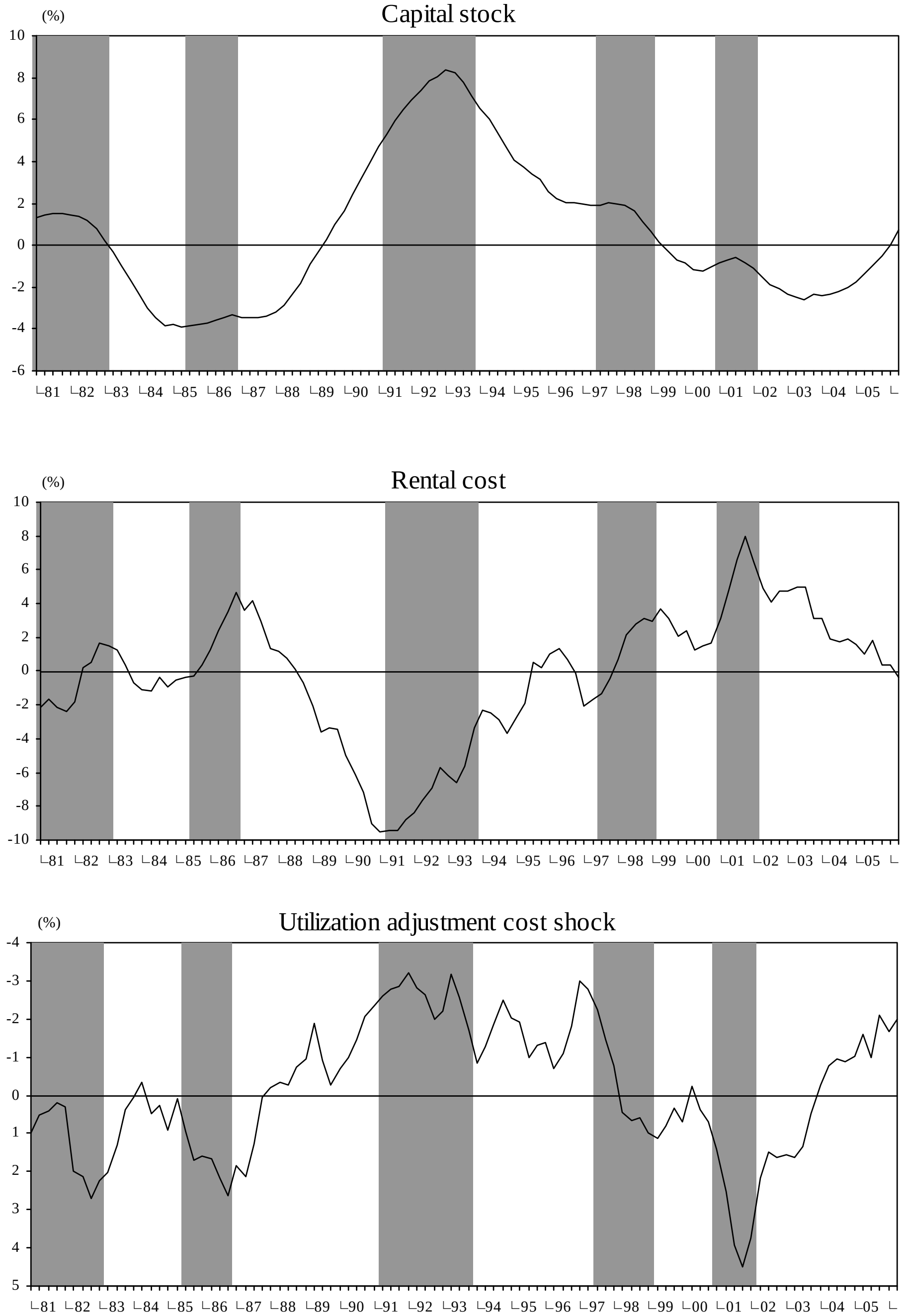

Figure 10: Supply side variables (2)

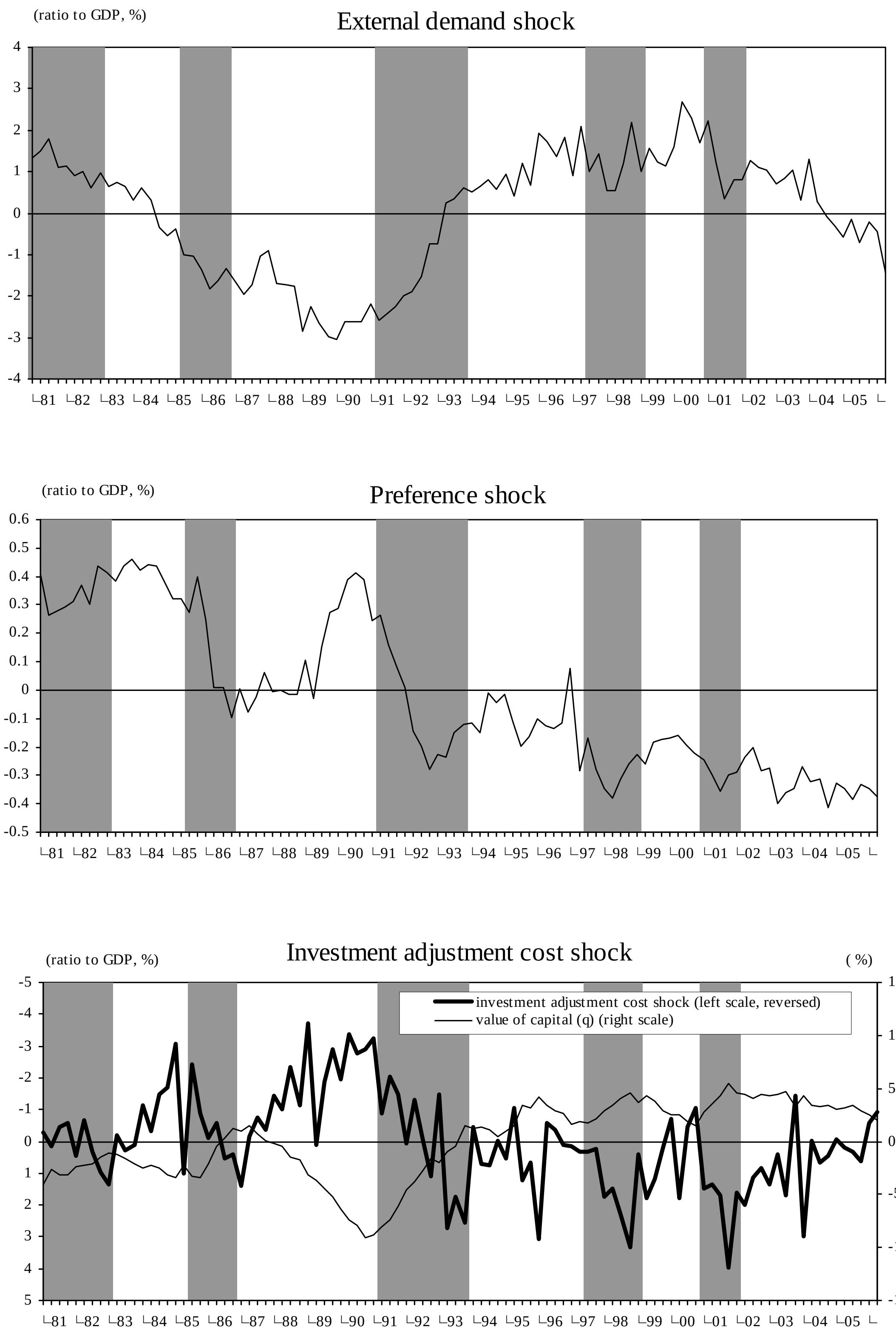

Figure 11: Demand side variables

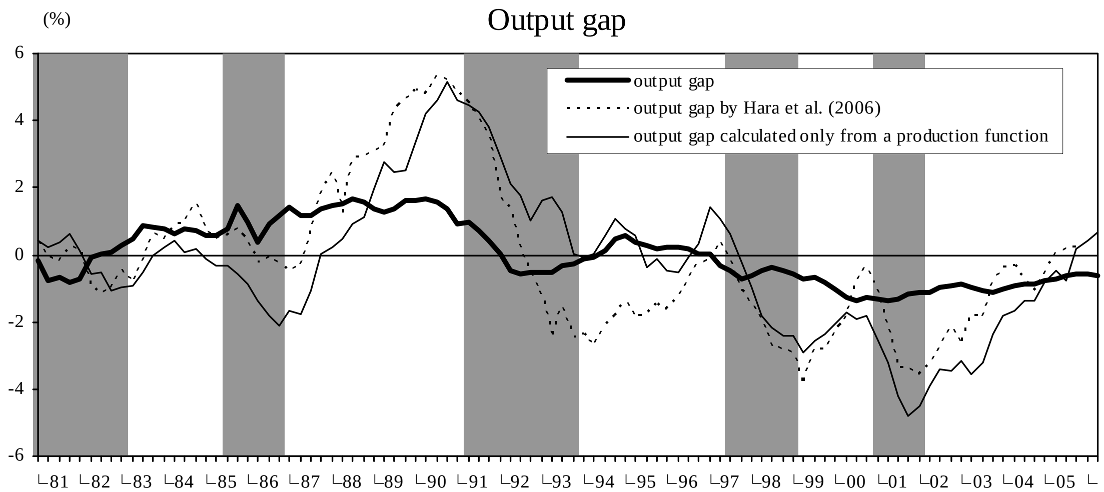

Figure 12: Output gap

welfare losses[32,33]. In fact, broadly speaking, this gap becomes high in the late 1980's during the asset price bubble era, and low in 1990's and 2000's. In the recent years, the gap is gradually recovering. However, we are not confident enough that this output gap reflects the 'true' gap. Once we closely look at the figure, we may have such a bad implication that, in terms of welfare, the recession in 1997-8 was not so serious as the economic recovery from 2002 to 2006. Neither is the recession in 2001 compared to the preceding IT boom in 2000. Such a concern is shared by Walsh (2005) who criticizes the odd movement of the U.S. output gap obtained by LOWW. We suspect that an intrinsic reason for this dissatisfaction is because this model does not take account of any real costs. Apart from nominal rigidity and markup shocks, there should exist real costs such as involuntary unemployment and mismatched unemployment. Since our model neglects real costs, it is highly likely that we underestimate the welfare losses. For instance, we may simply interpret involuntary unemployment as an increase in households's labor disutility shock, which is not a cost at all.

Impact on Prices and Wages The impact on prices is investigated by looking at real marginal costs, which equal to real wages deducted by the marginal product of labor (MPL).

[32] We can also calculate another definition of output gap using only firm's production function. Supposing that only the productivity shock contributes to 'potential' output, y^p, we describe it as

$$y_t^p = \phi \epsilon_t^a.$$

The output gap by the second definition is given by $y - y^p$. A thin solid line indicates this second output gap while a dotted line does the output gap reported by Hara et al. (2006). The definition of the latter output gap is the same as that of our second output gap, and these two gaps look very similar. Compared with them, our output gap by the first definition exhibits similar ups and downs. All of them became high in the era of asset price bubble in the late 1980's and low in the 1990's and 2000's. However, our first output gap exhibits less volatile movement. The reason for this is because the natural output is largely affected by demand shocks as well as the productivity shock. The demand shocks cause a large swing of the natural output, which leads to less volatility of the output gap than the other two output gaps.

[33] Gali, Gerlter and Lopez-Salido (2003) considers so-called an inefficiency gap: marginal rate of substitution (MRS) - marginal product of labor (MPL). This is equal to the sum of the real marginal costs and MRS deducted by real wages, and the movement of this new gap seems to be very similar to that of our output gap although their magnitude differs.

The real marginal costs enter into a Phillips curve, and directly affects inflation. A price markup shock is shown in figure 13. This shock represents the degree of competition among firms. But in practice, this shock represents all the remaining factors as the determinants of inflation which the real marginal costs fail to explain. The prices of raw material such as crude oil or currency appreciation/depreciation is evaluated as the price markup shock. We find that the real marginal costs have been negative for most of the time since 1991, which is considered to cause disinflation. This matches mostly with Japanese experiences, but price markup shocks seem to move in the extremely opposite way to the real marginal costs. Some periods may be validly interpreted as representing currency appreciation (1986 and 1995) or a surge in oil prices (2004-5), but we cannot find a good reason why the markup shock jumped up in 2000. This misspecification of the marginal cost is possibly related to little volatility of wages and hours worked compared to capital utilization. We will discuss this point more in concluding remarks.

Next, we look at the impact on nominal wages through the marginal rate of substitution (MRS) between consumption and labor deducted by real wages. This variable enters into a wage Phillips curve, and affects nominal wages. High MRS over real wages suggests that the disutility of labor is high or wages are low, and results in a upward pressure on nominal wages. The figure demonstrates that nominal wages were put under downward pressure in the 1990's and 2000's, especially, soon after the bubble burst (1991-93), credit crunch (1997-98) and the IT bubble burst (2001). The wage markup shock exhibits a little opposite movement to the MRS deducted by real wages, but this is not so bad as the previous price markup shock.

Monetary Policy and Inflation Expectations Figure 14 demonstrates two monetary policy shocks represented by the short-run η^r and the medium-run $\overline{\pi}$. The interpretation of the former shock is simple; if the shock is high, the interest rate is high, and monetary policy is tight. Regarding the latter shock, we transform this by adding the mean of the inflation rates which were deducted for estimation. Doing so enables us to compare this target inflation shock with actual inflation rates. The higher the target inflation than actual inflation, the more accommodative the monetary policy is. We can see that, at the beginning of the bubble era (1986-7), monetary policy was accommodative, and that at the end of the bubble era (around 1990) and when the call rate was raised from almost zero (around 2000), the policy was estimated as being tight.

Regarding the target inflation shock, however, it is not sensible to think that the target inflation which the central bank aims at is so volatile. As is shown in the figure, it varies from minus two percent to plus four percent. Looking at the figure closely, we find that the shock follows the actual inflation at least until the middle of 1990's. This observation makes us feel that the target inflation shock actually represents people's belief about equilibrium inflation rates; and people adjust their belief about equilibrium inflation by learning the past inflation movement with the persistence of ρ_π[34]. The inertia of $\rho_\pi = 0.97$ may suggest that people modify their belief of equilibrium inflation by half at the speed of about six years. An implication from this interpretation is that it may well take long time for people to change their belief about the equilibrium inflation rate. This finding is opposite to Erceg and Levin (2003), who points out that, in the U.S., people's expectations about inflation are not adaptive to the past inflation

[34]Such interpretation seems to be almost valid because our model is not changed mathematically by expressing the inflation and the nominal interest rates as the deviation from $\overline{\pi}$ in Eqs. (2.13), (2.14) and (2.23). However, in order to hold the Phillips curves of inflation and wages, Eqs. (2.21) and (2.22), we need an addition assumption that firms' pricing is *not* indexed with $\overline{\pi}$.

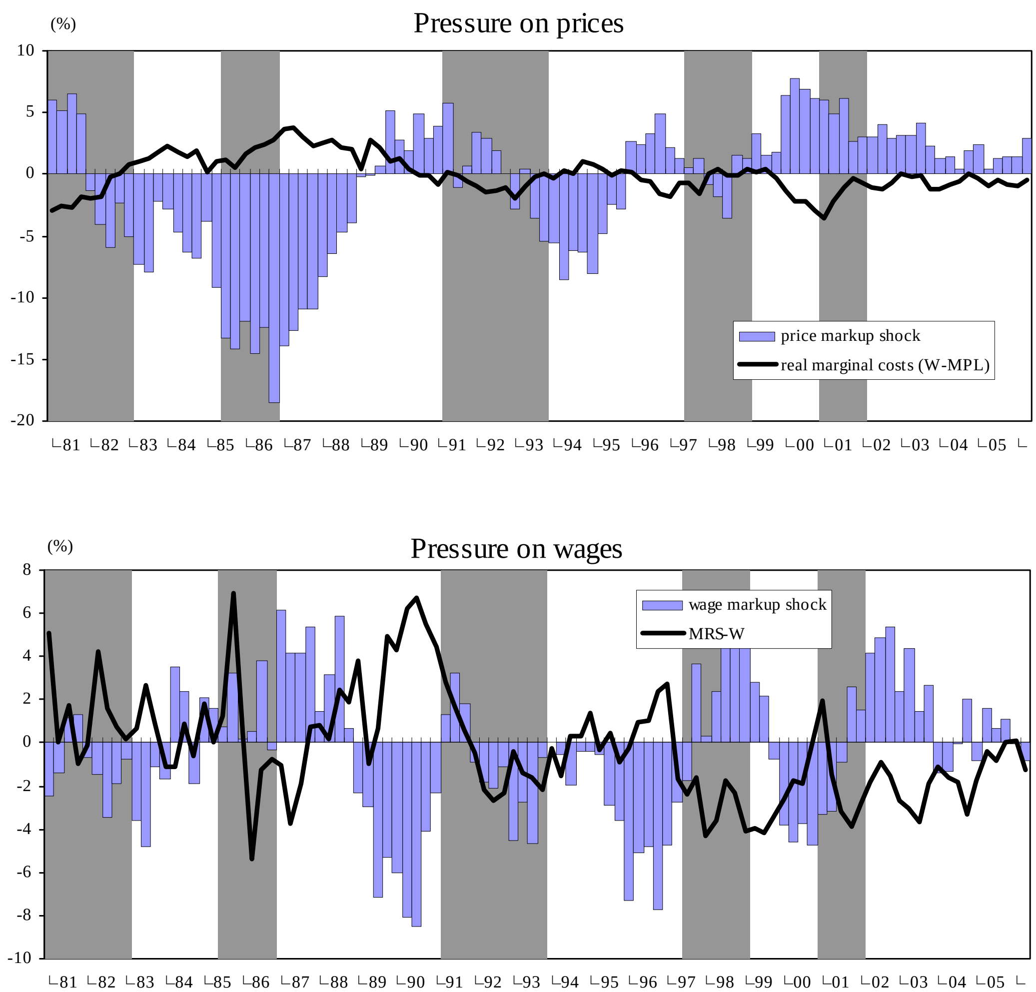

Figure 13: Pressure on prices and wages. Wage and price markup shocks are moving-averaged for two years.

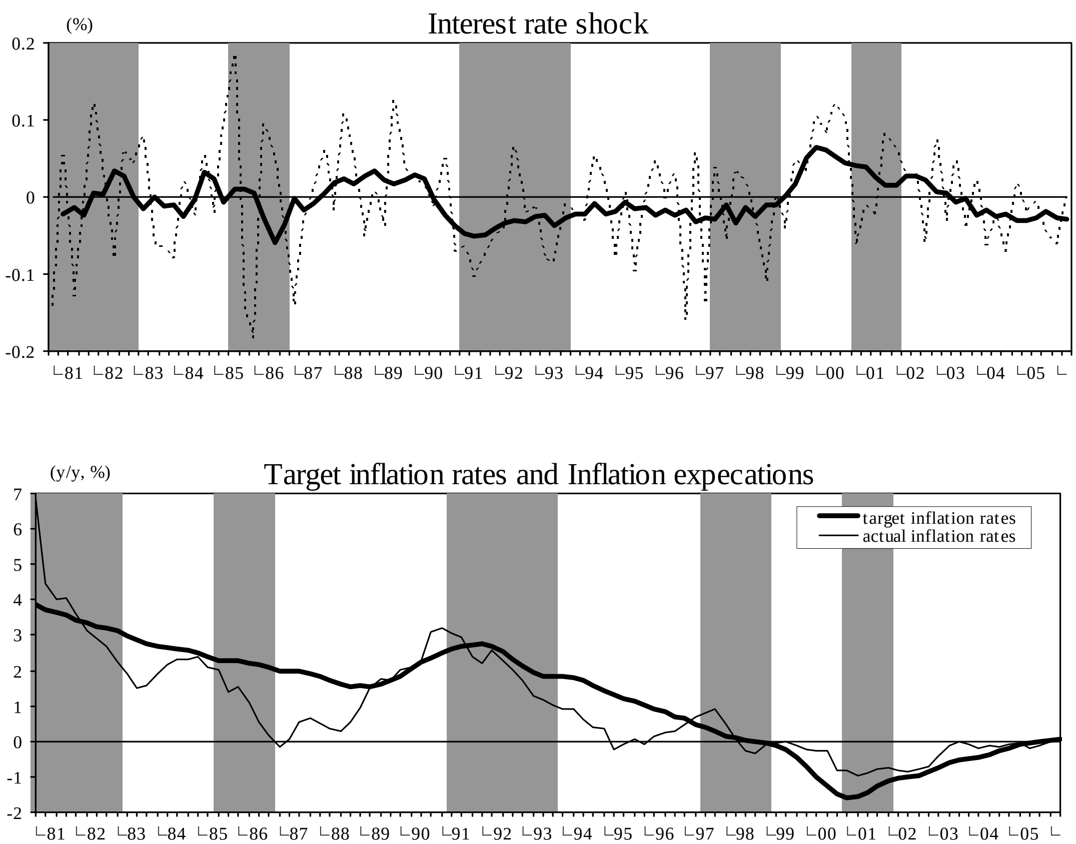

Figure 14: Monetary policy shock and inflation expectations. In the top figure, a solid line indicates the two-year moving averages of the dotted line.

but sensitive to a current change in monetary policy, and attribute the reason for this to strong credibility of the U.S. monetary policy.

However, from 2001 onward, it appears that people's belief about equilibrium inflation rates increase preceding actual inflation. This observation may force us to go back to the first interpretation. In other words, by adopting quantitative easing policy and clarifying the commitment in 2001, the Bank of Japan raised target inflation. If we apply the argument by Erceg and Levin (2003), the movement after 2001 may imply that the Bank of Japan obtains stronger credibility about their newly adopted monetary policy.

A.4 Social Welfare Analysis

This appendix aims to analyze social welfare. This study is important because one of the objectives of central banks is considered to maximize social welfare. In the presence of frictions such as sticky prices and wages, when shocks arise, the economy cannot immediately and costlessly return to desirable states, and households' utility declines. This appendix calculates the social welfare costs of business cycles from our model and considers what kind of factors strongly affect the welfare costs. Such a study is expected to provide a useful guideline as to which variables central bankers should stabilize. In a simple New-Kenyesian model with purely forward-looking IS and Phillips curves, it is known that a social welfare loss function is written as

$$L = \pi^2 + \lambda(y - y^*)^2,$$

where the second term represents the output gap[35]. However, this function needs to be modified in more realistic models. For instance, if we consider sticky wages, then the loss function comes to depend on wages. If inflation itself has persistence, then the loss function comes to depend on the past inflation rate. Since our model is not small, it is very difficult for us to analytically derive a social loss function. We thus firstly calculate not the loss function but the value of social welfare losses numerically[36].

A.4.1 Social Welfare Losses due to Business Cycles

According to numerical calculation, when central banks follow a policy reaction function from 1981 to 1995, social welfare losses due to business cycles amount to approximately a one percent reduction in steady-sate consumption. This value is far larger than 0.05%, which Lucas (2003) derives from merely a consumption equation with the U.S. data. But, our value is about a half of that by LOWW, 2.6%, who use almost the same model as ours. This discrepancy is because, in Japan, both wage stickiness and the standard deviation of wage markup shocks are estimated lower. Lower stickiness of wages is consistent with Yoshikawa (1992), but considering some problems around labor market formalization, it would be better to take these result with sensible reservation[37].

A.4.2 Deriving a Welfare Loss Function

True that it is extremely difficult to analytically derive a welfare loss function in middle-scale DSGE models, but in order to conduct monetary policy, it is still very important to see which

[35] See Woodford (2003).

[36] To this end, we modify the code by LOWW and use Dynare.

[37] See our concluding remarks.

variables central banks should stabilize. In order to grasp some intuitions about this, we devise the way to calculate an approximate welfare loss function in the following way[38].

Define a vector of structure shocks as e. These shocks have a variance of

$$\Sigma = E(ee'), \tag{A.8}$$

and are independent each other, that is, $E(e_i e_j) = 0$ for $i \neq j$. Provided that households maximize their utility and that there is no efficiency loss in a steady state, these shocks affect utility U in a second order:

$$U = e'Me. \tag{A.9}$$

A matrix M is a coefficient which represents the extent how much utility is affected by the shocks[39]. We describe some variables as

$$y = Ae. \tag{A.10}$$

y is a kind of target variables, and its example is a set of inflation, wage inflation, and an output gap. A matrix A represents the extent how much y is affected by the shocks.

Here, let us assume that the number of elements of y is lower than that of shocks e. In this case, we cannot accurately write utility U with respect to y. Speaking of our model, since our model has ten structure shocks, we cannot accurately write utility as a function of inflation, wage inflation and an output gap. However, if we know the variance of the shocks (Eq. (A.8)) from estimation or prior knowledge, by using Eq. (A.10) and observing y, we can infer what kind of shocks occur. Then from Eq. (A.9), we can infer the utility U. Regarding the optimal method to infer U, we obtain the following proposition.

Proposition 1 *With respect to y, utility U is optimally approximated as*

$$\begin{aligned} U &\sim y'Py \qquad &(A.11)\\ P &= (A\Sigma A')^{-1} A\Sigma M \Sigma A' (A\Sigma A')^{-1}. \qquad &(A.12) \end{aligned}$$

Proof. *Find a matrix P so that*

$$\arg\min E[U - y'Py]^2.$$

Expanding this leads to

$$\begin{aligned} E[U - y'Py]^2 &= E[e'Me - y'Py]^2 \\ &= E[e'Mee'Me + y'Pyy'Py - 2e'Mey'Py] \\ &= Ee'[Mee'M + A'PAee'A'PA - 2Mee'A'PA]e \\ &= [M_{jk}\Sigma_{kk}M_{kj} + A_{ij}P_{ik}A_{kl}\Sigma_{ll}A_{ml}P_{mn}A_{nj} - 2M_{ji}\Sigma_{ii}A_{ki}P_{kl}A_{lj}]\Sigma_{jj}, \end{aligned}$$

[38]There exists previous literature which tries to derive a loss function in a similar model. Onatski and Williams (2004) derives an analytical form of a loss function with ten independent variables $S_t = (Y_t, K_t, K_{t-1}, u_t, G_t, \epsilon_t^i, I_{t-1}, \epsilon_t^a, \epsilon_t^b \epsilon_t^l)$ in addition to the current and lagged inflation and wages, and reports that it is approximated as

$$\pi_t^2 + 0.21K_t^2 - 0.51\pi_t\pi_{t-1} + 0.24(w_t + \pi_t)(w_t - w_{t-1}).$$

In short, the loss function depends not only on inflation rates but also on wages and lagged capital stocks.

However, it seems that their analysis has a serious problem. This is because the vector S_t has a number of variables which affect the current inflation and wages. For instance, a productivity shock, ϵ_t^a, has a negative influence on the current inflation rate, so it is not appropriate to include this shock.

[39]With the help of Dynare, if we assume a specific form of monetary policy reaction function, this matrix can be numerically obtained by second order approximation.

because $E(e_i e_j) = 0$ *for* $i \neq j$. *Differentiating this with respect to* P_{uv} *yields*

$$\begin{aligned} 0 &= [A_{uj}A_{vl}\Sigma_{ll}A_{ml}P_{mn}A_{nj} - M_{ji}\Sigma_{ii}A_{ui}A_{vj}]\Sigma_{jj} \\ &= A_{uj}\Sigma_{jj}A_{nj}P_{nm}A_{ml}\Sigma_{ll}A_{vl} - A_{ui}\Sigma_{ii}M_{ij}\Sigma_{jj}A_{vj} \end{aligned}$$

because P *and* M *are obviously symmetric. This can be simplified as*

$$0 = A\Sigma A' P A\Sigma A' - A\Sigma M\Sigma A'.$$

Thus we can obtain

$$P = (A\Sigma A')^{-1} A\Sigma M\Sigma A' (A\Sigma A')^{-1}.$$

■

Applying this proposition, we obtain the loss function approximated as[40,41]

$$\pi^2 + 1.9\pi_w^2 + 1.8(y - y^*)^2 - 0.1\pi\pi_w + 0.6\pi(y - y^*) + 0.2\pi_w(y - y^*). \quad \text{(A.13)}$$

Compared with a coefficient on inflation, those on wage inflation and an output gap become almost twice as large. In other words, social welfare depends more largely on wage inflation and an output gap than inflation. This result is consistent with LOWW, who propose a monetary policy rule reacting not to inflation but to wage inflation, based on numerical calculation of social welfare.

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[40] In order to calculate M and A, we use an estimated policy reaction function from 1981 to 1995. The same estimation provides Σ. It is important to be aware that a different policy rule may yield a different result.

[41] Notice that this calculation takes account only of the impact of current shocks on welfare. By assuming that the economy was at steady states before, we neglect the impacts of predetermined variables such as capital on welfare.

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Table 1: Data sources

Variables	Sources
Real GDP	Cabinet Office "National Accounts"
Real consumption	Cabinet Office "National Accounts"
Real investment	Cabinet Office "National Accounts"
Hours worked	Ministry of Health, Labour and Welfare "Monthly Labor Survey"
Real wages	Ministry of Health, Labour and Welfare "Monthly Labor Survey" Ministry of Internal Affairs and Communications "Consumer Price Index"
Capital utilization rates	Ministry of Economy, Trade and Industry "Indices of Industrial Production"
Inflation rates (excluding fresh food)	Ministry of Internal Affairs and Communications "Consumer Price Index"
Overnight call rates	Bank of Japan

Table 2: Prior distribution of parameters

Parameters	Descriptions	Distribution	Mean	S.D.
Structural parameters				
θ	consumption habit	beta	0.7	0.15
σ	inverse of the elasticity of substitution	normal	1	0.375
χ	inverse of the elasticity of work	normal	2	0.75
$1/\zeta$	investment adjustment costs	normal	4	1.5
ψ	inverse of the elasticity of capital utilization costs	normal	1	1
$\phi - 1$	a fixed-cost share	gamma	0.075	0.0125
ξ_p	price no-revise probability	beta	0.375	0.1
ξ_w	wage no-revise probability	beta	0.375	0.1
γ_p	price indexation	beta	0.5	0.25
γ_w	wage indexation	beta	0.5	0.25
Policy parameters				
r_i	lagged interest rate	normal	1	0.15
r_π	inflation	normal	0.5	0.2
r_y	output gap	normal	0.01	0.1
$r_{\Delta\pi}$	change in inflation	normal	0.1	0.1
$r_{\Delta y}$	change in output gap	normal	0.1	0.5
S.D. of shocks				
σ_a	productivity shock	inv. gamma	1	inf
σ_π	target inflation shock	inv. gamma	0.1	inf
σ_b	preference shock	inv. gamma	0.1	inf
σ_g	external demand shock	inv. gamma	0.4	inf
σ_l	labor supply disutility shock	inv. gamma	2	inf
σ_i	investment adjustment cost shock	inv. gamma	1	inf
σ_u	utilization adjustment cost shock	inv. gamma	0.5	inf
σ_r	interest rate shock	inv. gamma	0.1	inf
σ_q	external finance premium shock	-	-	-
σ_p	price markup shock	inv. gamma	0.2	inf
σ_w	wage markup shock	inv. gamma	0.2	inf
Persistence of shocks				
ρ_a	productivity shock	beta	0.85	0.1
ρ_π	target inflation shock	beta	0.85	0.1
ρ_b	preference shock	beta	0.85	0.1
ρ_g	government spending shock	beta	0.85	0.1
ρ_l	labor supply disutility shock	beta	0.85	0.1
ρ_i	investment adjustment cost shock	beta	0.85	0.1
ρ_u	utilization adjustment cost shock	beta	0.85	0.1

Table 3: Posterior distribution of parameters

Parameters	SW (2003) mean	OW (2004) mean	LOWW (2005) mean	INW (2006) mean	This paper mean	90 % interval		
Structural parameters								
θ	0.592	0.4	0.294	0.641	0.102	0.042	-	0.164
σ	1.391	2.178	2.045	2.041	1.249	0.960	-	1.522
χ	2.503	3	1.405	2.427	2.149	1.764	-	2.532
$1/\zeta$	6.962	6.579	1.822	8.338	6.319	4.297	-	8.266
ψ	4.975	2.8	0.198	0.182	2.370	1.398	-	3.336
$\phi - 1$	0.417	0.8	0.082	0.581	0.084	0.061	-	0.106
ξ_p	0.905	0.93	0.824	0.65	0.875	0.8844	-	0.914
ξ_w	0.742	0.704	0.807	0.367	0.516	0.428	-	0.599
γ_p	0.477	0.323	0.116	0.613	0.862	0.740	-	0.995
γ_w	0.728	0	0.0773	0.578	0.246	0.011	-	0.458
Policy parameters								
r_i	0.956	0.962	0.832	0.682	0.842	0.725	-	0.957
r_π	0.074	0.152	0.460	0.505	0.606	0.481	-	0.729
r_y	0.004	0.004	0.000	0.017	0.110	0.046	-	0.170
$r_{\Delta\pi}$	0.151	0.14	0.285	-	0.250	0.133	-	0.366
$r_{\Delta y}$	0.158	0.159	0.481	-	0.647	0.445	-	0.864
S.D. of shocks								
σ_a	0.639	0.343	0.594	11	0.843	0.717	-	0.970
σ_π	0.033	1	0.107	-	0.062	0.032	-	0.091
σ_b	0.407	0.24	0.121	7.7	0.102	0.063	-	0.138
σ_g	0.335	0.354	0.285	4.3	0.403	0.344	-	0.462
σ_l	3.818	2.351	2.322	7.4	1.538	1.073	-	2.085
σ_i	0.113	0.059	1.035	4.6	1.413	1.134	-	1.681
σ_u	-	-	-	-	0.646	0.522	-	0.766
σ_r	0.089	0	0	1.1	0.066	0.025	-	0.110
σ_q	0.613	7	3.678	11.4	-	-	-	-
σ_p	0.165	0.172	0.205	24.5	0.151	0.123	-	0.179
σ_w	0.297	0.246	0.299	7.9	0.212	0.174	-	0.249
Persistence of shocks								
ρ_a	0.811	0.957	0.961	0.851	0.949	0.926	-	0.976
ρ_π	0.855	0.582	0.994	-	0.974	0.952	-	0.998
ρ_b	0.838	0.876	0.944	0.368	0.892	0.827	-	0.957
ρ_g	0.943	0.972	0.942	0.792	0.960	0.931	-	0.990
ρ_l	0.881	0.974	0.980	0.462	0.563	0.379	-	0.727
ρ_i	0.913	0.943	0.731	0.871	0.350	0.247	-	0.455
ρ_u	-	-	-	-	0.901	0.850	-	0.958

Table 4: Variance decomposition

Nominal interest rates

	$T = 1$	$T = 4$	$T = 10$	$T = 30$
ν_a	26.6	23.4	31.1	31.1
ν_b	26.1	19.1	18.5	8.3
ν_i	5.9	24.3	9.1	9.6
ν_g	0.9	0.6	1.7	3.4
ν_u	6.4	6.2	8.1	0.6
ν_l	26.9	1.4	0.0	0.0
η_p	0.1	19.5	0.1	0.4
η_w	0.0	0.3	0.7	0.1
η_r	3.9	0.4	0.0	0.0
ν_π	3.3	4.7	30.7	46.5

Inflation rates

	$T = 1$	$T = 4$	$T = 10$	$T = 30$
ν_a	1.8	32.9	2.8	3.7
ν_b	0.0	1.2	2.0	0.6
ν_i	0.0	0.0	0.0	0.8
ν_g	0.0	0.2	0.2	0.3
ν_u	0.2	4.0	0.2	0.0
ν_l	0.0	0.0	0.0	0.0
η_p	97.1	27.7	16.9	0.1
η_w	0.2	3.8	0.1	0.0
η_r	0.0	0.6	0.1	0.0
ν_π	0.5	29.6	77.6	94.4

Real wages

	$T = 1$	$T = 4$	$T = 10$	$T = 30$
ν_a	12.9	52.3	85.8	90.1
ν_b	2.0	1.7	0.1	4.0
ν_i	3.6	9.5	7.7	4.4
ν_g	0.0	0.0	0.1	1.0
ν_u	0.6	2.4	2.8	0.3
ν_l	0.8	0.2	0.0	0.0
η_p	28.4	29.8	3.3	0.1
η_w	50.4	2.3	0.0	0.0
η_r	0.2	0.1	0.0	0.0
ν_π	1.2	1.6	0.2	0.1

Hours worked

	$T = 1$	$T = 4$	$T = 10$	$T = 30$
ν_a	16.5	0.3	0.2	48.7
ν_b	4.7	0.1	24.6	6.2
ν_i	41.9	57.3	4.6	17.3
ν_g	16.2	12.6	65.6	27.0
ν_u	3.6	0.6	0.5	0.4
ν_l	8.0	1.9	0.8	0.0
η_p	1.2	21.7	0.1	0.2
η_w	2.4	2.0	3.2	0.1
η_r	2.3	0.5	0.0	0.0
ν_π	3.3	3.1	0.5	0.1

Note:

ν_a	productivity shock
ν_b	preference shock
ν_i	investment adjustment cost shock
ν_g	external demand shock
ν_u	utilization adjustment cost shock
ν_l	labor supply disutility shock
η_p	price markup shock
η_w	wage markup shock
η_r	interest rate shock
ν_π	target inflation shock

Table 5: Variance decomposition (continued)

Consumption

	$T = 1$	$T = 4$	$T = 10$	$T = 30$
ν_a	62.5	72.1	84.0	78.2
ν_b	19.9	9.8	0.6	5.4
ν_i	2.4	0.3	3.5	8.4
ν_g	5.7	6.3	8.2	7.4
ν_u	5.9	5.6	3.4	0.3
ν_l	1.5	0.2	0.0	0.0
η_p	0.8	5.0	0.0	0.1
η_w	0.0	0.1	0.1	0.0
η_r	0.5	0.1	0.0	0.0
ν_π	0.9	0.6	0.0	0.1

Investment

	$T = 1$	$T = 4$	$T = 10$	$T = 30$
ν_a	1.6	13.1	65.3	69.9
ν_b	0.6	3.8	12.5	1.6
ν_i	97.4	80.6	19.1	27.7
ν_g	0.0	0.1	0.5	0.2
ν_u	0.0	0.1	0.6	0.0
ν_l	0.0	0.1	0.1	0.1
η_p	0.3	2.0	1.6	0.4
η_w	0.0	0.0	0.1	0.1
η_r	0.0	0.0	0.0	0.0
ν_π	0.0	0.2	0.2	0.0

Output

	$T = 1$	$T = 4$	$T = 10$	$T = 30$
ν_a	43.7	56.6	84.0	94.9
ν_b	7.0	0.3	1.7	2.9
ν_i	36.7	32.1	10.3	1.5
ν_g	6.2	2.2	1.1	0.4
ν_u	3.3	2.7	2.1	0.3
ν_l	1.0	0.2	0.1	0.0
η_p	1.0	5.2	0.5	0.0
η_w	0.0	0.1	0.1	0.0
η_r	0.4	0.1	0.0	0.0
ν_π	0.7	0.6	0.1	0.1

Table 6: Comparison of two models of capital utilization

Parameters	Our model mean	Alternative model (same as CEE/SW/LOWW) mean	90 % interval		
Structural parameters					
θ	0.102	0.087	0.033	-	0.141
σ	1.249	1.240	0.947	-	1.555
χ	2.149	2.144	1.770	-	2.531
$1/\zeta$	6.319	4.732	2.529	-	6.983
ψ	2.370	0.863	0.176	-	1.599
$\phi - 1$	0.084	0.088	0.064	-	0.110
ξ_p	0.875	0.875	0.843	-	0.912
ξ_w	0.516	0.568	0.473	-	0.659
γ_p	0.862	0.908	0.817	-	0.998
γ_w	0.246	0.237	0.012	-	0.443
Policy parameters					
r_i	0.842	0.889	0.775	-	1.008
r_π	0.606	0.515	0.376	-	0.649
r_y	0.110	0.115	0.056	-	0.185
$r_{\Delta\pi}$	0.250	0.196	0.079	-	0.308
$r_{\Delta y}$	0.647	0.471	0.230	-	0.713
S.D. of shocks					
σ_a	0.843	0.741	0.626	-	0.847
σ_π	0.062	0.067	0.032	-	0.098
σ_b	0.102	0.101	0.063	-	0.138
σ_g	0.403	0.407	0.346	-	0.465
σ_l	1.538	1.261	0.612	-	1.748
σ_i	1.413	1.331	1.074	-	1.596
σ_u	0.646	-	-	-	-
σ_r	0.066	0.085	0.031	-	0.147
σ_q	-	-	-	-	-
σ_p	0.151	0.152	0.122	-	0.180
σ_w	0.212	0.205	0.170	-	0.240
Persistence of shocks					
ρ_a	0.949	0.975	0.955	-	0.995
ρ_π	0.974	0.976	0.955	-	0.997
ρ_b	0.892	0.894	0.821	-	0.969
ρ_g	0.960	0.957	0.924	-	0.987
ρ_l	0.563	0.689	0.503	-	0.910
ρ_i	0.350	0.445	0.315	-	0.566
ρ_u	0.901	-	-	-	-

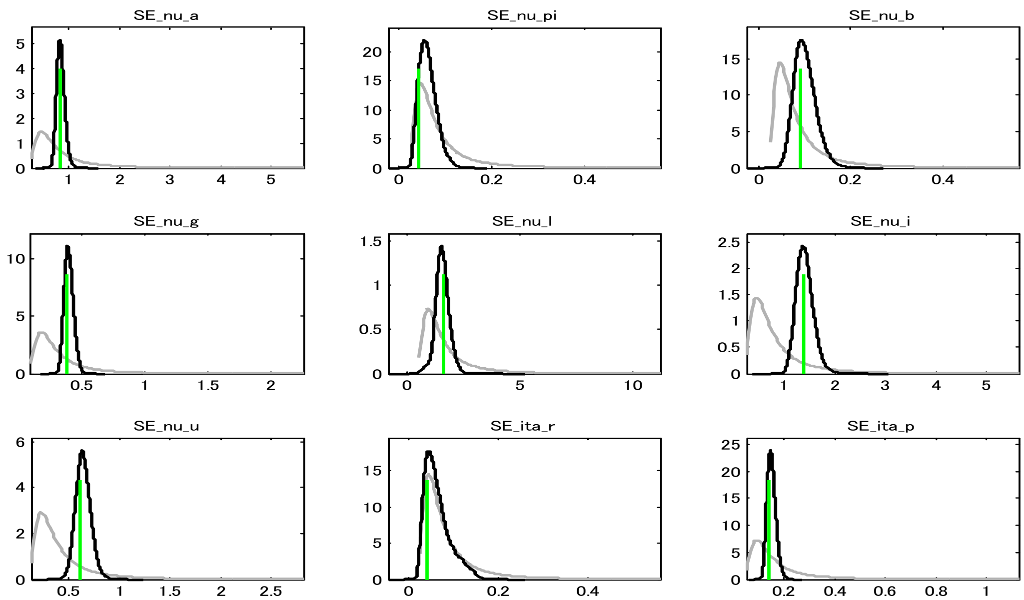

Figure 15: Prior and posterior distributions. Thick and thin curves indicate the posterior and prior distribution of parameters respectively. Vertical lines represent their mode obtained by a maximum liklihood method.

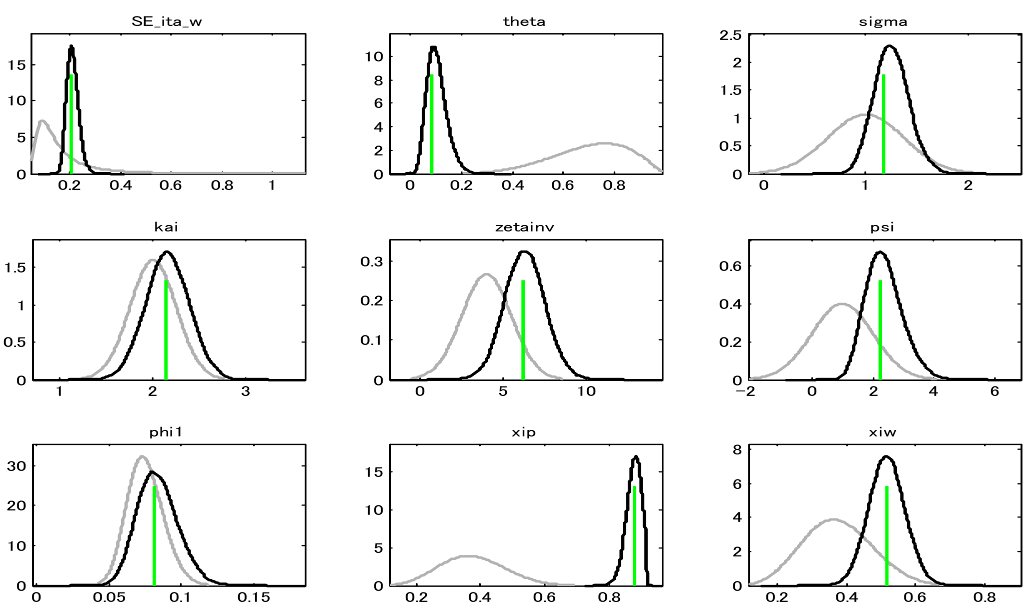

Figure 16: Prior and posterior distributions (continued)

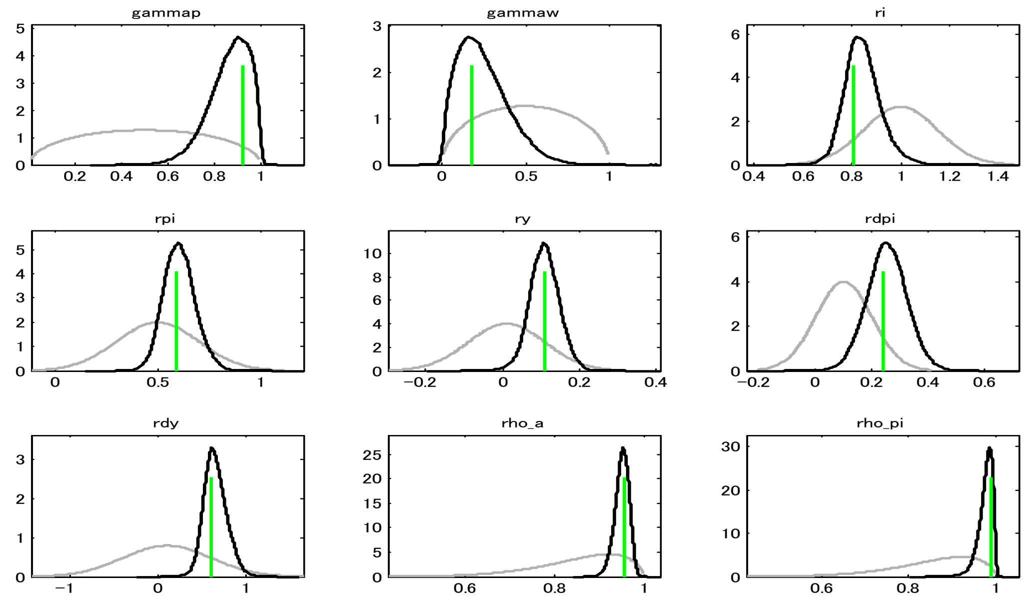

Figure 17: Prior and posterior distributions (continued)

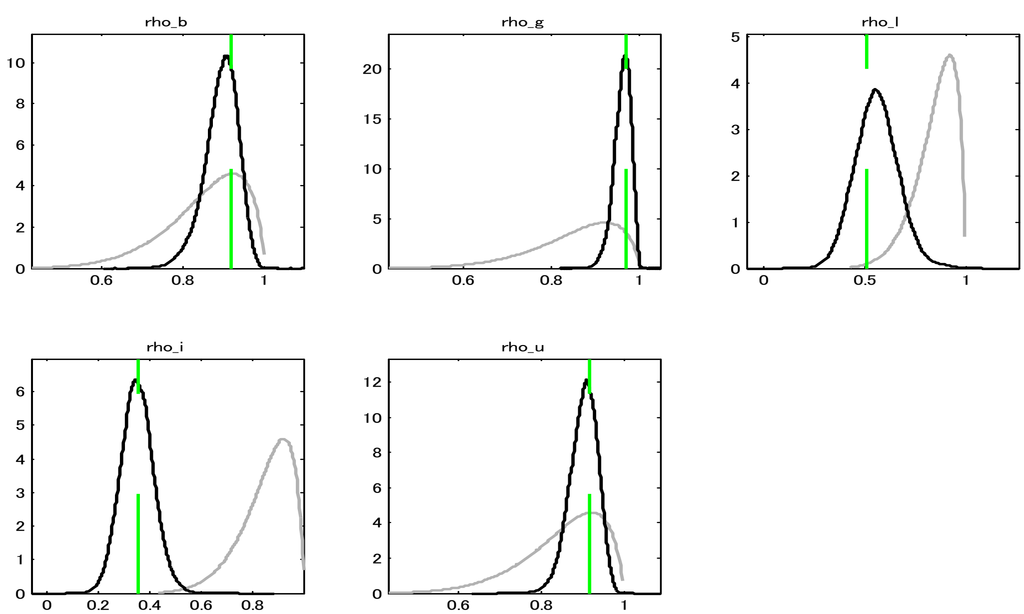

Figure 18: Prior and posterior distributions (continued)

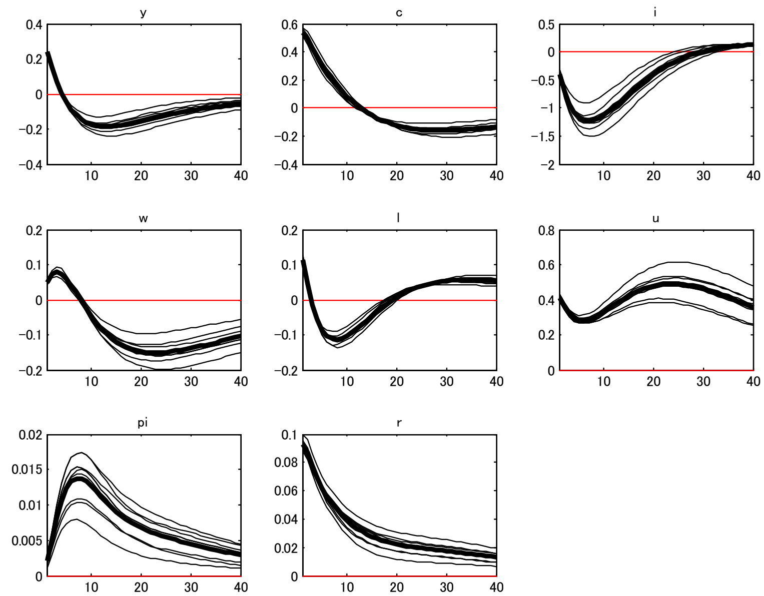

Figure 19: Impulse responses to a preference shock

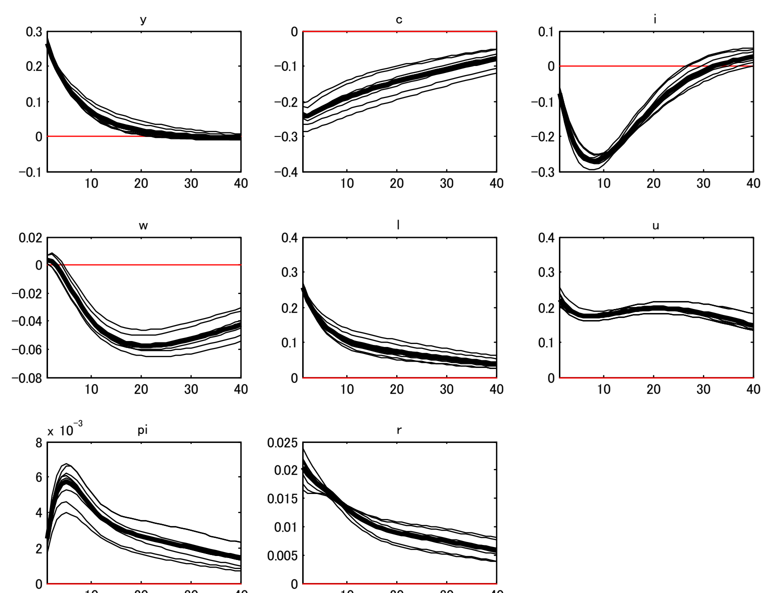

Figure 20: Impulse responses to an external demand shock

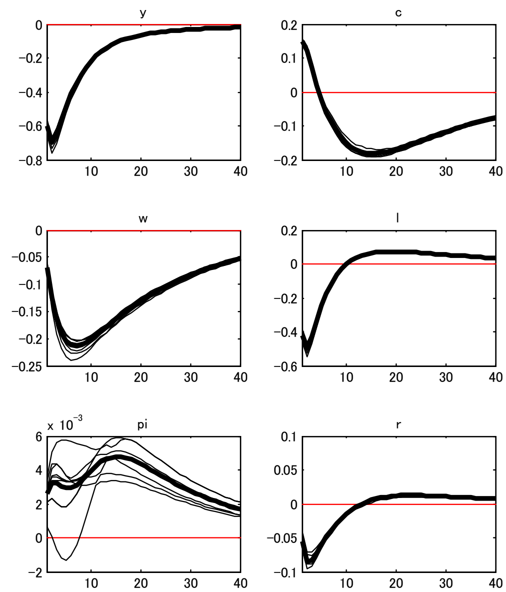

Figure 21: Impulse responses to an investment adjustment cost shock

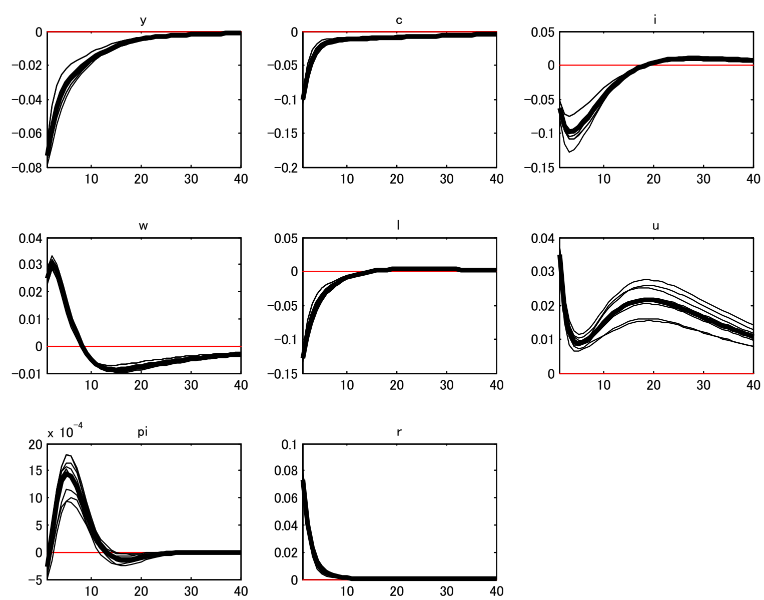

Figure 22: Impulse responses to a labor supply disutility shock

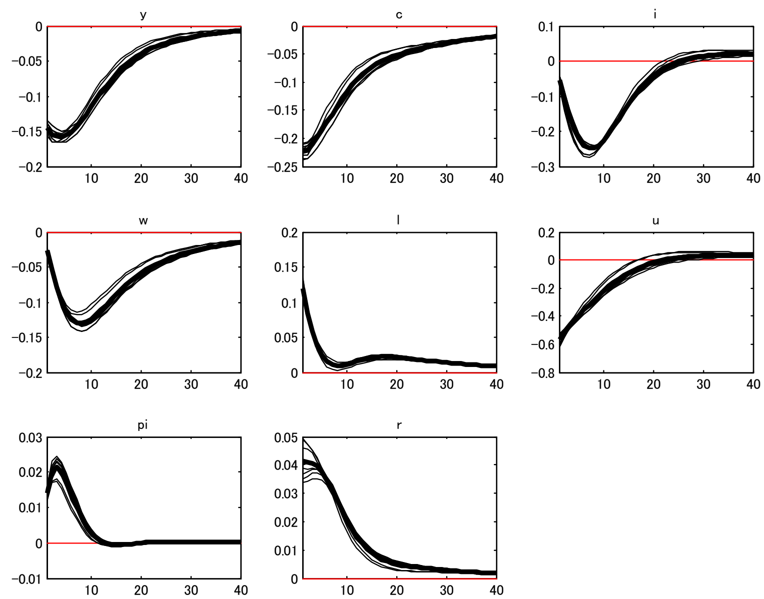

Figure 23: Impulse responses to a capital utilization adjustment cost shock

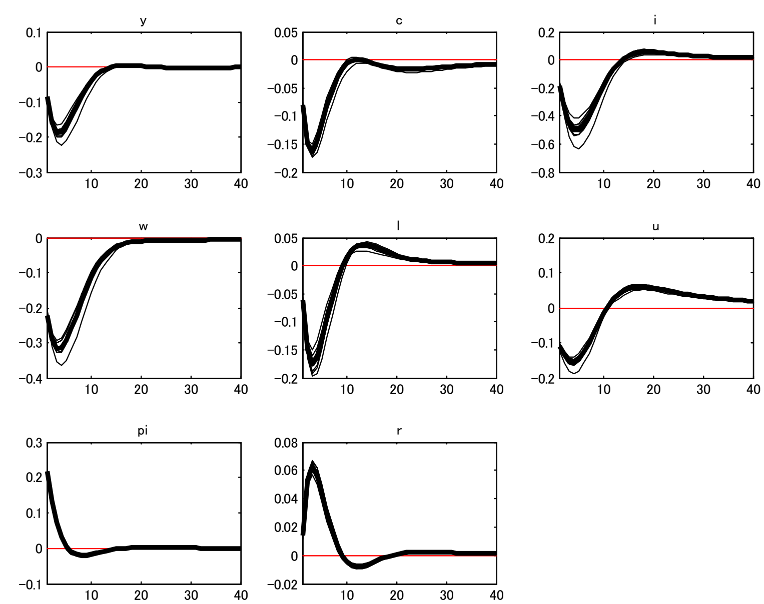

Figure 24: Impulse responses to a price markup shock

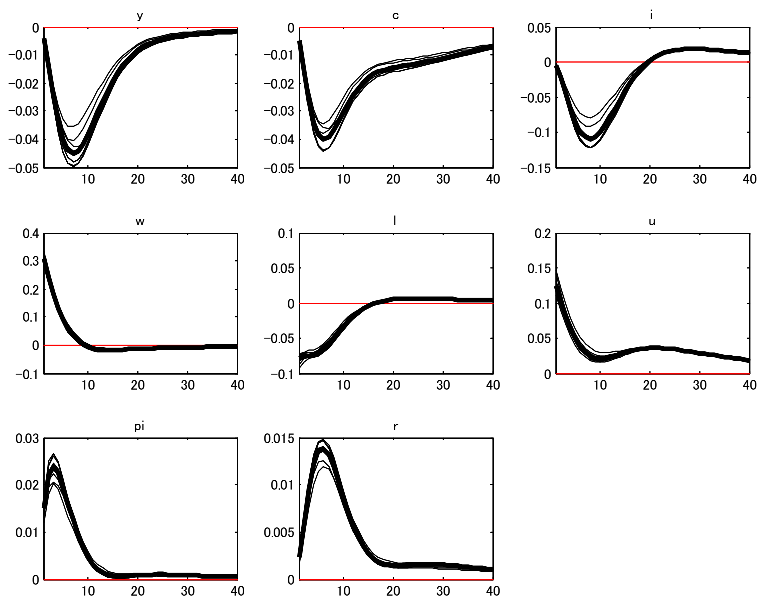

Figure 25: Impulse responses to a wage markup shock