Osaka Metropolitan University
Osaka Metropolitan University
Graduate School of Economics
Discussion Paper Series

Increase in Non-Ricardian Households, Monetary-Policy Posture's Changes, and Structural Shocks' Effects under OccBin Constraints in Japan

Motonori Yoshida

Discussion Paper No. 25-03

February 2026

Graduate School of Economics

Osaka Metropolitan University

Osaka City, 558-8585, Japan

Increase in Non-Ricardian Households, Monetary-Policy Posture's Changes, and Structural Shocks' Effects under OccBin Constraints in Japan[1]

Motonori Yoshida
Graduate School of Economics, Osaka Metropolitan University

Abstract

In a situation of deepening wealth maldistribution and depreciating Japanese yen, the Bank of Japan implemented unconventional monetary-easing policies during 1999q2-2023q4 to overcome economic stagnation and deflation. Here, I estimated the social-structure and policy-posture changes over 1972Q3-1999Q1 (normal regime) and 1999Q2-2023Q4 (unconventional regime) by using a New Keynesian dynamic stochastic general equilibrium (DSGE) model and derived impulse responses to fiscal/monetary-policy and productivity shocks under occasionally binding (OccBin) constraints on nominal interest rates. My analysis revealed that (1) in the second term, non-Ricardian households' share became 3.5 times that in the first term, (2) nominal interest-rate shocks lost their influences to the variations in economic variables in the second term, and (3) the differences in impulse response between the linear and piecewise-linear solutions are relatively remarkable on $\hat{r}_t$ and $\widehat{m_t}$ through all structural shocks.

Keywords: DSGE model, Non-Ricardian households, Taylor rule, Zero/Effective lower bound (ZLB/ELB), Occasionally binding (OccBin) constraints, Piecewise-linear solution

JEL Classification Numbers: E62, E63, H30, H31, H63

[1] This paper is a revised and extended version of Yoshida (2024). In the current version, I implemented an elaborate estimation to more clearly elucidate the influences of unconventional monetary easing. Concretely, I set 1999q2-2023q4, during which the Bank of Japan adopted a series of unconventional monetary-easing policies, as the second sample term and obtained the modes of the posterior distribution of the DSGE-model parameters in a more elaborate way. I also derived the impulse responses of endogenous variables to structural shocks by using a piecewise-linear solution method with OccBin constraints. Therefore, while this paper is based on Yoshida (2024), it adds some modifications to the model and differs in terms of the sample terms, estimation method, estimation results, and discussion: Yoshida (2024) is available from URL: file:///C:/Users/owner/Downloads/CV_20260212_2024000152.pdf (accessed on February 12, 2026).

1. Introduction

The Japanese economy lost its vitality after the collapse of its bubble economy in the early 1990s. According to the International Money Fund (IMF), Japan's status in the world economy has fallen during the subsequent decades. Regarding the size of its gross domestic product (GDP) (in nominal U.S. dollars), Japan ranked second among all countries in 2000. However, its ranking dropped to third in 2010 and to fourth in 2024. Regarding per capita GDP, although Japan's position was third in 2000, its ranking dropped to 18th in 2010 and to 39th in 2024.[2] To scrutinize the mired situation of the Japanese economy more deeply, I have prepared Figures 1-2. Figure 1 describes the long-term downturn of the year-on-year growth rate of Japan's nominal GDP (in Yen) since the 1970s. Japan has not fully recovered from the devastation when its bubble economy burst. Figure 2, indicating the changes in the GDP deflator and the unsecured overnight call rate, reveals that Japan had been suffering from deflation from the end of 1990s through to the beginning of 2020s and the Bank of Japan (BOJ) had tackled this deflation trend with unconventional monetary-easing policies (including zero and negative interest policies). In the context of this economic sluggishness, I infer that the number of *non-Ricardian* households (also referred to "rule-of-thumb" or "hand-to-mouth" ones) has been increasing in Japan in line with the deepening worldwide wealth maldistribution. The Gini coefficient on income in Japan rose from 0.349 in 1981 to 0.586 in 2023: the coefficient after income redistribution rose from 0.314 to 0.383. These figures show that income inequality in Japan is clearly growing (however, Japan's government has ameliorated this unfair situation to some extent).

Considering the facts and inference above, investigating Japan's economic structural changes since the 1970s is quite meaningful in the context of implementing appropriate

[2] See the IMF's website on World Economic Outlook for details: https://www.imf.org/external/datamapper/datasets/WEO (accessed on February 11, 2026).

monetary and fiscal policies. Hence, I investigated them employing a middle-scale New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model. However, analyzers trying this task should take care of the following two problems. First, standard NK DSGE models, such as Smets and Wouters (2003, 2005, 2007) and Christiano et al. (2005), cannot deal with consumption growth in response to positive government-spending shock, i.e., crowding in. While standard models assume that representative households rationally make their decisions from a lifecycle perspective, Gali et al. (2007) introduced *non-Ricardian* households that consume all their disposable income every period to solve the crowding-in puzzle.[3] Following Gali et al. (2007), Forni et al. (2009) obtained an estimate (0.34) of the *non-Ricardian* household share in the Euro area over 1980Q1-2005Q4. Iwata (2009) estimated this share to be 0.248 in Japan over 1980Q1-1998Q4. Also, Smets and Wouters (2007) estimated the coefficient parameters of the inflation rate and output gap of 2.04 and 0.08 on the monetary-policy reaction function over 1966Q1-2004Q4 in the U.S. Smets and Wouters (2003) obtained estimates of (0.956, 0.098) over 1980Q2-1999Q4 in the Euro area. Sugo and Ueda (2008) and Hirose and Kurozumi (2012) respectively estimated these parameters (0.606, 0.110) over 1981Q1-1995Q4 and (1.683, 0.079) over 1981Q1-1998Q4 for Japan.

Second, the multimodality and non-convexity of the model parameters' posterior distribution hinder the search for their posterior modes, which is the first procedure of the Markov chain Monte Carlo (MCMC) method used to estimate a DSGE-model parameters with Bayesian estimation. An and Schorfheide (2007) reports the existence of multiple modes regarding even a small-scale NK DSGE model. Furthermore, when analyzers utilize time-series variables' data including zero interest-rate periods, this problem tends to become more

[3] There exist other measures that can solve this crowding-in puzzle. Corsetti et al. (2012) introduced a government-spending soothing rule in response to outstanding government bonds. Fève et al. (2013) and Iwata (2013) adopted Edgeworth complementarity between private and government consumption.

apparent.

Given these problems, I decided to employ the following tactics to complete my study. First, I incorporated *non-Ricardian* households into my model (see Section 2 for the details). Second, I estimated my DSGE-model parameters over two sample terms, the first term 1972Q3-1999q1 of which is set as the normal monetary-policy regime and the second term 1999q2-2023q4 as the unconventional regime (Figures. 1-2). Third, I included the Monte Carlo Optimization Method (Rastrigin, 1963; Solis and Wets, 1981) in the second term, which is not gradient based, to obtain the parameters' posterior modes, contemplating the possibility of the posterior distribution being multi-modal and highly non-linear.

Next, I will briefly discuss the zero lower bound (ZLB) / effective lower bound (ELB) constraint on nominal interest rates. As discussed above, the BOJ introduced a zero interest-rate policy in the late 1990s to address prolonged stagnation following the collapse of the bubble economy. Subsequently, central banks in other advanced economies adopted near-zero, zero, and even negative interest-rate policies in response to the Global Financial Crisis. Reflecting these developments, the DSGE literature has increasingly incorporated the ZLB/ELB constraint on nominal interest rates into model analysis. Guerrieri and Iacoviello (2015) developed a piecewise-linear solution method that extends the standard first-order perturbation approach, i.e., typically a local approximation around the steady state, to accommodate occasionally binding (OccBin) constraints such as the ZLB/ELB. Eggertsson et al. (2021) incorporated Guerrieri and Iacoviello's (2015) deterministic dynamic model into a stochastic setting by utilizing an exogenous shock following a two-state Markov process with an absorbing state. In contrast, Gust et al. (2017) and Aruoba et al. (2021) estimated a DSGE-model parameters by using global nonlinear methods based on projection techniques, whereby equilibrium policy functions are approximated over the entire state space rather than locally around the steady state.[4] Other contributions, such as Chen (2017) and Maih et al. (2021), analyzed the ZLB/ELB problem by using Markov-switching models that allow monetary policy parameters to stochastically change across regimes. Building on this literature, I adopted the piecewise-linear approach of Guerrieri and Iacoviello (2015) in order to analyze impulse responses to structural fiscal/monetary and productivity shocks under OccBin ZLB/ELB constraints. This choice was motivated by the structure of my empirical analysis. Specifically, I estimated the monetary policy parameters separately for two distinct sample terms corresponding to different monetary policy regimes. I then conducted deterministic OccBin simulations using these regime-specific parameter estimates, calibrating structural shocks based on the variance estimates obtained from the first sample term (the normal monetary-policy regime). Through this analysis, I observed how the structural shocks influence the Japanese economy with the latest economic situation being the initial steady state.

The following are the main results of this study. (1) The share of *non-Ricardian* households in the second term was 3.5 times that of the first term. (2) While the BOJ's response to output gaps strengthened in the second term compared with the first term, its response to inflation rates considerably weakened. (3) Nominal interest rates have become more inert since the late 1990s. (4) The Japanese government had implemented sustainable fiscal policies throughout both terms. (5) While production-technology shocks maintained their influence on endogenous economic-variable variations in both terms, interest-rate shocks lost theirs in the second term. Government-spending shocks grew in influence in the second term. (6) The differences in impulse response between the LSs and PWLSs were relatively remarkable on $\widehat{r_t}$ and $\widehat{m_t}$ through all structural shocks.

The rest of this paper is organized as follows. Section 2 describes my model. Section 3

[4] Projection methods can cope with occasionally binding constraints in a direct way, but they also incur considerable computational burden (suffer from the curse of dimensionality).

explains the data and the parameter estimation methods. Section 4 reports the estimation results and discusses the socio-economic changes and effects of Japan's fiscal and monetary policies. Section 5 concludes the paper.

[Figures 1-3 near here]

2. Model

I made a medium-scale closed-economy NK DSGE model along the lines of such previous studies as Smets and Wouters (2003, 2005) and Christiano et al. (2005) and included the following features in it: (1) "sticky prices on intermediate goods," following Calvo (1983),[5] (2) "investment adjustment cost," like in Smets and Wouters (2003) and others, (3) "*non-Ricardian* households," like in Gali et al. (2007), and (4) "stochastic trends in neutral technological changes" for considering balanced growth, like in Erceg et al. (2006) and Smets and Wouters (2007).

Since the end of Japan's period of rapid economic growth which lasted from the mid-1950s through the early 1970s, the Japanese government has implemented various countercyclical fiscal policies as well as monetary-easing policies (Figure 2) in economic recession periods. To examine these policies' effects, I incorporated government-spending and tax shocks as well as monetary-policy (interest) and product-technology ones like those of Forni et al. (2009) and Iwata (2013). Regarding the model's basic description, I followed Smets and Wouters (2003, 2005, 2007), Hirose and Kurozumi (2010, 2012), and Eguchi (2011).

2.1 Assumptions of the model

[5] For simplicity, I omitted "staggered wage contract" and "habit formation of consumption."

The economy includes households, a final-good firm, intermediate-good firms, the government,[6] and the central bank as agents, and a final-good market, intermediate-good markets, labor markets, a capital market, and a government-bond[7] market. The necessary assumptions are as follows. (1) A continuum of households is indexed by $i \in [0,1]$. A fraction $1-\omega$ of the continuum consists of *Ricardian* households that maximize intertemporal expected utility. The remaining fraction ω consists of *non-Ricardian* ones (also referred to as "rule-of-thumb" or "hand-to-mouth" households) that consume all their disposable income every period. Since non-Ricardian households cannot divert funds into savings, only the Ricardian ones can invest, purchase government bonds, and save their remaining income as money stock. However, since each household is homogeneous in its category, I will omit the index i for describing the households' behaviors. (2) Except for the intermediate-good markets, which are monopolistic competitive, and the labor markets,[8] all markets are perfectly competitive. (3) There is a continuum of intermediate-good firms, indexed by $j \in [0,1]$, that can control their goods' supply prices because each intermediate good is differentiated. However, only a fraction $1-\eta$ of the continuum can reoptimize prices every period (the remaining fraction η leaves prices identical to those in the previous period). Each firm reoptimizes its price on a stochastic basis every period, and the probability of reoptimization is independent of the history up to the previous period. (4) The intermediate-good firms utilize labor and capital as their production factors. The final-good firm produces its goods from intermediate goods, and the final good is used for consumption or investment.

2.2 Households

2.2.1 *Ricardian* households

[6] The government is assumed to be identical to a "general government in the National Accounts," which consists of a central government, local governments, and social security funds.
[7] Government bonds denote both central and local government bonds.
[8] See Footnote 10 for the details.

The following is the *Ricardian* household's expected lifetime utility function, LTU_0^{rc}:

$$LTU_0^{rc} = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{rc\,1-\theta}}{1-\theta} + \frac{z_t^{-\theta}}{1-\zeta} \left(\frac{M_t^{rc}}{P_t} \right)^{1-\zeta} - \frac{z_t^{1-\theta} l_t^{rc\,1+\varphi}}{1+\varphi} \right], \tag{1}$$

where C_t, M_t ,P_t, l_t, and z_t respectively indicate the nominal consumption-goods amount, nominal money balance (based on the money-in-utility assumption), aggregate price level, labor-supply amount, and production technique level. $\beta > 0$, $\theta > 0$, $\zeta > 0$, and $\varphi > 0$ respectively represent the subjective discount factor, coefficient of relative risk aversion of households or inverse of intertemporal elasticity of substitution, inverse of money demand elasticity, and inverse of labor supply elasticity. E indicates an expected operator, and t indexes periods. However, z_t to the power of $-\theta \,/\, 1-\theta$ appears in the second and third terms in [·] of Equation (1) in a similar way to Erceg et al. (2006) and Hirose and Kurozumi (2010). This z_t part ensures the existence of a balanced growth path for the model economy. The superscript *rc* indicates that the corresponding variable is one regarding *Ricardian* households.

This household's budget constraint is given by

$$\begin{aligned} &P_t c_t^{rc} + P_t i_t^{rc} + M_t^{rc} + B_t^{rc} \\ &= W_t l_t^{rc} + r_t^k P_t k_{t-1}^{rc} + R_{t-1} B_{t-1}^{rc} + M_{t-1}^{rc} + D_t^{rc} - P_t \tau_t^{rc}. \end{aligned} \tag{2}$$

In Equation (2), i_t, B_t, W_t, r_t^k, R_t, D_t, and τ_t respectively represent the real investment amount, nominal government-bond amount purchased in period t, nominal wage rate, real rental rate of capital, gross nominal interest rate, nominal dividends from the excess profits of the intermediate-good firms, and real lump-sum tax amount. Dividing both sides of Equation (2) by P_t, the following is derived:

$$c_t^{rc} + i_t^{rc} + m_t^{rc} + b_t^{rc} = w_t l_t^{rc} + r_t^k k_{t-1}^{rc} + \frac{R_{t-1}}{\Pi_t} b_{t-1}^{rc} + \frac{1}{\Pi_t} m_{t-1}^{rc} + d_t^{rc} - \tau_t^{rc}. \tag{3}$$

In Equation (3), $b_t \equiv B_t/P_t$, $m_t \equiv M_t/P_t$, $d_t \equiv D_t/P_t$, $w_t \equiv W_t/P_t$, and. $\Pi_t \equiv P_t/P_{t-1}$.

The capital accumulation equation is given by

$$k_t^{rc} = (1-\delta)k_{t-1}^{rc} + i_t^{rc} - S\left(\frac{i_t^{rc}}{i_{t-1}^{rc}}\right) i_t^{rc}. \tag{4}$$

In Equation (4), δ and S(·) are the capital depreciation rate and the adjustment cost function of investment. For simplicity, I assume that $S(z) = S'(z) = 0$ and $S''(z) > 0$: $z > 0$ is the (gross) trend rate of neutral technological changes.

This household optimizes Equation (1) subject to Equations (3) and (4). As a result, the following first-order conditions (FOCs) are obtained regarding the control variables: c_t^{rc}, l_t^{rc}, m_t^{rc}, k_t^{rc}, i_t^{rc}, and b_t^{rc}:

$$c_t^{rc-\theta} = \Lambda_\mathrm{t}\ , \tag{5}$$

$$z_t^{1-\theta} l_t^{rc\varphi} = \Lambda_t w_t\ , \tag{6}$$

$$z_t^{-\theta} m_t^{rc-\zeta} = \Lambda_t - \beta E_t\left[\Lambda_{t+1}\frac{1}{\Pi_{t+1}}\right], \tag{7}$$

$$\Lambda_t = \mathrm{MU}_t\left[1 - S'\left(\frac{i_t^{rc}}{i_{t-1}^{rc}}\right)\frac{i_t^{rc}}{i_{t-1}^{rc}} - S\left(\frac{i_t^{rc}}{i_{t-1}^{rc}}\right)\right] + \beta \mathrm{MU}_{t+1} S'\left(\frac{i_{t+1}^{rc}}{i_t^{rc}}\right)\left(\frac{i_{t+1}^{rc}}{i_{t1}^{rc}}\right)^2, \tag{8}$$

$$\mathrm{MU}_t = \beta E_t\left[\Lambda_{t+1} r_{t+1}^k + \mathrm{MU}_{t+1}(1-\delta)\right], \tag{9}$$

$$\Lambda_t = \beta E_t\left[\frac{R_t}{\Pi_{t+1}}\Lambda_{t+1}\right]. \tag{10}$$

In Equations (5)-(10), Λ_t and MU_t denote Lagrange multipliers, specifically the marginal utility of consumption and the investment in period t.

Finally, Euler's equation of consumption, the optimal condition of labor supply, the money demand function, Tobin's q,[9], and the optimal condition of capital are derived from the above FOCs:

$$c_t^{rc^{-\theta}} = \beta E_t \left[\frac{R_t}{\Pi_{t+1}} c_{t+1}^{rc^{-\theta}} \right], \tag{11}$$

$$l_t^{rc\varphi} = \left(\frac{w_t}{z_t} \right) \left(\frac{c_t^{rc}}{z_t} \right)^{-\theta}, \tag{12}$$

$$m_t^{rc^{-\zeta}} = \left(\frac{R_t - 1}{R_t} \right) \left(\frac{c_t^{rc}}{z_t} \right)^{-\theta}, \tag{13}$$

$$q_t \left[1 - S' \left(\frac{i_t^{rc}}{i_{t-1}^{rc}} \right) \frac{i_t^{rc}}{i_{t-1}^{rc}} - S \left(\frac{i_t^{rc}}{i_{t-1}^{rc}} \right) \right] = 1 - E_t \left[\frac{\Pi_{t+1}}{R_{t+1}} q_{t+1} S' \left(\frac{i_{t+1}^{rc}}{i_t^{rc}} \right) \left(\frac{i_{t+1}^{rc}}{i_{t1}^{rc}} \right)^2 \right], \tag{14}$$

$$q_t = E_t \left\{ \frac{\Pi_{t+1}}{R_t} \left[r_{t+1}^k + q_{t+1}(1 - \delta) \right] \right\}. \tag{15}$$

In Equations (14) and (15), q_t represents $\mathrm{MU}_t / \Lambda_t$.

2.2.2 *Non-Ricardian* households

Non-Ricardian households consume all their disposal income every period in accordance with Equation (16):

$$c_t^{nrc} = w_t l_t^{nrc} - \tau_t^{nrc}. \tag{16}$$

Note that variables with superscript *nrc* are those of *non-Ricardian* households. Following

[9] Tobin's q is derived by dividing both sides of Equation (8) by Λ_t .

Gali et al. (2007), I assume that the labor supply of these households is identical to that of the *Ricardian* households[10]:

$$l_t^{nrc} = l_t^{rc} \ . \tag{17}$$

2.2.3 Aggregation

The aggregate amount of each variable concerning household decision-making is given by a weighted average of that variable over each household type:

$$c_t \equiv (1-\omega)c_t^{rc} + \omega c_t^{nrc} \ , \tag{18}$$

$$l_t \equiv (1-\omega)l_t^{rc} + \omega l_t^{nrc} \ , \tag{19}$$

$$\tau_t \equiv (1-\omega)\tau_t^{rc} + \omega \tau_t^{nrc} \ . \tag{20}$$

$$i_t \equiv (1-\omega)i_t^{rc} \ , \tag{21}$$

$$m_t \equiv (1-\omega)m_t^{rc} \ , \tag{22}$$

$$k_t \equiv (1-\omega)k_t^{rc} \ , \tag{23}$$

$$b_t \equiv (1-\omega)b_t^{rc} \ . \tag{24}$$

2.3 Final-good firm

Final goods are produced by a representative firm in a perfectly competitive market with a Dixit-Stiglitz-type constant elasticity of substitution (CES) function:

[10] Imperfectly competitive labor markets with the following features are assumed as a backdrop. (1) Intermediate-good firms allocate labor demand uniformly across different worker types and indifferently of the household type. (2) The ratio of non-Ricardian households is the same across worker types. (3) A unique and representing labor union exists for each worker type. In each period, each union sets wages that maximizes the weighted average utility for Ricardian and non-Ricardian households belonging to the union. See Section 3.1 and Appendix A of Gali et al. (2007) for the details.

$$y_t = \left[\int_0^1 y_t(j)^{\frac{\psi-1}{\psi}} dj\right]^{\frac{\psi}{\psi-1}}, \tag{25}$$

where y_t and $y_t(j)$ represent the output amount of the final good and the input amount of the jth intermediate good. The real profit of the final-good firm, RP_t, is given by

$$RP_t = y_t - \int_0^1 \frac{P_t(j)}{P_t} y_t(j) dj , \tag{26}$$

where $P_t(j)$ represents the price of the jth intermediate good.

Finally, by optimizing Equation (26) subject to Equation (25), the final-good firm obtains the demand function of the jth intermediate good:

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\psi} y_t . \tag{27}$$

Subsequently, the following zero-profit condition is derived upon substituting Equation (27) into Equation (25):

$$P_t = \left[\int_0^1 P_t(j)^{1-\psi} dj\right]^{\frac{1}{1-\psi}} . \tag{28}$$

2.4 Intermediate-good firms

Each intermediate-good firm decides its optimal behavior in two steps: the first is cost minimization of production, and the second is profit maximization.

Cost minimization

Each firm produces its differentiated good by using the following Cobb-Douglass production function:

$$y_t(j) = k_{t-1}(j)^{\alpha}[z_t l_t(j)]^{1-\alpha} \ . \tag{29}$$

Here, $k_{t-1}(j)$ and $l_t(j)$ are the capital stock and the amount of labor hired by the jth firm. z_t represents the level of neutral technology,[11] which is assumed to obey the following stochastic process:

$$\log z_t = \log z + \log z_{t-1} + z_t^z \ . \tag{30}$$

Here, z_t^z represents a shock to the technology-level change rate, which follows a stationary first-order autoregressive process. Given r_t^k and w_t, cost minimization subject to Equation (29) yields the following capital-labor ratio:

$$\frac{l_t(j)}{k_{t-1}(j)} = \frac{(1-\alpha)r_t^k}{\alpha w_t} \ . \tag{31}$$

The capital stock and labor demand functions are derived for the jth firm by substituting Equation (31) into Equation (29). The following marginal cost, mc_t, is derived from those demand functions:

$$mc_t = \left[\frac{w_t}{(1-\alpha)z_t}\right]^{1-\alpha} \left(\frac{r_t^k}{\alpha}\right)^{\alpha} \ . \tag{32}$$

[11] I assumed a labor-augmenting technical change in order to maintain balanced growth. See King et al. (2002) for the details about balanced growth constraints.

Profit maximization

Since only a fraction, i.e., $1-\eta$, of the intermediate-good firms can reoptimize the prices every period, the jth firm decides the optimal price of its good, ${P_t}^*(j)$, to maximize the following expected profit, PF_t(j), in a forward-looking manner under the constraint of Equation (27):

$$PF_t(j) = E_t \sum_{k=0}^{\infty} \beta^k \frac{\Lambda_{t+k}}{\Lambda_t} \eta^k \left[\left(\frac{P_t^*(j)}{P_t} \right) y_{t+k}(j) - mc_{t+k} y_{t+k}(j) \right]. \quad (33)$$

The FOC and ${P_t}^*(j)$ are derived accordingly:

$$E_t \sum_{k=0}^{\infty} \beta^k \frac{\Lambda_{t+k}}{\Lambda_t} \eta^k \left[\frac{P_t^*(j)}{P_t} - \frac{\psi}{\psi-1} mc_{t+k} \right] y_{t+k}(j) = 0 , \quad (34)$$

$$P_t^*(j) = \frac{\psi}{\psi-1} \frac{E_t \sum_{k=0}^{\infty} \beta^k \frac{\Lambda_{t+k}}{\Lambda_t} \eta^k y_{t+k}(j) \left[\frac{w_t}{(1-\alpha) z_t} \right]^{1-\alpha} \left(\frac{r_t^k}{\alpha} \right)^{\alpha}}{E_t \sum_{k=0}^{\infty} \beta^k \frac{\Lambda_{t+k}}{\Lambda_t} \eta^k \frac{y_{t+k}(j)}{P_{t+k}}} . \quad (35)$$

Note that $\psi/(\psi-1)$ indicates the mark-up ratio for the monopolistic jth firm. Since $p_t(j) = p_{t-1}(j)$ for the remaining fraction η of the intermediate-good firms, the aggregate price law of motion is expressed as

$$P_t = \left[\eta P_{t-1}^{1-\psi} + (1-\eta) P_t^*(j)^{1-\psi} \right]^{\frac{1}{1-\psi}} . \quad (36)$$

Note that $P = P^*(j)$ and $y(j) = y$ (see Equation (27)) are held in a steady state.

Aggregation

Equations (31) and (32), the capital stock demand function, and the labor demand function, are identical among the intermediate-good firms. Consequently, the following aggregated relationships are derived:

$$\frac{l_t}{k_{t-1}} = \frac{(1-\alpha)r_t^k}{\alpha w_t}, \tag{37}$$

$$\int_0^1 y_t(j)dj = {k_{t-1}}^{\alpha}[z_t l_t]^{1-\alpha}, \tag{38}$$

where $k_{t-1} = \int_0^1 k_{t-1}(j)dj$ and $l_t = \int_0^1 l_t(j)dj$.

2.5 Government, central bank, and market clearing of the final good

The government implements its fiscal policies under the following budget constraint:

$$B_t = R_{t-1}B_{t-1} + P_t g_t - P_t \tau_t, \tag{39}$$

where g_t represents the real amount of government spending, which follows a stationary first-order autoregressive process. Dividing both sides of Equation (39) by P_t, the budget constraint is reshaped into the following. The details of the lump-sum taxation rule are explained in Section 2.6.

$$b_t = \frac{R_{t-1}}{\Pi_t} b_{t-1} + g_t - \tau_t. \tag{40}$$

Next, the central bank conducts its monetary policy in accordance with the Taylor (1993) rule.[12] This policy's details are mentioned in Section 2.6. The market clearing condition for the final goods is:

[12] See Clarida et al. (1999) for the objective function of the central bank.

$$y_t = c_t + i_t + gt\ . \tag{41}$$

2.6 Log-linearized equilibrium conditions

The real economic variables have a common growth trend stemming from the (gross) trend rate of neutral technological changes. Hence, before log linearizing the equilibrium conditions, I detrended these variables: $yd_t \equiv y_t/z_t$, $cd_t \equiv c_t/z_t$, $wd_t \equiv w_t/z_t$, $id_t \equiv i_t/z_t$, $kd_t \equiv k_t/z_t$, $bd_t \equiv b_t/z_t$, $gd_t \equiv g_t/z_t$, $\tau d_t \equiv \tau_t/z_t$, and $\lambda_t \equiv \Lambda_t z_t^{\theta}$.

After log-linearizing the equilibrium conditions, the system of these equations was converted into the following form:[13]

$$\widehat{cd_t^{rc}} = E_t\left[z_{t+1}^z + \widehat{cd_{t+1}^{rc}}\right] - \frac{1}{\theta}\left[\widehat{r_t} - \pi_{t+1}\right] \text{ (see Equation (11)).} \tag{42}$$

$$\widehat{cd_t^{nrc}} = \left(\frac{wdl}{cd}\right)\left[\widehat{wd}_t + \widehat{l_t}\right] - \left(\frac{yd}{cd}\right)\widehat{\tau d_t} \tag{43}$$
(see Equations (16), (17), (19), and (20)).

$$\widehat{cd_t} = (1-\omega)\widehat{cd_t^{rc}} + \omega\ \widehat{cd_t^{nrc}} \text{ (see Equation (18)).} \tag{44}$$

$$\widehat{l_t} = \frac{1}{\varphi}\widehat{wd}_t - \frac{\theta}{\varphi}\widehat{cd_t} \text{ (see Equations (12) and (19)).} \tag{45}$$

$$\widehat{m_t} = \frac{\theta}{\zeta}\widehat{cd_t} - \frac{1}{\zeta(R-1)}\widehat{r_t} \text{ (see Equations (13) and (22)).} \tag{46}$$

$$\begin{aligned}\widehat{\iota d_t} &= \frac{1}{1+z(z^{-\theta}\beta)}\widehat{\iota d_{t-1}} + \frac{z(z^{-\theta}\beta)}{1+z(z^{-\theta}\beta)}E_t\widehat{\iota d_{t+1}} \\ &\quad - \frac{1}{1+z(z^{-\theta}\beta)}\frac{\kappa}{z^2}\widehat{q_t} - \frac{1}{1+z(z^{-\theta}\beta)}z_t^z, \kappa = \frac{1}{S''(z)},\end{aligned} \tag{47}$$
(see Equations (14) and (21)).

$$\widehat{q_t} = E_t\pi_{t+1} - \widehat{r_t} + \frac{r^k}{1+r^k-\delta}\widehat{r_{t+1}^k} + \frac{1-\delta}{1+r^k-\delta}E_t\widehat{q_{t+1}} \text{ (see Equation (15)).} \tag{48}$$

[13] In log-linearizing the equations, I also utilized Uhlig's (1999) method.

$$\pi_t = \frac{\beta}{z^\theta} E_t \pi_{t+1} + \frac{(1-\eta)\left(1-\frac{\beta\eta}{z^\theta}\right)}{\eta}\left[(1-\alpha)\widehat{wd}_t + \alpha\widehat{r_t^k}\right] \tag{49}$$

(see Equations (35) and (36)).

$$\widehat{yd}_t = \alpha\widehat{kd_{t-1}} - z_t^z + (1-\alpha)\widehat{l}_t \text{ (see Equations (25) and (38)).} \tag{50}$$

$$z_t^z + \widehat{l}_t - \widehat{kd_{t-1}} = \widehat{r_t^k} - \widehat{wd}_t \text{ (see Equation (37)).} \tag{51}$$

$$\widehat{kd}_t = \frac{1-\delta}{z}\widehat{kd_{t-1}} - \frac{1-\delta}{z}z_t^z + \frac{z-(1-\delta)}{z}\widehat{\iota d}_t \text{ (see Equations (4) and (23)).} \tag{52}$$

$$\widehat{bd}_t = \frac{R}{z}\widehat{bd_{t-1}} + \frac{R}{z}\frac{bd}{yd}\widehat{r_{t-1}} - \frac{R}{z}\frac{bd}{yd}\pi_t - \frac{R}{z}\frac{bd}{yd}z_t^z + \widehat{gd}_t - \widehat{\tau d}_t \tag{53}$$

(see Equation (40)).

$$\widehat{yd}_t = \frac{cd}{yd}\widehat{cd}_t + \frac{id}{yd}\widehat{\iota d}_t + \widehat{gd}_t \text{ (see Equation (41)).} \tag{54}$$

$$\widehat{\tau d}_t = \frac{\phi_b}{z}\widehat{bd_{t-1}} + \varepsilon_{\tau t}. \tag{55}$$

$$\widehat{gd}_t = \rho_g\widehat{gd_{t-1}} + \varepsilon_{gt}. \tag{56}$$

$$z_t^z = \rho_z z_{t-1}^z + \varepsilon_{zt}. \tag{57}$$

$$\widehat{r}_t = \rho_r\widehat{r_{t-1}} + \phi_\pi\pi_t + \phi_y\widehat{yd}_t + \varepsilon_{rt}. \tag{58}$$

Here, let me note the important points about the above equations. (1) The hatted variables (except $\widehat{bd}_t$, $\widehat{gd}_t$, $\widehat{\tau d}_t$, and $\widehat{r}_t$) represent the log deviations from their steady-state values. (2) The variables without subscript t mean the steady-state values. (3) π_t is the net inflation rate. (4) r_t is the net nominal interest rate, $\widehat{r}_t$ indicates $r_t - r$, and $\widehat{r}_t = \widehat{R}_t$ holds. (5) Equation (49) is the New Keynesian Philips curve (NKPC). (6) In Equation (53), the following definitions are used: $\widehat{bd}_t \equiv (bd_t - bd)/yd$; $\widehat{gd}_t \equiv (gd_t - gd)/yd$; $\widehat{\tau d}_t \equiv (\tau d_t - \tau d)/yd$.[14] (6) Equation (55) represents the lump-sum taxation rule. If $(R-\phi_b)/z <$

[14] Following Chapter 3 of Eguchi (2011), I assumed that $\widehat{\tau d_t^r} = \widehat{\tau d_t^{nr}}$ in the dynamic pass.

1, then $\widehat{bd}_t$ does not diverge. (7) Equation (58) explains the monetary policy following the Taylor rule. Each ε_{xt} , $x \in \{\tau, g, z, r\}$ in Equations (55)-(58) represents the exogenous structural shock following an i.i.d. normal distribution with standard deviation σ_x.[15]

3. Data and Estimation Methods

3.1 Data

To estimate the structural parameters of the model by using a Bayesian inference, I used the following nine Japanese quarterly time series as observable variables: (1) the net real "GDP" growth rate from the last period (gr_y_t_obs); (2) the net real "consumption" growth rate from the last period (gr_c_t_obs); (3) the net real "investment" growth rate from the last period (gr_i_t_obs); (4) the net real "wage" growth rate from the last period (gr_w_t_obs); (5) the deviation rate of "employed persons" from the steady-state value (dev_l_t_obs); (6) the deviation rate of real "government spending/GDP" from the steady-state value (dev_g_t_obs); (7) the deviation rate of the real "outstanding net government bonds/GDP" from the steady-state value (dev_b_t_obs); (8) the net inflation rate (observed) (π_t_obs); (9) the difference of the "unsecured overnight call rate" from the steady-state value (dif_r_t_obs). The data sources of these variables are shown in Table 1.

Note that (1) all of the above time-series data were seasonally adjusted using X12-ARIMA, and (2) the necessary steady-state values were estimated using the Hodrick-Prescott (HP) filter.[16] Additionally, (3) "consumption" is the "Private final consumption expenditure" in the National Accounts; "government spending" consists of "Government final consumption expenditure," "Government gross fixed capital formation," and "Government changes in inventories"; "investment" is GDP minus "consumption" and "government spending."

---

[15] Appendices 1-2 show the detrended equations of the model and the derivation of the steady state values needed in the Bayesian estimation of parameters and simulation analysis in this study. Additionally, see Sims (2001) for the procedure that derives the rational expectation solution of a DSGE model.

[16] I set the penalty parameter of the HP filter to 1,600.

I also selected two sample terms in which to consider the changes in Japan's socio-economic state for the past five decades. The first term from 1972Q3 to 1999Q1 was set as the normal monetary-policy (Taylor-rule) regime. The second term from 1999Q2 to 2023Q4 was set as the unconventional monetary-policy regime.

3.2 Measurement (observation) equations

The measurement (observation) equations, which correspond to the nine quarterly time series explained in Section 3.1, are shown below:

$$\text{gr\_}y_t\text{\_}obs = \text{logz} + z_t^z + \widehat{yd}_t - \widehat{yd_{t-1}} + \nu_{yt}, \tag{59}$$

$$\text{gr\_}c_t\text{\_}obs = \text{logz} + z_t^z + \widehat{cd}_t - \widehat{cd_{t-1}} + \nu_{ct}, \tag{60}$$

$$\text{gr\_}i_t\text{\_}obs = \text{logz} + z_t^z + \widehat{\imath d}_t - \widehat{\imath d_{t-1}} + \nu_{it}, \tag{61}$$

$$\text{gr\_}w_t\text{\_}obs = \text{logz} + z_t^z + \widehat{wd}_t - \widehat{wd_{t-1}} + \nu_{wt}, \tag{62}$$

$$\text{dev\_}l_t\text{\_}obs = \widehat{l_t} + \nu_{lt}, \tag{63}$$

$$\text{dev\_}g_t\text{\_}obs = \widehat{gd}_t + \nu_{gt}, \tag{64}$$

$$\text{dev\_}b_t\text{\_}obs = \widehat{bd}_t + \nu_{bt}, \tag{65}$$

$$\pi_t\text{\_}obs = \pi_t + \nu_{\pi t}, \tag{66}$$

$$\text{dif\_}r_t\text{\_}obs = \widehat{r_t} + \nu_{rt}. \tag{67}$$

Note that each ν_{xt} , $x \in \{y, c, i, w, l, g, b, \pi, r\}$, in Equations (59)-(67) represents the observation error following an i.i.d. normal distribution with standard deviation σ_x.

3.3 Preliminary setting

I utilized Bayesian estimation on the important structural parameters for monetary and fiscal policies in order to investigate the effects of those policies on the economy. I set the remaining structural parameters' values by calibration (Table 2), following Eguchi (2011), Sugo and Ueda (2008), Iwata (2009), and Smets and Wouters (2003). Also, I set the exogenously given values of gd/yd and bd/yd, to those in Table 2, on the basis of the actual average values during each analysis term. Table 3 reports the prior distributions of the estimation parameters, following Sugo and Ueda (2008), Iwata (2009), Hirose and Kurosumi (2010, 2012), Eguchi (2011), Smets and Wouters (2003, 2007).

3.4 Estimation methods

I used Dynare (Ver. 5.5) software for MATLAB to conduct the Bayesian estimation. Dynare calculates the posterior distributions of the structural parameters from the prior distributions of the structural parameters, the calibrated parameter values, and the data of observable variables. Hence, using the posterior distribution and the Metropolis-Hastings (MH) MCMC algorithm, I sampled two separate chains of 500,000 replications to confirm the convergence of the parameter estimation (Here, I treated the first half of the sample as the burn-in period). Then, using the posterior draws, I closely examined the parameter-estimation results, performed a variance-decomposition analysis, and derived the Bayesian impulse responses to the structural shocks.[17]

Here, I should describe how the parameters' modes of the posterior distribution were determined in the first step of the MH-MCMC algorithm. Dynare utilizes the trust-region quasi-Newton-type method[18] as its default mode-search method, which often obtain a local mode rather than the global one or, even worse, may fail to converge due to its use of a

[17] See, e.g., An and Schorfheide (2007) for details of Bayesian estimation using a Metropolis-Hastings MCMC algorithm.
[18] See Chapters 4-6 of Nocedal and Wright (2006), and Chapters 4-5 of Gill et al. (1981) for details.

gradient technique when the posterior distribution is multimodal or non-convex. This failure might happen in the second-term estimation due to the existence of unconditional monetary policies (near-zero, zero, negative interest policies, etc.). Therefore, while I utilized the default mode-search method for the first-term estimation, for the second-term estimation, I adopted a Monte Carlo optimization method that explores the parameter space by evaluating the posterior distribution function at randomly drawn points to circumvent this problem.

Next, I will describe how the deterministic OccBin simulations were conducted with the OccBin ZLB/ELB constraints on nominal interest rates to derive impulse responses to structural shocks. Here, I assumed the following two regimes regarding the monetary-policy (Taylor) rule, depending on the absolute value of $\widehat{r_t}$.

Regime 1

If $|\widehat{r_t}| \leq 0.000668$, the regime is set as Regime 1, where the Taylor rule uses the coefficient estimates from the second term as follows. Here, the threshold value, 0.000668, is the average of $|\widehat{r_t}|$ in the second term. This regime can be recognized as the unconventional monetary-policy regime in which the ZLB/ELB constraint is effective.

$$\widehat{r_t} = \rho_r^{\text{2nd}} \widehat{r_{t-1}} + \phi_\pi^{\text{2nd}} \pi_t + \phi_y^{\text{2nd}} \widehat{yd_t} \text{ (See Equation (58)).} \quad (68)$$

Regime 2

If $|\widehat{r_t}| > 0.000668$, the regime is set as Regime 2, where the Taylor rule uses the coefficient estimates from the first term as follows. This regime can be recognized as the normal monetary-policy regime.

$$\widehat{r_t} = \rho_r^{\text{1st}} \widehat{r_{t-1}} + \phi_\pi^{\text{1st}} \pi_t + \phi_y^{\text{1st}} \widehat{yd_t} \text{ (See Equation (58)).} \quad (69)$$

First, the superscripts in Equations (68)-(69) indicate the terms from which term the estimated mean value originates. Second, the second-term estimates (mean values) are used as all other structural parameter values except ρ_r, ϕ_π, and ϕ_y. Third, linear solutions (LSs) are calculated only for Regime 1: this method ignores regime changes. In contrast, piecewise-linear solutions (PWLSs) are calculated under allowance of changes between Regimes 1 and 2. Fourth, impulse responses to the following four structural shocks (A–D) are computed using the standard-deviation estimates (mean value) in the first term of the corresponding innovation: no other shocks are applied simultaneously.

Shock A (lump-sum tax shocks): 0.022 is imposed for periods 1-4 (see Equation (55)).
Shock B (nominal interest-rate shocks): 0.008 is imposed in period 1 and 0.004, half of 0.008, in period 2 (see Equation (58)).
Shock C (government-spending shocks): 0.008 is imposed for periods 1-4 (see Equation (56)).
Shock D (productivity shocks): 0.007 is imposed for periods 1-4 (see Equation (57)).

[Tables 1-3 near here]

4. Estimation Results and Discussion

4.1 Estimated structural parameters

Table 4 lists the results of estimating the structural parameters. (1) The share of *non-Ricardian* households in the second term was 3.5 times that of the first term, as expected. (2) While the BOJ's response to output gaps strengthened in the second term relative to the first term, its response to inflation rates considerably weakened. This result is consistent with the fact that it had been engaged in monetary-easing policies since the late 1990s along a long-lasting deflation trend (Figure. 2). (3) In both estimation terms, there existed a positive (gross) trend rate of neutral technological changes, which became slightly higher as time passed. (4) Based on the parameter estimates, $(R - \phi_b)/z < 1$ held in both analysis durations in terms of a 90% confidence interval. This means that the Japanese government had sustainably managed its finances through the entire term. (5) The ρ_r estimate in the second term was quite high, i.e., nominal interest rates became more inert, which matches the BOJ's monetary-easing policies since the late 1990s.

4.2 Comparison with previous studies

Table 5 compares estimation results of this study with those of previous reports. This table lists my study's performance as follows (note, however, that since all the models in Table 5 have different aspects, this assessment is merely a guide). (1) This study's parameter estimates generally fall within the band between the lower and upper values of the previous studies. (2) In all of the studies, the parameter estimates (except ω and ρ_z) tend to have similar values.[19]

4.3 Variance-decomposition analysis

The results of the variance decomposition on the endogenous-variables (Table 6) indicate the following. (1) While interest-rate and production-technology shocks were the main factors for endogenous-variable variations in the first term, interest-rate shocks lost their influence in the second term. Government-spending shocks grew in influence in the second term. The loss in influence of interest-rate shocks in the second term reflects the fact that nominal interest rates did not vary much through the second term due to the near-zero, zero, or negative interest policies. (2) In the first term, tax and government-spending shocks strongly influenced the variations in *non-Ricardian* household consumption as well as variations in investment, outstanding government bonds, and Tobin's q. Moreover, those shocks affected total consumption, labor supply (demand), and wage rate in the second term. These facts indicate that fiscal policies of the government had succeeded in manipulating the Japanese economy to some extent throughout both terms. (3) The variations in output, *Ricardian*

[19] Hatano (2004) used a Kalman-filter estimation technique to show that the non-Ricardian household share in Japan stayed in the range of about 0.200-0.300 during the late 1970s to the late 1990s.

household consumption, money balance, and interest rates were significantly affected by production-technology shocks for the entire duration. (4) Production-technology shocks affected *Ricardian* households' consumption more than that of *non-Ricardian* households for the entire duration.

4.4 Bayesian impulse responses to structural shocks

Figures 4-11 show the Bayesian impulse responses of the observation variables to the lump-sum tax, nominal interest rate, government spending, and production-technology shocks, the magnitudes of which are estimated to one standard deviation (mean value). Note that instead of % expressions, this study uses the bare values of each growth rate, deviation rate, difference, and net inflation rate. These figures indicate the following. (1) The lump-sum tax shock decreases dev_b_t_obs. (2) The nominal interest-rate shock increases dev_b_t_obs. (3) The government-spending shock increases dev_g_t_obs, π_t_obs, dif_r_t_obs, dev_l_t_obs, and dev_b_t_obs. However, in neither analysis term, the estimated model cannot explain the consumption growth, i.e., a crowding-in effect, caused by increased government spending. (4) The production-technology shock increases gr_y_t_obs, π_t_obs, dif_r_t_obs, and dev_l_t_obs and decreases dev_b_t_obs.

Here, let me briefly discuss the above findings. Items (1) and (2) can be directly understood. Regarding Item (3), I infer that the following chain happens. Firstly, the increase in government spending causes a decrease in consumption and investment. Secondly, both households increase their labor supply. Thirdly, this labor-supply increase causes the real rental rate of capital to increase. Fourthly, these changes induce variations in output, net inflation rate, and nominal interest rate. Additionally, the increase in outstanding government bonds is straightforward. Regarding Item (4), the following can be inferred. Firstly, a positive shock of the labor-augmenting production technology modeled in this study (see Equation

(29)) increases output. Secondly, this increase makes the labor supply/demand and wage rate increase. Thirdly, these changes provoke an increase in the net inflation rate and nominal interest rate as well as a decrease in the ratio of outstanding government bonds to output.

4.5 OccBin impulse responses to structural shocks

Figures 12-15 show the OccBin impulse responses of the endogenous variables to the structural shocks (see Section 3.4). These Figures indicate the following. (1) The differences between the LSs and PWLSs are relatively large on $\widehat{r_t}$ and $\widehat{m_t}$ through Shocks A-D. This result is consistent with the OccBin simulation structure and Equations (46), (58), (68), and (69). (2) The differences between the LSs and PWLSs in Shock D generally exceed those observed in Shocks A-C. This result stems from the significant role of production technology in my model (see Equations (50) - (53)). (3) In Shock A, the variations of $\widehat{r_t}$ and $\widehat{m_t}$ of PWLSs are larger than those of the LSs. This result is attributed to the relationships among $\widehat{\tau d_t}$, $\widehat{cd_t^{nrc}}$, $\widehat{cd_t}$, $\widehat{yd_t}$, and $\widehat{cd_t^{rc}}$ (see Equations (43), (44), (54), and (42)), those among $\widehat{\tau d_t}$, $\widehat{cd_t^{nrc}}$, $\widehat{cd_t}$, $\widehat{yd_t}$, $\widehat{l_t}$, $\widehat{kd_t}$, $\widehat{wd_t}$, $\widehat{r_t^k}$, and π_t (see Equations (50), (45), and (49)), and the structure of Regimes 1 and 2. (4) In Shock B, the variations of $\widehat{r_t}$ and $\widehat{m_t}$ of PWLSs are smaller than those of LSs. Here, this phenomenon is induced by the relationships among $\widehat{r_t}$, $\widehat{cd_t^{rc}}$, $\widehat{bd_t}$, $\widehat{\tau d_t}$, $\widehat{cd_t^{nrc}}$, $\widehat{cd_t}$, and $\widehat{yd_t}$ (see Equations (53), (42), (55), (43), (44), and (54)), those among $\widehat{r_t}$, $\widehat{bd_t}$, $\widehat{\tau d_t}$, $\widehat{cd_t^{nrc}}$, $\widehat{cd_t}$, $\widehat{yd_t}$, $\widehat{l_t}$, $\widehat{kd_t}$, $\widehat{wd_t}$, $\widehat{r_t^k}$, and π_t (see Equations (50), (45), (51), and (49)), and the regimes' structure. (5) In Shock C, the variations of $\widehat{r_t}$ and $\widehat{m_t}$ of PWLSs surpass those of LSs. This result stems from the relationships among $\widehat{gd_t}$, $\widehat{bd_t}$, $\widehat{yd_t}$, $\widehat{\tau d_t}$, $\widehat{cd_t^{nrc}}$, $\widehat{cd_t}$, and $\widehat{cd_t^{rc}}$ (see Equations (53), (54), (55), (43), (44), and (42)), those among $\widehat{yd_t}$, $\widehat{l_t}$, $\widehat{kd_t}$, $\widehat{wd_t}$, $\widehat{r_t^k}$, and π_t (see Equations (50), (45), (51), and (49)), and the regimes' structure. Moreover, note that this shock analysis does not indicate an increase in $\widehat{cd_t}$ to positive government-spending shocks but does indicate an increase in $\widehat{cd_t^{nrc}}$: this result can partly explain a crowding-in effect. (6) In Shock D, the variations of $\widehat{r_t}$ and $\widehat{m_t}$ of PWLSs are less than those of the LSs. This result stems from the relationships among z_t^Z, $\widehat{bd_t}$, $\widehat{\tau d_t}$, $\widehat{cd_t^{nrc}}$, $\widehat{cd_t}$, $\widehat{yd_t}$, and $\widehat{cd_t^{rc}}$ (see Equations (53), (55), (43), (44), (54), and (42)), those among $\widehat{yd_t}$, $\widehat{l_t}$, $\widehat{kd_t}$, $\widehat{wd_t}$, $\widehat{r_t^k}$, and π_t (see Equations (50), (45), (51), and (49)), and the regimes' structure.

[Tables 4-6 and Figures 4-15 near here]

5. Concluding Remarks

I investigated Japan's economic structural changes since the 1970s by using a medium-scale NK DSGE model featuring *non-Ricardian* households in light of Japan's lackluster economy for almost last 30 years and the unconventional monetary-easing condition since the end of the 1990s. Moreover, I estimated the model over two terms: 1972Q3-1999Q1 (normal monetary-policy regime) and 1999Q2-2023Q4 (unconventional regime). This study revealed the following facts. (1) In the second term, the share of *non-Ricardian* households was 3.5 time that of the first term. (2) While the BOJ's response to output gaps strengthened in the second term compared with the first term, its response to inflation rates considerably weakened. (3) Nominal interest rates became more inert in the second term, in line with the BOJ's monetary-easing policies since the late 1990s. (4) The Japanese government had implemented sustainable fiscal policies throughout both terms. (5) While interest-rate and production-technology shocks were the main factors for endogenous economic-variable variations in the first term, interest-rate shocks lost their influence and government-spending shocks influences grew in influence in the second term. (6) The differences in impulse response between the LSs and PWLSs were relatively remarkable on $\widehat{r_t}$ and $\widehat{m_t}$ throughout all structural shocks.

Finally, I will mention some remaining tasks. First, it is necessary to estimate the parameters of middle-scale NK DSGE models with Occbin ZLB/ELB constraints as in Kulish et al. (2017). Also, the issues of downward wage rigidity and labor market friction (Iwasaki et al., 2021; Zhang et al., 2021) and variety in type of government expenditure and tax (Kotera and Sakai, 2018) should be considered.

Appendix 1: Detrended equations

$$cd_t^{rc\,-\theta} = \beta E_t\left[\frac{R_t}{\Pi_{t+1}}\left(ze^{z_{t+1}^z}\right)^{-\theta} cd_{t+1}^{rc\;-\theta}\right] \text{ (see Equation (11))} \qquad \text{(A1-1)}$$

$$l_t^{rc\varphi} = wd_t(cd_t^{rc})^{-\theta} \text{ (see Equation (12))} \qquad \text{(A1-2)}$$

$$m_t^{rc-\zeta} = \left(\frac{R_t-1}{R_t}\right)(cd_t^{rc})^{-\theta} \text{ (see Equation (13))} \qquad \text{(A1-3)}$$

$$q_t\left[1 - S'\left(\frac{id_t^{rc}}{id_{t-1}^{rc}}ze^{z_t^z}\right)\frac{id_t^{rc}}{id_{t-1}^{rc}}ze^{z_t^z} - S\left(\frac{id_t^{rc}}{id_{t-1}^{rc}}ze^{z_t^z}\right)\right]$$
$$= 1 - E_t\left[\frac{\Pi_{t+1}}{R_{t+1}}q_{t+1}S'\left(\frac{id_{t+1}^{rc}}{id_t^{rc}}ze^{z_{t+1}^z}\right)\left(\frac{id_{t+1}^{rc}}{id_{t1}^{rc}}ze^{z_{t+1}^z}\right)^2\right] \qquad \text{(A1-4)}$$
(see Equation (14))

$$cd_t^{nrc} = wd_t l_t^{nrc} - \tau d_t^{nrc} \text{ (see Equation (16))} \qquad \text{(A1-5)}$$

$$cd_t = (1-\omega)cd_t^{rc} + \omega cd_t^{nrc} \text{ (see Equation (18))} \qquad \text{(A1-6)}$$

$$\tau d_t = (1-\omega)\tau d_t^{rc} + \omega\tau d_t^{nrc} \text{ (see Equation (20))} \qquad \text{(A1-7)}$$

$$id_t = (1-\omega)id_t^{rc} \text{ (see Equation (21))} \qquad \text{(A1-8)}$$

$$kd_t = (1-\omega)kd_t^{rc} \text{ (see Equation (23))} \qquad \text{(A1-9)}$$

$$bd_t = (1-\omega)bd_t^{rc} \text{ (see Equation (24))} \qquad \text{(A1-10)}$$

$$\sum_{k=0}^{\infty}(\beta\eta)^k \frac{P_t^*(j)}{P_{t+k}}\frac{\lambda_{t+k}}{\lambda_t}\left[\frac{1}{z^{k\theta}}\frac{1}{e^{\theta\sum_{i=1}^{k} z_{t+i}^{z}}}\right] yd_{t+k}(j)$$
$$= \frac{\psi}{\psi-1}\sum_{k=0}^{\infty}(\beta\eta)^k\, mc_{t+k}\frac{\lambda_{t+k}}{\lambda_t}\left[\frac{1}{z^{k\theta}}\frac{1}{e^{\theta\sum_{i=1}^{k} z_{t+i}^{z}}}\right] yd_{t+k}(j) \quad \text{(A1-11)}$$
(see Equation (35))

$$\int_0^1 yd_t(j)dj = \left(kd_{t-1}\frac{1}{ze^{z_t^z}}\right)^{\alpha} {l_t}^{1-\alpha} \text{ (see Equation (38))} \quad \text{(A1-12)}$$

$$ze^{z_t^z}\frac{l_t}{kd_{t-1}} = \frac{1-\alpha}{\alpha}\frac{r_t^k}{wd_t} \text{ (see Equation (37))} \quad \text{(A1-13)}$$

$$kd_t = (1-\delta)kd_{t-1}\frac{1}{ze^{z_t^z}} + id_t - S\left(\frac{id_t^{rc}}{id_{t-1}^{rc}}ze^{z_t^z}\right)id_t \quad \text{(A1-14)}$$
(see Equations (4), (21), and (23))

$$bd_t = \frac{R_{t-1}}{\Pi_t}bd_{t-1}\frac{1}{ze^{z_t^z}} + gd_t - \tau d_t \text{ (see Equation (40))} \quad \text{(A1-15)}$$

$$yd_t = cd_t + i_{dt} + gdt \text{ (see Equation (41))} \quad \text{(A1-16)}$$

Appendix 2: Steady-state values

$$R = \frac{1}{\beta z^{-\theta}} \text{ (see Equation (A1-1))} \quad \text{(A2-1)}$$

$$r^k = R - (1-\delta) \text{ (see Equation (15))} \quad \text{(A2-2)}$$

$$\frac{id}{yd} = \frac{z-(1-\delta)}{z}\frac{kd}{yd} \text{ (see Equation (A1-14))} \quad \text{(A2-3)}$$

$$\frac{kd}{yd} = z\left(\frac{1-\alpha}{\alpha}\right)^{\alpha-1}\left(\frac{r^k}{wd}\right)^{\alpha-1} \quad \text{(A2-4)}$$

Equation (A2-4) is derived using $k_{t-1} = \int_0^1 k_{t-1}(j)dj$, the demand function of $k_t(j)$, the detrend procedure, $yd = yd(j)$ in a steady state, and $yd = \int_0^1 yd\, dj$.

$$wd = \left[\frac{\psi-1}{\psi}\frac{(1-\alpha)^{1-\alpha}\alpha^{\alpha}}{r^k}\right]^{\frac{1}{1-\alpha}} \text{ (see Equation (35))} \quad \text{(A2-5)}$$

Eventually, the final version of id/yd is derived from Equations (A2-3) - (A2-5).

$$\frac{cd}{yd} = 1 - \frac{id}{yd} - \frac{gd}{yd} \text{ (see Equation (A1-16))} \tag{A2-6}$$

Here, gd/yd is exogenously given.

$$\frac{l}{yd} = \left(\frac{1-\alpha}{\alpha}\frac{r^k}{wd}\right)^{\alpha} \tag{A2-7}$$

Equation (A2-7) is derived using $l_t = \int_0^1 l_t\,(j)dj$, the demand function of $l_t(j)$, $yd = yd(j)$ in a steady state, and $yd = \int_0^1 yd\,dj.$ The final version of wdl/cd is derived from Equations (A2-5) - (A2-7).

References

An, S. and F. Schorfheide (2007) "Bayesian Analysis of DSGE Models," *Econometric Reviews*, 26(2-4), pp. 113-172.

Aruoba, S. B., oraˇgana, P. Cuba-Borda, K. Higa-Flores, F. Schorfheide, and S. Villalvazo (2021) "Piecewise-linear approximations and filtering for DSGE models with occasionally-binding constraints," *Review of Economic Dynamics*, 41, pp. 96-120.

Calvo, G. A. (1983) "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12, pp. 383-398.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005) "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113(1), pp. 1-45.

Clarida, R., J. Gali, and M. Gertler (1999) "The Science of Monetary Policy: New Keynesian Perspective," *Journal of Economic Literature*, 37(4), pp. 1661-1707.

Corsetti, G., A. Meier, and G. J. Müller (2012) "Fiscal Stimulus with Spending Reversals," *The Review of Economics and Statistics*, 94(4), pp. 878-895.

Eggertsson, G. B., S. K. Egiev, A. Lin, J. Platzer, and L. Riva (2021) "A toolkit for solving models with a lower bound on interest rates of stochastic duration," *Review of Economic Dynamics*, 41, pp. 121-173.

Egucji, M. (2011) *Analysis of Fiscal Policy Using Dynamic General Equilibrium Models*, The Mitsubishi Economic Research Institute, Tokyo. (In Japanese)

Erceg, C. J., L. Guerrieri, and C. Gust (2006) "SIGMA: A New Open Economy Model for Policy Analysis," *International Journal of Central Banking*, March 2006, pp. 1-50.

Fève, P., J. Matheron, and J. Sahuc (2013) "A Pitfall with Estimated DSGE-Based Government Spending Multipliers," *American Economic Journal: Macroeconomics*, 5(4), pp. 141-178.

Forni, L., L. Monteforte, L. Sessa (2009) "The general equilibrium effects of fiscal policy: Estimates for the Euro area," *Journal of Public Economics*, 93, pp. 559-585.

Gali, J., J. Vallés, and J. D. López-Salido (2007) "Understanding the Effects of Government Spending on Consumption," *Journal of the European Economic Association*, 5 (1), Part 1, pp. 227-270.

Gill, E. G., W. Murray, and M. H. Wright (1981) *Practical Optimization*, chaps. 4-5, Academic Press Inc., London.

Guerrieri, L. and M. Iacoviello (2015) "OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily," *Journal of Monetary Economics*, 70, pp. 22-38.

Gust, C., E. Herbst, D. López-Salido, and M. E. Smith (2017) "The Empirical Implications of the Interest-Rate Lower Bound," *American Economic Review*, 107 (7), pp. 1971-2006.

Hatano, T. (2004) "The Macroeconomic Effects of Fiscal Deficits: Verification of the Equivalence Theorem by the Kalman Filter," *Financial Review (Policy Research Institute, Ministry of Finance, Japan)*, 74, pp. 65-91. (In Japanese)

Han, C. (2017) "The effects of the near-zero interest rate policy in a regime-switching dynamic stochastic general equilibrium model," *Journal of Monetary Economics*, 90, pp. 176-192.

Hirose, Y. and T. Kurozumi (2010) "Do Investment-specific Technological Changes Matter for Business Fluctuations? Evidence from Japan," *Bank of Japan Working Paper series*, No. 10-E-4.

Hirose, Y. and T. Kurozumi (2012) "Do Investment-specific Technological Changes Matter for Business Fluctuations? Evidence from Japan," *Pacific Economic Review*, 17(2), pp. 208-230.

Iwasaki, Y., I. Muto, and M. Shintani (2021) "Missing wage inflation? Estimating the natural rate of unemployment in a nonlinear DSGE model," *European Economic Review*, 132, 103626.

Iwata, Y. (2009) "Fiscal Policy in an Estimated DSGE Model of the Japanese Economy: Do Non-Recardian Households Explain All?" *ESRI Discussion Paper Series*, 216.

Iwata, Y. (2013) "Two fiscal policy puzzles revisited: New evidence and an explanation," *Journal of International Money and Finance*, 33, pp. 188-207.

King, R. G., C. I. Plosser, and S. T. Rebelo (2002) "Production, Growth, and Business Cycles: Technical Appendix," *Computational Economics*, 20 pp. 87-116.

Kotera, G. and S. Sakai (2018) "Policy Simulation of Government Expenditure and Taxation Based on the DSGE Model," *Public Policy Review (Policy Research Institute, Ministry of Finance, Japan)*, 14(4), pp.613-640.

Kulish, M., J. Morley, and T. Robinson (2017) "Estimating DSGE models with zero interest rate policy," *Journal of Monetary Economics*, 88 pp. 35-49.

Maih, J., F. Mazelis, R. Motto, and, A. Ristiniemi (2021) "Asymmetric monetary policy rules for the euro area and the US," *Journal of Macroeconomics*, 70, 103376.

Nocedal, J. and S. J. Wright (2006) *Numerical Optimization (Second ed.)*, chaps. 4-6, Springer, Berlin.

Rastrigin, L. A. (1963) "The convergence of the random search method in the extremal control of a many parameter system," *Automation and Remote Control*, 24 pp. 1337-1342.

Sims, C. A. (2001) "Solving Linear Rational Expectations Models," *Computational Economics*, 20 pp. 1-20.

Smets, F and R. Wouters (2003) "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro

Area," *Journal of the European Economic Association*, 1(5), Part 1, pp. 1123-1175.

Smets, F and R. Wouters (2005) "Comparing Shocks and Frictions in US and Euro Area Business Cycles: A Bayesian DSGE Approach," *Journal of Applied Econometrics*, 20, pp. 161-183.

Smets, F and R. Wouters (2007) "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *The American Economic Review*, 97(3), pp. 586-606.

Soris, F. J. and R. J-B. Wets (1981) "Minimization by Random Search Techniques," *Mathematics of Operations Research*, 6, pp. 19-30.

Sugo, T. and K. Ueda (2008) "Estimating a dynamic stochastic general equilibrium model for Japan," *Journal of the Japanese and International Economies*, 22, pp. 476-502.

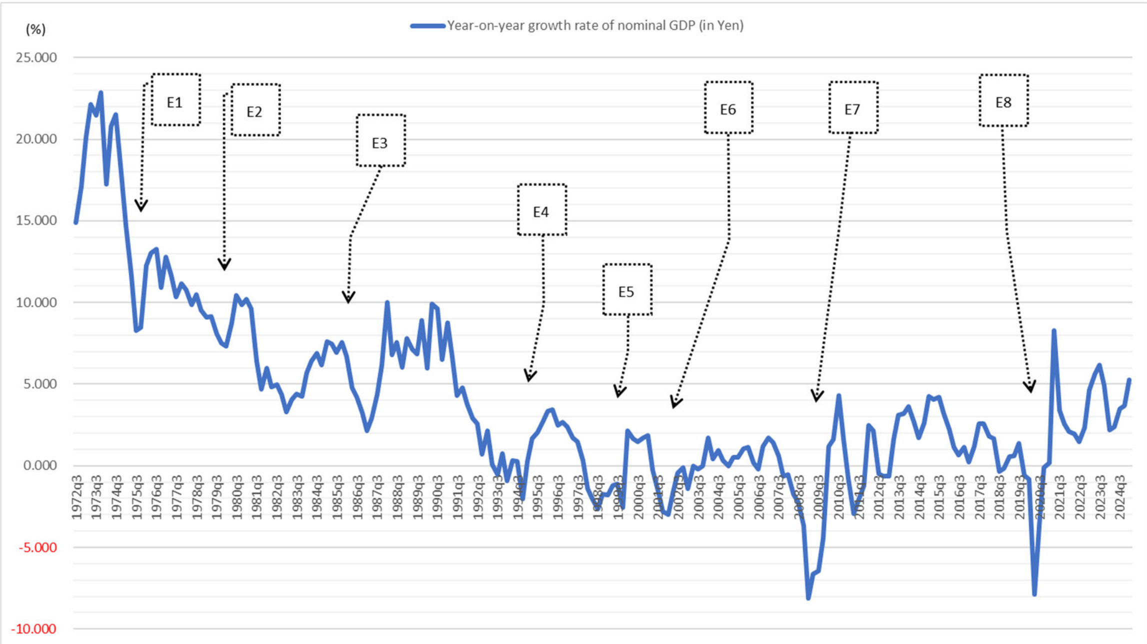
Taylor, J. B. (1993) "Discretion versus policy rules in practice," *Carnegie-Rochester Conference Series on Public Policy*, 39, pp. 195-214.

Uhlig, H. (1999) "A Toolkit for Analyzing Nonlinear Dynamic Stochastic Models Easily," In Marimon, R. and A. Scott eds., *Computational Methods for the Study of Dynamic Economics*, pp. 30-61, Oxford University Press, Oxford..

Yoshida, M. (2024) "Increase of Non-Ricardian Households and Monetary-Policy Posture's Changes in Japan", *Discussion Paper New Series (Osaka Prefecture University)*, No. 2024-1. [online: cited in Sep. 2024.] Available from URL: file:///C:/Users/moto/Downloads/CV_20240903_2024000152.pdf

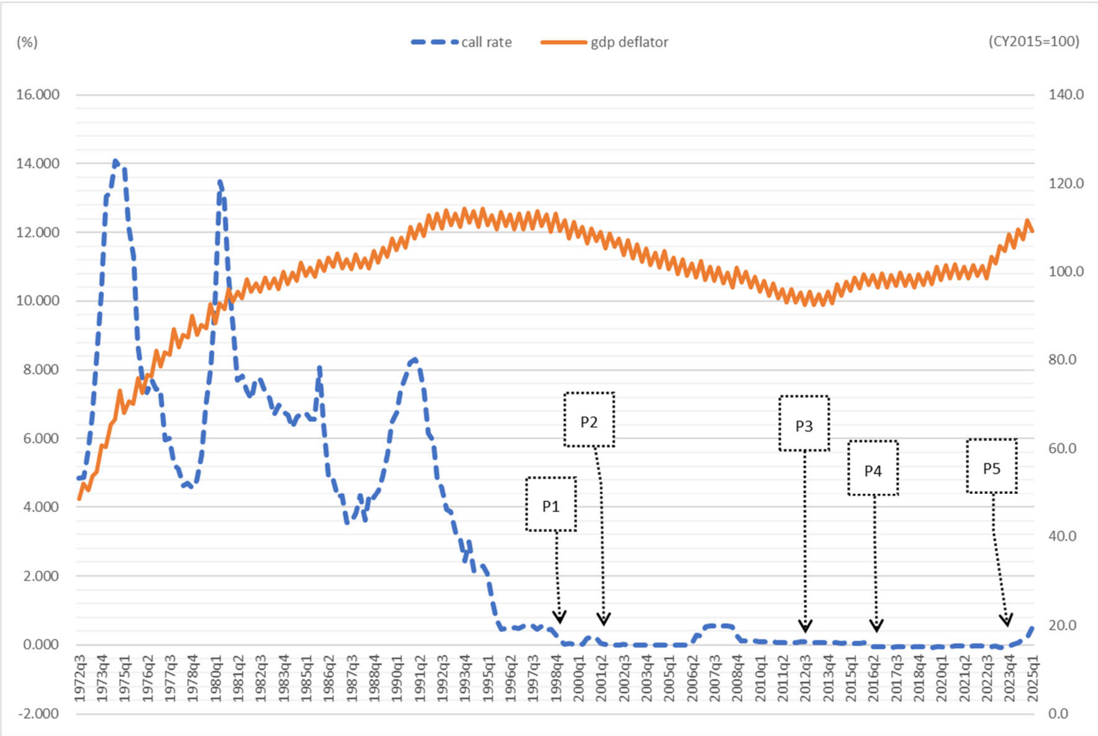
Zhang, Y. (2018) "Financial factors and labor market fluctuations," *Economic Modeling*, 74, pp. 24-44.

Tables and Figures



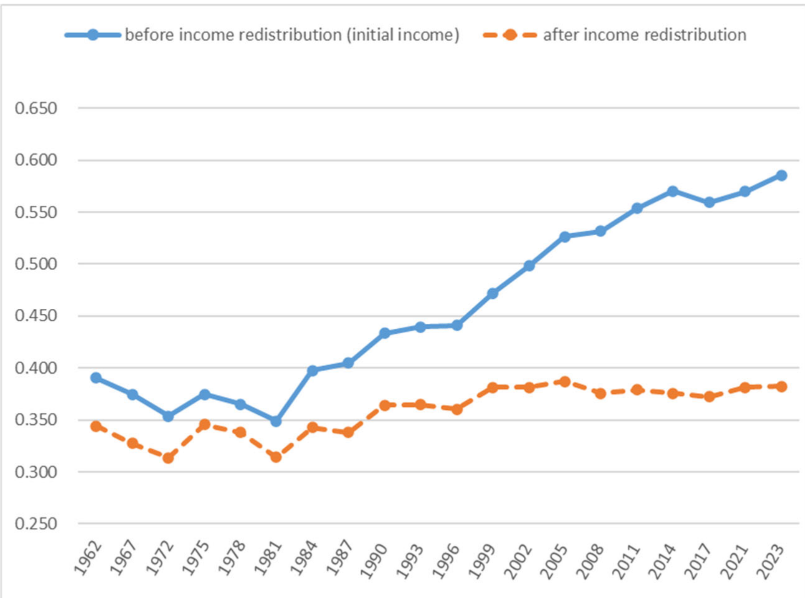
Legends: E1: First oil crisis; E2: Second oil crisis; E3: Plaza Accord; E4: Heisei-era depression; E5: Second Heisei-era depression; E6: IT bubble burst; E7: Global financial crisis; E8: New COVID-19 shock.
Source: By author using data in Table 1.

Figure 1 Change in year-on-year growth rate of nominal GDP in Japan



Legends: P1: Zero interest-rate policy; P2: Quantitative Easing (QE); P3: Quantitative and Qualitative Easing (QQE); P4: Negative interest-rate policy; P5: Normalization of monetary policy.
Source: By author using data in Table 1.

Figure 2 Changes in call rate and GDP deflator in Japan



Source: By author using "Income redistribution survey" data (Ministry of Health, Labour and Welfare).

Figure 3 Change in Gini coefficients of income (before and after redistribution) in Japan

Table 1 Data sources

Item	Variable	Necessary data (quarterly)	Data sources	Notes
1	**gr_yt_obs**	a. GDP	National Accounts (Cabinet Office)	
		b. GDP deflator	https://www.esri.cao.go.jp/jp/sna/menu.html (Accessed on January 13, 2026.)	
2	**gr_ct_obs**	a. Private final consumption expenditure	National Accounts (Cabinet Office)	
		b. GDP deflator	See Item 1	
3	**gr_it_obs**	a. Private final consumption expenditure	National Accounts (Cabinet Office)	
		b. GDP deflator	See Item 1	
4	**gr_wt_obs**	a. Wage index	Monthly Labor Statistics Survey (Ministry of Health, Labour and Welfare)	
		b. Salary paid on a fixed basis	https://www.mhlw.go.jp/toukei/list/30-1a.html (Accessed on January 13, 2026.)	
		c. GDP deflator	See Item 1	
5	**dev_lt_obs**	a. Employed persons	Labor Force Survey (Ministry of Health, Labour and Welfare) https://www.stat.go.jp/data/roudou/index.html (Accessed on January 13, 2026.)	Calculated quarterly figures by averaging monthly figures every quarter.
6	**dev_gt_obs**	a. Government final consumption expenditure	National Accounts (Cabinet Office)	
		b. Government gross fixed capital formation	See Item 1	
		c. Government changes in inventories		
		e. GDP		
		f. GDP deflator		
7	**dev_bt_obs**	a. Government outstanding net-financial liabilities	Flow of Fund Statistics (Bank of Japan)	Estimated the figures of outstanding net-financial liabilities before 1998Q4 following Yoshida (2021).
			https://www.stat-search.boj.or.jp/ (Accessed on January 13, 2026.)	
		b. GDP	See Item 1	
		c. GDP deflator		
8	**dev_πt_obs**	a. GDP deflator	National Accounts (Cabinet Office)	
			See Item 1	
9	**dif_rt_obs**	a. Unsecured overnight call rate	(Bank of Japan)	Calculated quarterly figures by averaging monthly figures every quarter; used "unconditional call rate" before 1985Q2.
			See Item 7	
		b. GDP	See Item 1	
		c. GDP deflator		

Note: I collected relatively old figures of the above data, which were not on public web pages, from printouts of each survey.

Table 2 Calibrated parameter values and steady-state values of variables

	β	θ	ζ	φ	δ	ψ	α	η	κ
Both analysis terms	0.996	1.500	2.000	2.000	0.060	11.000	0.330	0.750	7.000
	gd/yd	bd/yd							
First term	0.188	0.647							
Second term	0.227	3.742							

Note: First term and Second term indicate 1972Q3-1999Q1 and 1999Q2-2023Q4.

Table 3 Prior distributions of parameters

Parameter	Distribution	Mean		S.D.	
		First term	Second term	First term	Second term
ω	Beta	0.250	0.250	0.100	0.050
ϕ_{π}	Normal	1.050	1.050	0.200	0.100
ϕ_{y}	Normal	0.100	0.100	0.100	0.100
ϕ_{b}	Normal	0.030	0.200	0.010	0.010
ρ_g	Beta	0.630	0.630	0.100	0.100
ρ_z	Beta	0.500	0.500	0.100	0.100
ρ_r	Beta	0.850	0.950	0.100	0.100
logz	Normal	0.010	0.030	0.030	0.010
$\sigma_{s\tau}$	Inv. Gamma	0.050	0.010	Inf	Inf
$\sigma_{s g}$	Inv. Gamma	0.050	0.010	Inf	Inf
σ_{sr}	Inv. Gamma	0.050	0.000	Inf	Inf
σ_{sz}	Inv. Gamma	0.050	0.010	Inf	Inf
σ_y	Inv. Gamma	0.050	0.020	Inf	Inf
σ_c	Inv. Gamma	0.050	0.020	Inf	Inf
σ_i	Inv. Gamma	0.050	0.020	Inf	Inf
σ_w	Inv. Gamma	0.050	0.020	Inf	Inf
σ_g	Inv. Gamma	0.050	0.020	Inf	Inf
σ_{π}	Inv. Gamma	0.050	0.020	Inf	Inf
σ_r	Inv. Gamma	0.050	0.010	Inf	Inf
σ_l	Inv. Gamma	0.050	0.020	Inf	Inf
σ_b	Inv. Gamma	0.050	0.020	Inf	Inf

Notes: (1) First term and Second term indicate 1972Q3-1999Q1 and 1999Q2-2023Q4.
(2) Each σ with subscript s indicates the standard deviation of the corresponding exogenous structural shock.

Table 4 Posterior distributions of parameters

Parameter	Distribution	Mean		90% interval	
		First term	Second term	First term	Second term
ω	Beta	0.047	0.165	[0.018, 0.074]	[0.151, 0.175]
ϕ_{π}	Normal	1.676	0.943	[1.412, 1.951]	[0.924, 0.957]
ϕ_{y}	Normal	0.253	0.340	[0.097, 0.411]	[0.309, 0.382]
ϕ_{b}	Normal	0.035	0.282	[0.020, 0.049]	[0.271, 0.301]
ρ_g	Beta	0.722	0.622	[0.639, 0.808]	[0.614, 0.626]
ρ_z	Beta	0.464	0.388	[0.325, 0.605]	[0.371, 0.419]
ρ_r	Beta	0.834	0.912	[0.680, 0.994]	[0.906, 0.918]
logz	Normal	0.011	0.018	[0.009, 0.012]	[0.017, 0.021]
z		1.011	1.018	[1.009, 1.012]	[1.017, 1.021]
$\sigma_{s\tau}$	Inv. Gamma	0.022	0.003	[0.012, 0.032]	[0.002, 0.004]
$\sigma_{s\,g}$	Inv. Gamma	0.008	0.004	[0.007, 0.010]	[0.004, 0.005]
σ_{sr}	Inv. Gamma	0.008	0.000	[0.006, 0.009]	[0.000, 0.000]
σ_{sz}	Inv. Gamma	0.007	0.003	[0.006, 0.009]	[0.002, 0.003]
σ_y	Inv. Gamma	0.010	0.020	[0.009, 0.012]	[0.017, 0.023]
σ_c	Inv. Gamma	0.012	0.021	[0.010, 0.013]	[0.018, 0.024]
σ_i	Inv. Gamma	0.022	0.039	[0.018, 0.025]	[0.034, 0.044]
σ_w	Inv. Gamma	0.042	0.021	[0.036, 0.047]	[0.017, 0.024]
σ_g	Inv. Gamma	0.020	0.017	[0.017, 0.023]	[0.015, 0.019]
σ_π	Inv. Gamma	0.038	0.031	[0.034, 0.042]	[0.027, 0.035]
σ_r	Inv. Gamma	0.018	0.001	[0.016, 0.020]	[0.001, 0.001]
σ_l	Inv. Gamma	0.007	0.007	[0.006, 0.009]	[0.006, 0.007]
σ_b	Inv. Gamma	0.673	0.016	[0.596, 0.748]	[0.012, 0.019]

Notes: See Table 3.

Table 5 Comparison with previous studies' estimates of "mean"

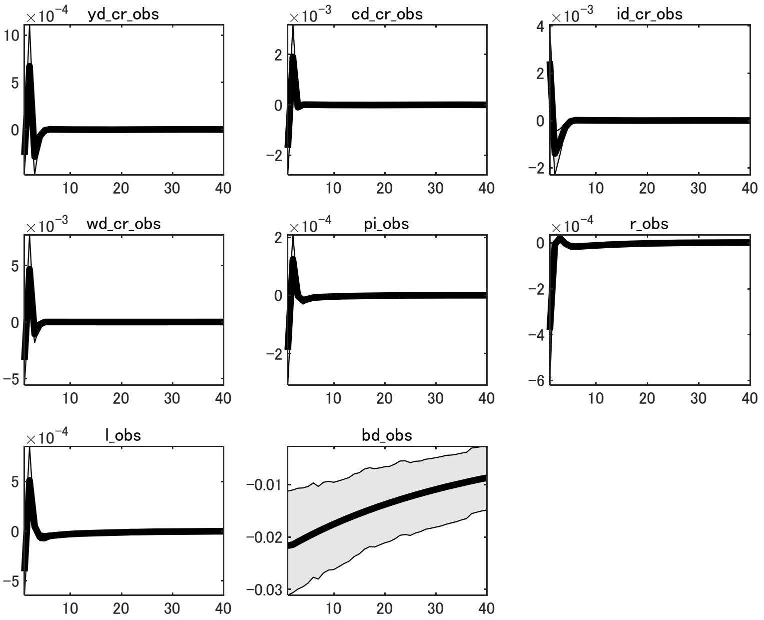
	Yoshida (2026)		Hirose and Kurozumi (2012)	Eguchi (2011)	Iwata (2009)	Sugo and Ueda (2008)	Forni et al. (2009)
Region	Japan		Japan	Japan	Japan	Japan	Euro
Term	1972Q3-1999Q1	1999Q2-2023Q4	1981Q1-1998Q4	1992Q1-2001Q4	1980Q1-1998Q4	1981Q1-1995Q4	1980Q1-2005Q4
Parameter							
ω	0.047	0.165		0.043	0.248		0.340
ϕ_{π}	1.676	0.943	1.683	1.602	1.533	0.606	1.720
ϕ_{y}	0.253	0.340	0.079	0.201	0.254	0.110	0.130
ϕ_{b}	0.035	0.282		0.035			
ϕ_{cb}					0.013		0.500
ϕ_{lb}					0.005		0.280
ϕ_{kb}					0.123		0.570
ρ_g	0.722	0.622		0.616	0.736	0.892	
ρ_z	0.464	0.388	0.067	0.757	0.518	0.949	
ρ_r	0.834	0.912		0.864	0.934	0.842	0.920
z	1.011	1.018	1.004				

Note: Subscripts c, l, and k respectively indicate consumption tax, labor-income tax, and capital-income tax in Iwata (2009) and Forni et al. (2009).

Table 6 Variance decomposition of endogenous-variable variation (%)

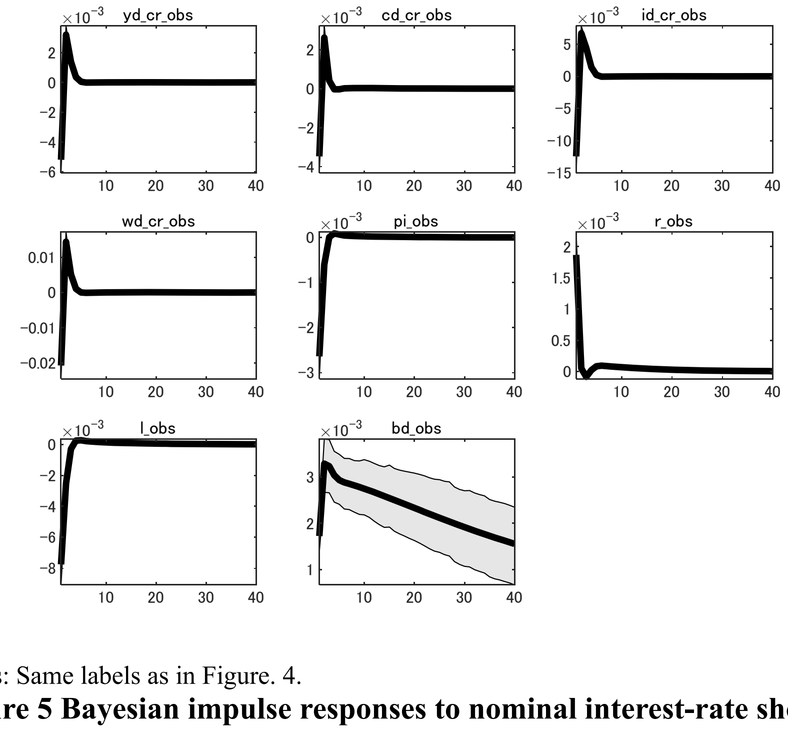
First term	Structural shocks				Second term	Structural shocks			
Endogenous variables	Tax ε_τ	Interest rate ε_r	Government spending ε_g	Production technology ε_z	Endogenous variables	Tax ε_τ	Interest rate ε_r	Government spending ε_g	Production technology ε_z
yd	0.17	20.54	7.86	71.43	yd	1.92	0.00	25.83	72.25
cd	0.83	3.81	16.75	78.61	cd	8.04	0.00	37.18	54.78
cd^{rc}	0.04	1.61	16.78	81.56	cd^{rc}	0.14	0.00	13.77	86.09
cd^{nrc}	55.40	30.21	5.45	8.95	cd^{nrc}	21.00	0.00	42.70	36.30
id	0.71	16.66	62.35	20.28	id	1.88	0.00	76.23	21.89
l	0.28	39.66	14.84	45.22	l	2.65	0.00	45.74	51.61
m	0.38	12.94	11.37	75.31	m	0.64	0.00	18.60	80.76
kd	0.03	0.80	8.90	90.28	kd	0.05	0.00	10.85	89.11
bd	31.97	0.83	65.76	1.45	bd	3.05	0.00	45.76	51.20
wd	1.74	59.72	5.47	33.07	wd	15.68	0.00	45.55	38.77
r^k	0.70	34.28	5.63	59.39	r^k	6.19	0.00	24.87	68.94
r	0.61	14.08	10.65	74.66	r	1.47	0.00	18.27	80.25
π	0.39	54.30	1.87	43.43	π	2.04	0.00	7.55	90.41
q	2.59	59.86	30.78	6.76	q	8.82	0.00	90.18	1.00
gd	0.00	0.00	100.00	0.00	gd	0.00	0.00	100.00	0.00
τd	95.19	0.06	4.65	0.10	τd	13.93	0.00	40.62	45.45

Notes: (1) First term and Second term indicate 1972Q3-2001Q1 and 1985Q1-2023Q1. (2) Endogenous variables in this table denote those with hats in Equations (42)-(58).



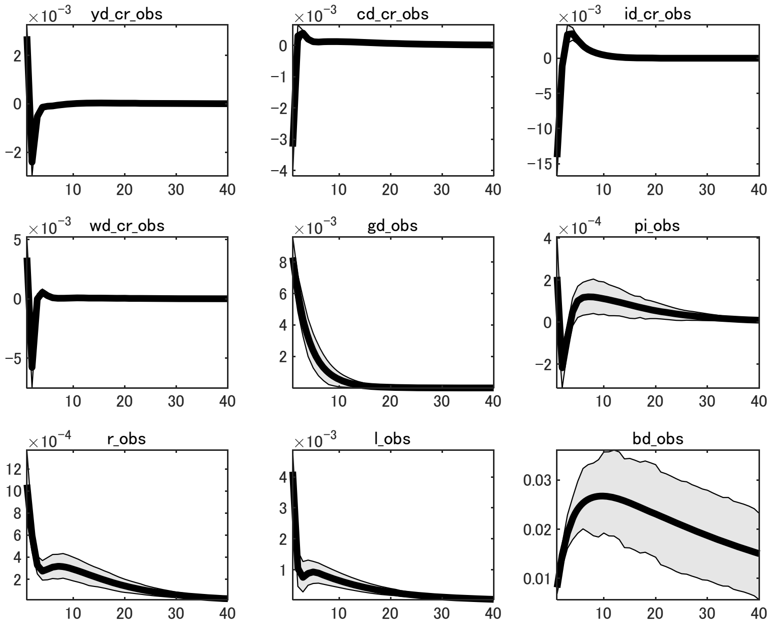
Notes: yd_cr_obs, cd_cr_obs, id_cr_obs, wd_cr_obs, pi_obs, r_obs, l_obs, and bd_obs respectively indicate gr_y_t_obs, gr_c_t_obs, gr_i_t_obs, gr_w_t_obs, π_t_obs, dif_r_t_obs, dev_l_t_obs, and dev_b_t_obs.

Figure 4 Bayesian impulse responses to lump-sum tax shock (first term)



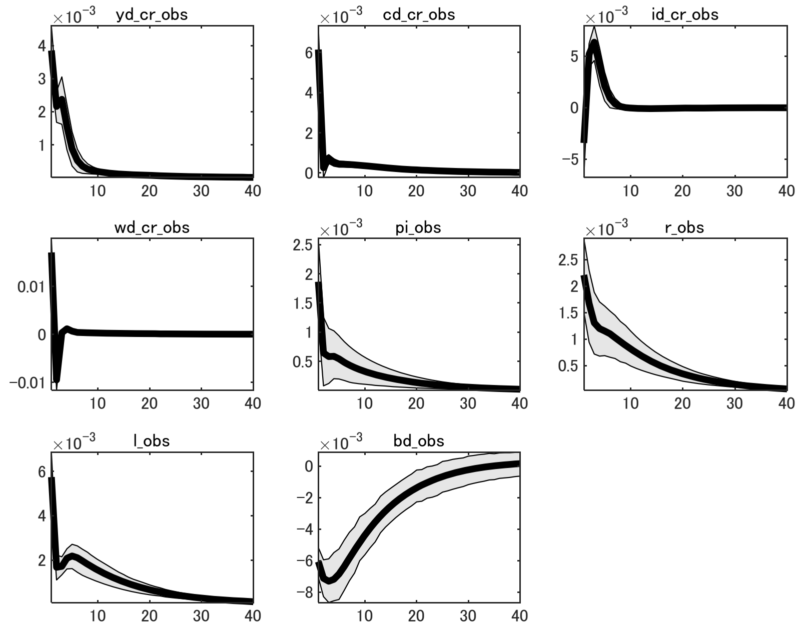
Notes: Same labels as in Figure. 4.

Figure 5 Bayesian impulse responses to nominal interest-rate shock (first term)



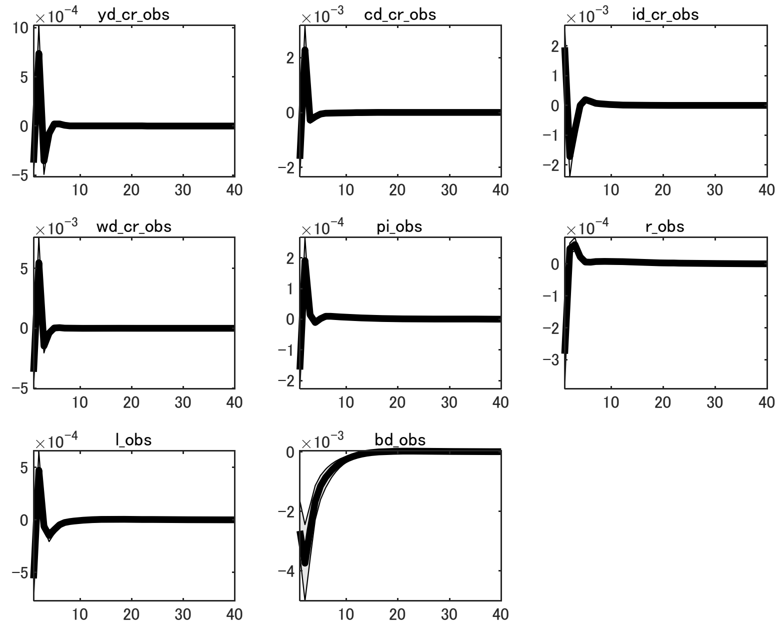
Notes: gd_obs indicates dev_g_t_obs. Other labels are identical to those in Figure. 4.

Figure 6 Bayesian impulse responses to government-spending shock (first term)



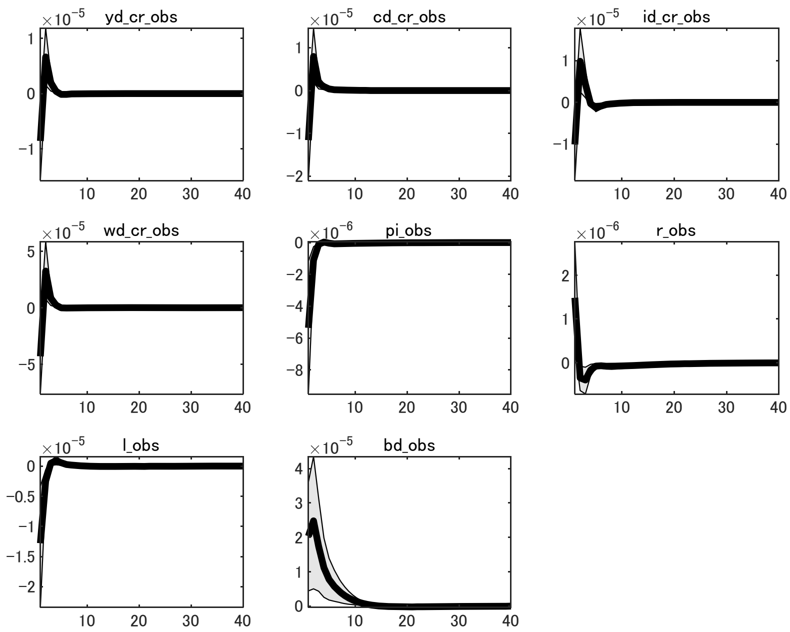
Notes: Same labels as in Figure. 4.

Figure 7 Bayesian impulse responses to production-technology shock (first term)



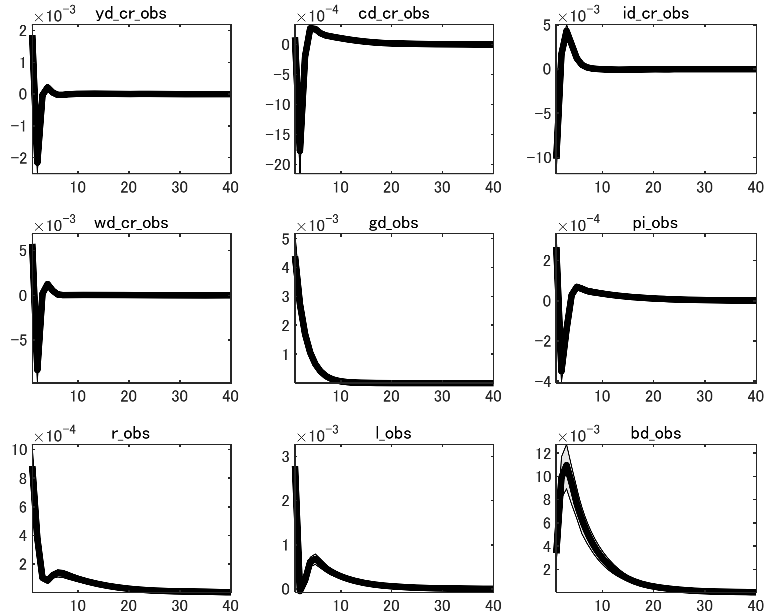
Notes: Same labels as in Figure. 4.

Figure 8 Bayesian impulse responses to a lump-sum tax shock (second term)



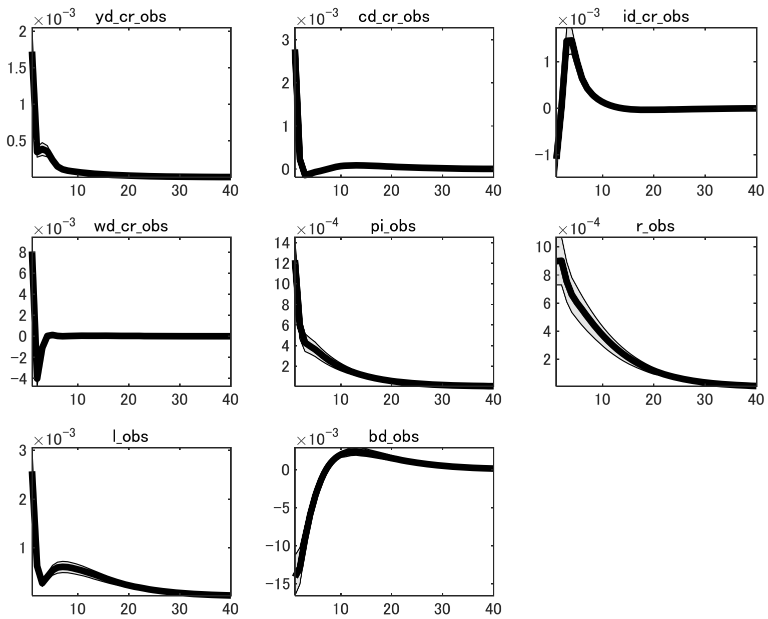
Notes: Same labels as in Figure. 4.

Figure 9 Bayesian impulse responses to nominal interest-rate shock (second term)



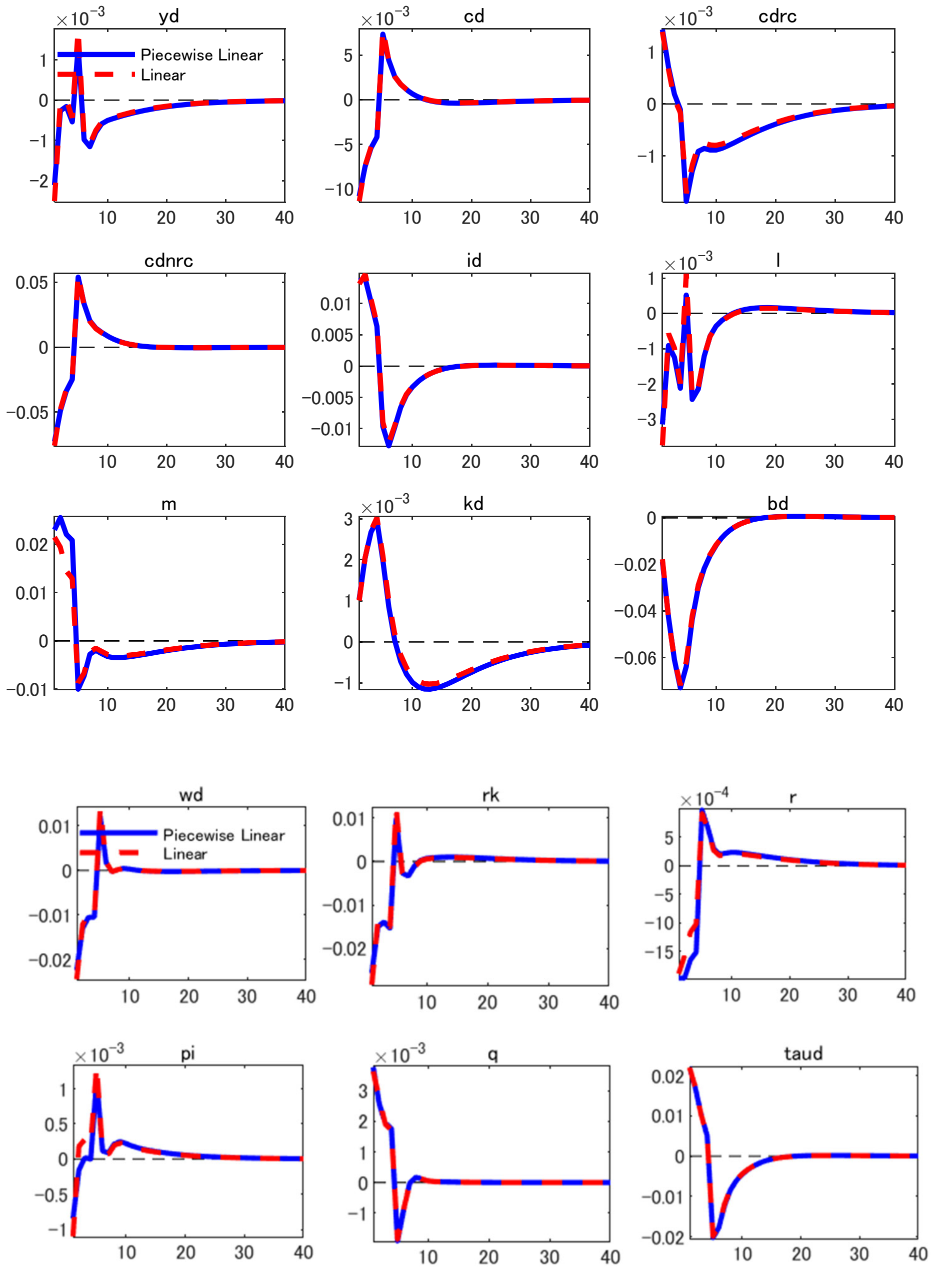
Notes: Same labels as in Figure. 6.

Figure 10 Bayesian impulse responses to government-spending shock (second term)



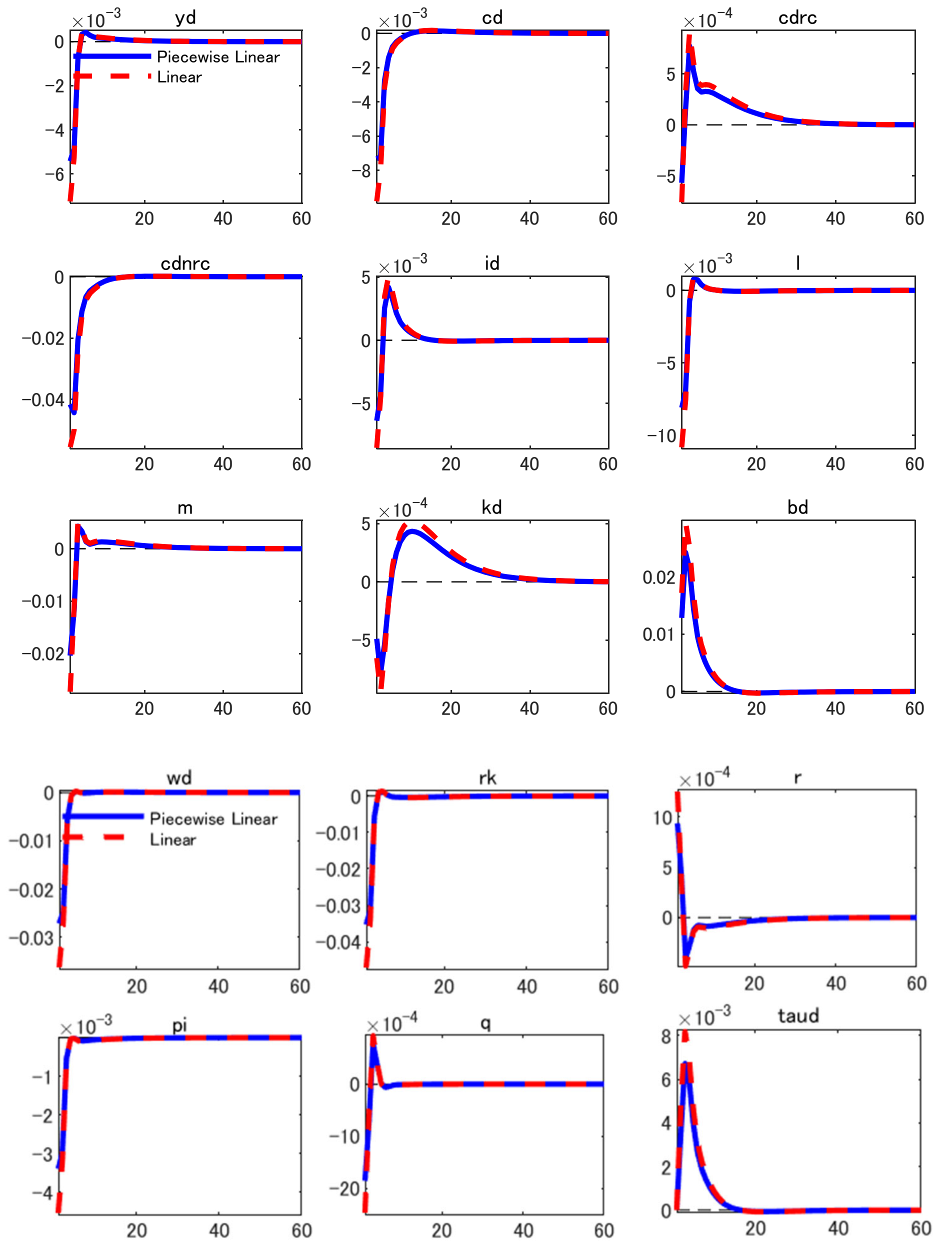
Notes: Same labels as in Figure. 4.

Figure 11 Bayesian impulse responses to production-technology shock (second term)



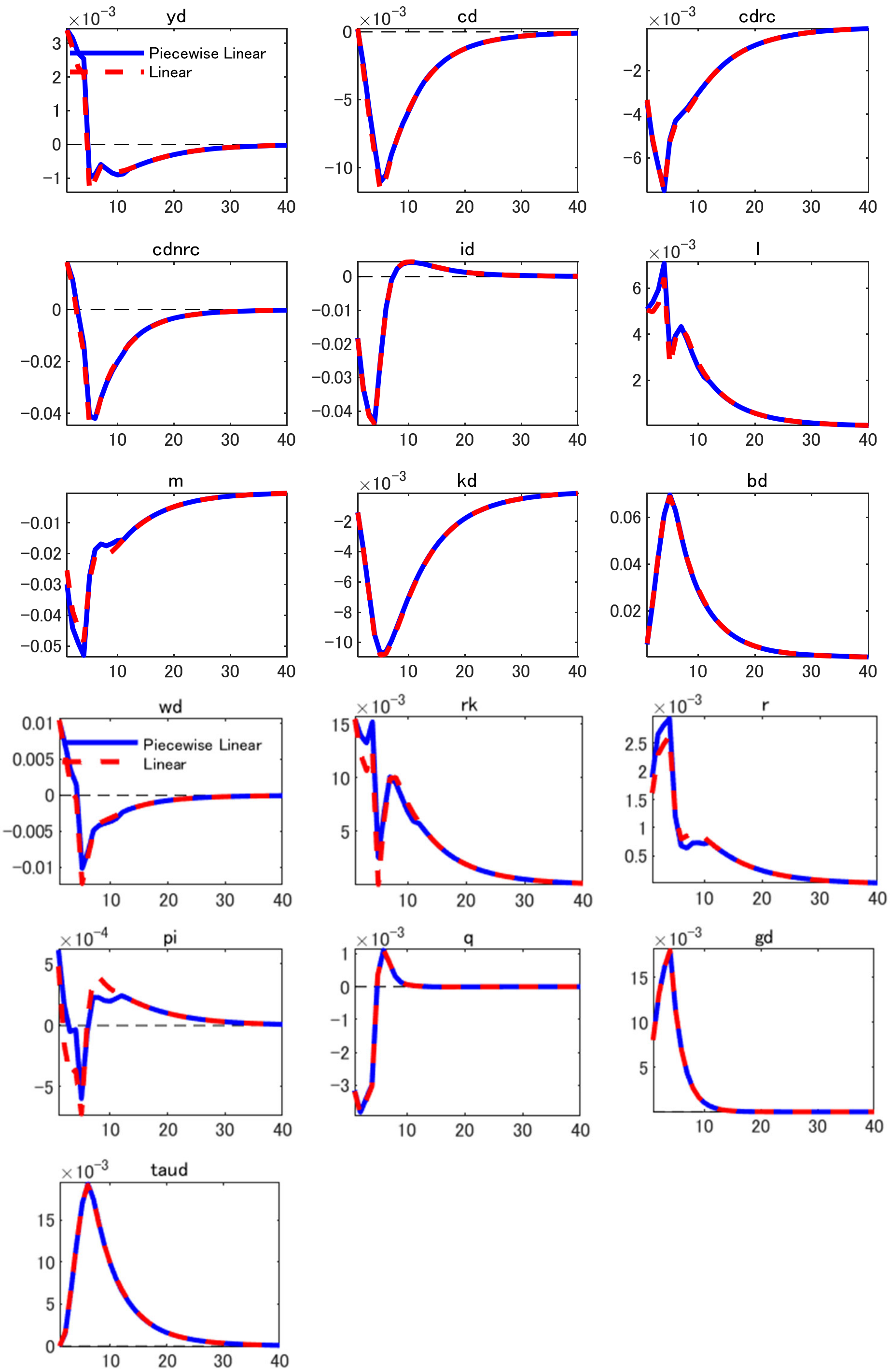
Notes: yd, cd, cdrc, cdnrc, id, l, m, kd, bd, wd, rk, r, pi, q, and taud respectively indicate $\widehat{yd}$, $\widehat{cd}$, $\widehat{cd^{rc}}$, $\widehat{cd^{nrc}}$, $\widehat{\iota d}$, $\hat{l}$, $\widehat{m}$, $\widehat{kd}$, $\widehat{bd}$, $\widehat{wd}$, $\widehat{r^{k}}$, $\hat{r}$, π, and $\hat{q}$.

Figure 12 OccBin impulse responses to lump-sum tax shocks (Shock A)



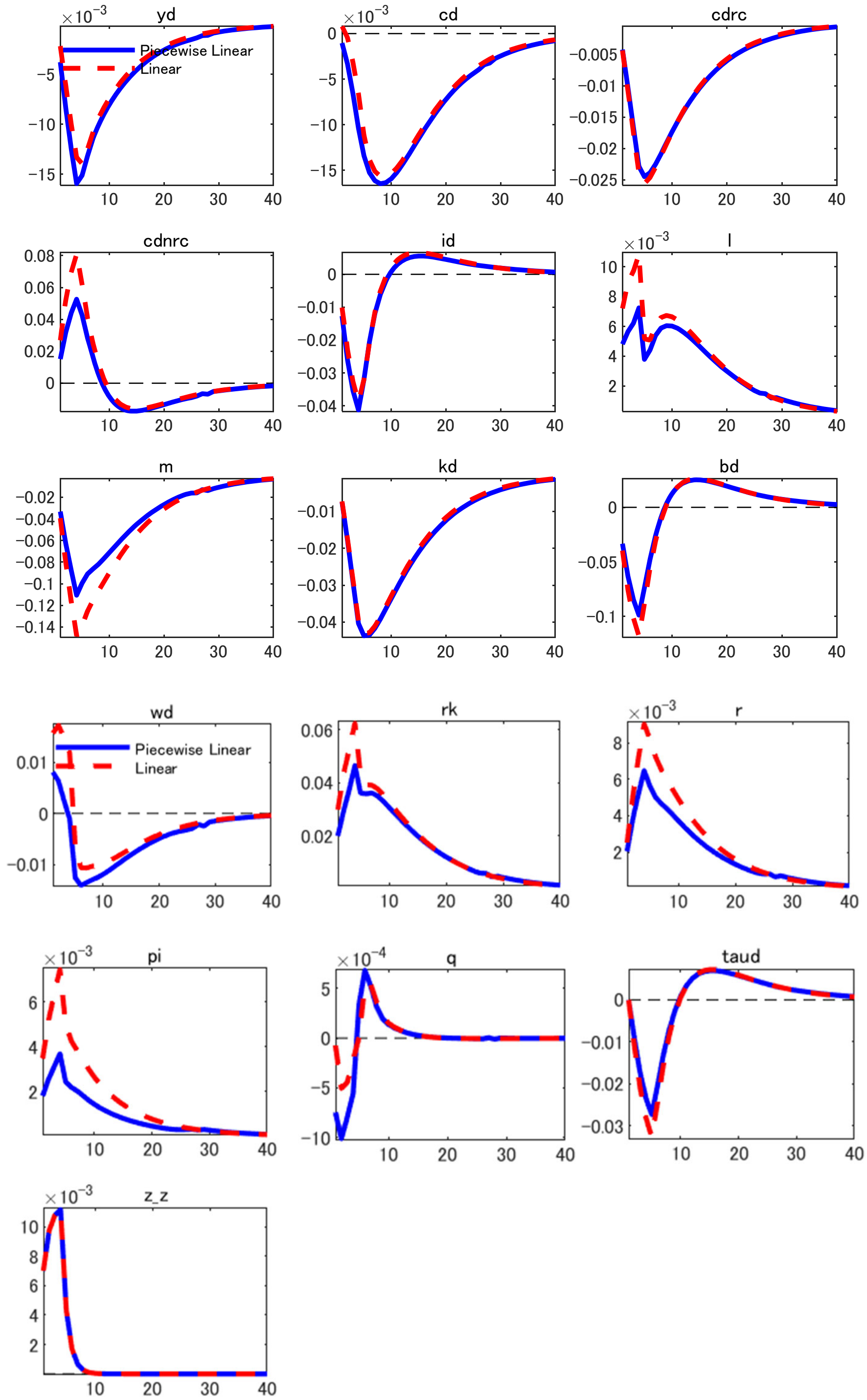
Notes: Same labels as in Figure. 12.

Figure 13 OccBin impulse responses to nominal interest-rate shocks (Shock B)



Notes: gd indicates $\widehat{gd}$. Other labels are identical to those in Figure. 12.

Figure 14 OccBin impulse responses to government-spending shocks (Shock C)



Notes: Same labels as in Figure. 12.

Figure 15 OccBin impulse responses to production-technology shocks (Shock D)