Increase of Non-Ricardian Households and Monetary-Policy Posture's Changes in Japan

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Abstract

Considering Japan's lackluster economy for almost last 30 years, I investigated its economic structural changes since the 1970s using a medium-scale NK DSGE model, which features *non-Ricardian* households, sticky goods prices, and investment-adjustment cost and also detrends real economic variables. I estimated my DSGE model by a Bayesian technique over two terms, 1972Q3-2001Q1 and 1985Q1-2023Q1. The estimation results revealed the following: (1) The share of *non-Ricardian* households in the population probably increased over time. (2) The Bank of Japan tended to emphasize the inflation rate over the output gap. However, it more weakly responded to the inflation rate in the second term. (3) The Japanese government probably has implemented sustainable fiscal policies through the entire analysis term. (4) Many economic-variable variations can be attributed to production-technology and the nominal interest-rate shock; the contribution intensity of the latter has grown with time.

Keywords: Non-Ricardian households, Monetary-easing policy, Taylor rule, DSGE modeling

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

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1. Introduction

The Japanese economy has lost its vitality since 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) as a whole country, Japan ranked second among all countries in 2000. However, its ranking dropped to third in 2010 and to fourth in 2023. Regarding per capita GDP, although Japan's position was also second in 2000, its ranking dropped to 18th in 2010 and to 34th in 2023.[1] To more deeply scrutinize the mired situation of the Japanese economy, I prepared Figs. 1-3. Fig. 1 explains the long-term downturn of the year-on-year growth rate of Japan's nominal GDP (in Yen) since the 1970s. Japan hasn't fully recovered from the devastation when its bubble economy burst. I indicated the changes of the GDP deflator and the unsecured overnight call rate in Fig. 2. This figure reveals that (1) Japan has been suffering from deflation since the mid-1990s and (2) the Bank of Japan (BOJ) has engaged in unconventional monetary-easing policies (including zero and negative interest policies) to solve this deflation trend. In the context of the sluggishness of Japan's economy, I infer that the number of *non-Ricardian* households (also referred to "rule-of-thumb" or "hand-to-mouth" households) is increasing in Japan in line with the worldwide deepening wealth maldistribution. I graphed the changes of the Gini coefficient on income since 1962 in Fig. 3. Based on this figure, income maldistribution is clearly developing in Japan (of course, Japan's government has successfully ameliorated this unfair situation to some extent).

Considering such difficulties of the Japanese economy over the last three decades, I believe that investigating Japan's economic structural changes since the 1970s is quite meaningful

[1] See the IMF's website on World Economic Outlook for details: https://www.imf.org/external/datamapper/datasets/WEO (accessed on March 6, 2024).

to implement appropriate monetary and fiscal policies. Therefore, I investigated using a dynamic stochastic general equilibrium (DSGE) model. After Kydland and Prescott (1982) launched a real business cycle (RBC) model in response to Lucas's (1976) critique, many researchers and policy makers have utilized DSGE models. This is why DSGE models are microfound and successfully reproduce socio-economic structure under dynamic general equilibrium, and therefore analyzers can indicate the impact paths in economies by various policy and structure changes (shocks) in a tractable way using DSGE models. Although the RBC model assumed perfectly competitive markets, subsequent researchers produced New Keynesian (NK) models that consider the imperfect conditions of markets and various costs in real economic activities. A series of studies (Kimball (1995), Roberts (1995), Yun (1996), McCallum and Nelson (1999), Clarida et al. (1999), King (2000), Gali (2002), and Christiano et al. (2005)) introduced the following features: sticky goods prices and wages due to monopolistic competition by intermediate good firms and households as labor suppliers, habit formation in preferences of consumption, and adjustment cost of investment. Smets and Wouters (2003, 2005) also made great progress in parameter-estimation methods by introducing a Bayesian technique. Because of this evolution, analyzers can estimate parameters in their models, matching data in real economies. In addition, Smets and Wouters (2007) detrended real economic variables, e.g., output, consumption, and wages, in their model and successfully matched the variables in it to the data under balanced growth. The above NK models had a shortcoming that failed to explain consumption growth, i.e., crowding-in, in response to positive government-spending shock since they assumed representative households that can perfectly anticipate the future and rationally make their decisions. Hence, Gali et al. (2007) introduced *non-Ricardian* households who consume all their disposable income every period into their model and solved the above crowding-in puzzle.[2] Forni et al. (2009) obtained an estimate (0.34) of the *non-Ricardian* household share in the Euro area over 1980Q1-2005Q4 by a DSGE model estimation. As did Forni et al. (2009), Iwata (2009) estimated this share to be 0.248 in Japan over 1980Q1-1998Q4. On the other hand, regarding the monetary-policy reaction function, Smets and Wouters (2007) estimated the parameters of the inflation rate and output gap of 2.04 and 0.08 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. Hirose and Kurozumi (2012) estimated these parameters (1.683, 0.079) over 1981Q1-1998Q4 in Japan, and Sugo and Ueda (2008) estimated the same Japanese parameters (0.606, 0.110) over 1981Q1-1995Q4.

Considering the above contents and results of the literature related to my study aim, I made a medium-scale NK DSGE model, which features *non-Ricardian* households, sticky goods prices, and investment-adjustment cost and also detrends real economic variables. Using a Bayesian technique, I estimated my DSGE model over two terms to consider the changes of Japan's socio-economic state for the past five decades. I set the first estimation term 1972Q3-2001Q1 since I designed it as a term that was not effectively influenced by quantitative easing (QE) policy (Fig. 2). Subsequently, I set the second estimation term 1985Q1-2023Q1 since I designed it as a term influenced by economic conditions after the Plaza Accord (including monetary-easing policies since the late 1990s) (Figs. 1-2).

The following are the main results of this study. (1) The share of *non-Ricardian* households in the population probably increased over time, as expected. (2) The BOJ tended to emphasize the inflation rate over the output gap. However, the BOJ more weakly responded to the inflation rate in the second term. This result seems consistent with the fact that the BOJ has engaged in monetary-easing policies since the late 1990s to extricate Japan from a long-

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

lasting deflation and achieve a moderate inflation rate. (3) The Japanese government probably has implemented sustainable fiscal policies through the entire analysis term. (4) Many economic-variable variations can be attributed to the production-technology and the nominal interest-rate shock. The latter's contribution intensity has grown with time.

The rest of this paper is organized as follows. Section 2 describes my estimated model. Section 3 explains the data and estimation methods. Section 4 reports the estimation results and discusses the socio-economic changes and effects of Japan's monetary and fiscal policies. Finally, Section 5 concludes the paper.

[Figs. 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 introduced the following features into my model: (1) "sticky prices on intermediate goods," following Calvo (1983),[3] (2) "investment adjustment cost," like Smets and Wouters (2003) and their followers, (3) "*non-Ricardian* households," like Gali et al. (2007), (4) "stochastic trends in neutral technological changes" for considering balanced growth, like Erceg et al. (2006) and Smets and Wouters (2007).

Since the end of Japan's rapid economic growth from the mid-1950s through the early 1970s, the Japanese government has implemented various countercyclical fiscal policies as well as monetary-easing policies (Fig. 2) in economic recession periods up to the present. Therefore, I set government-spending shock and tax shock as well as monetary-policy (interest) shock and productivity shock in my model like Forni et al. (2009) and Iwata (2013).

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

Regarding the model's basic description, I followed Smets and Wouters (2003, 2005, and 2007), Hirose and Kurozumi (2010, 2012), and Eguchi (2011).

2.1 Assumptions of the model

There are households, a final-good firm, intermediate-good firms, Government,[4] and Central bank as agents, and a final-good market, intermediate-good markets, a labor market, a capital market, and a government-bond[5] market as markets in the economy. I explain the necessary assumptions below. (1) A continuum of households is indexed by $i \in [0, 1]$. Fraction $1 - \omega$ of the continuum belongs to *Ricardian* households that maximize intertemporal expected utility. Remaining fraction ω belongs to the *non-Ricardian* households that consume all their disposable income every period; they are also referred to as "rule-of-thumb" or "hand-to-mouth" households. Since the latter households cannot divert funds into savings, only the former households can invest, purchase government bonds, and save their remaining income as money stock. However, since each household is homogeneous in its category (*Ricardian* or *non-Ricardian*), I omit index i for describing households' behaviors. (2) I dealt with only the intermediate-good markets as monopolistic competition markets; all the other markets are perfect competitive. (3) There is a continuum of intermediate-good firms indexed by $j \in [0, 1]$, which can control their goods' supply prices because each intermediate good is being differentiated. However, only fraction $1 - \eta$ of the continuum can re-optimize the prices every period (remaining fraction η leaves the prices identical as those at the previous period). The right of re-optimizing the price is granted to each firm on a stochastic basis every period, and this granted probability 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

[4] Government is assumed to be identical as "general government in the National Accounts," which consists of a central government, local governments, and social security funds.

[5] Government bonds denote both the central and local government bonds.

firm produces its goods from intermediate goods, and final goods are used as consumption or investment goods.

2.2 Households

2.2.1 *Ricardian* households

The following is each *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-good amount, the nominal money balance (based on the money-in-utility (MIU) assumption), the aggregate price level, the labor-supply amount, and the production technique level. $\beta > 0$, $\theta > 0$, $\zeta > 0$, and $\varphi > 0$ respectively represent the subjective discount factor, the coefficient of the relative risk aversion of households or the inverse of the intertemporal elasticity of substitution, the inverse of money demand elasticity, and the inverse of labor supply elasticity. E indicates an expected operator, and t indexes the periods. However, z_t's parts appear in the second and third terms in [·] of Equation (1) in a similar way to Erceg et al. (2006) and Hirose and Kurozumi (2010). These parts ensure the existence of a balanced growth path for the model economy. Superscript *rc* shows that the concerned 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, the nominal government-bond amount purchased at period t, the nominal wage rate, the real rental rate of capital, the gross nominal interest rate, the nominal dividends from the excess profits of the intermediate-good firms, and the 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), I define $b_t \equiv B_t/P_t$, $m_t \equiv M_t/P_t$, $d_t \equiv D_t/P_t$, $w_t \equiv W_t/P_t$, 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 $S(\cdot)$ 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}:

$$c_t^{rc-\theta} = \Lambda_t\ , \tag{5}$$

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

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

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

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

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

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

Finally, from the above FOCs, Euler's equation of consumption, the optimal condition of labor supply, a money demand function, Tobin's q,[6], and the optimal condition of capital are derived:

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

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

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

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

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

In Equations (14) and (15), q_t represents MU_t/Λ_t.

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

2.2.2 *Non-Ricardian* households

Since none of the *non-Ricardian* households implement intertemporal optimization, they consume all their disposal income every period in the following manner. Superscript *nrc* identifies a concerned variable as one regarding *non-Ricardian* households:

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

Following Gali et al. (2007), I assume that the amount of this household's labor supply is identical as that of this *Ricardian* household:

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

2.2.3 Aggregation

Each aggregate amount of consumption, labor supply, and lump-sum tax is respectively given by a weighted average of the corresponding variable for each household type:

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

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

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

I assume that the amount of lump-sum tax of a *non-Ricardian* household is identical as that of a *Ricardian* household as well as the amount of labor supply (Equation 17).

Similarly, the aggregate amount of investment, the money demand, the capital stock, and the government-bond demand are respectively given by:

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

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

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

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

2.3 Final-good firm

A Final good is produced by a representative firm under perfect competition with a Dixit=Stigliz type's CES (constant elasticity of substitution) function:

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

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

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

2.4 Intermediate-good firms

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

Cost minimization

Each firm produces its differentiated good 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 labor amount hired by the jth firm. z_t represents the level of neutral technology,[7] which is assumed to be the following stochastic process:

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

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

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:

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

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

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

Profit maximization

Since only fraction $1-\eta$ of the intermediate-good firms can re-optimize 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):

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

As a result, the FOC and ${P_t}^*(j)$ are derived:

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

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

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

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

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

Aggregation

Since Equations (31) and (32), the capital stock demand function, and the labor demand function are identical among all the intermediate-good firms, 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 goods

Government implements its fiscal policies under the following budget constraint:

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

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-tax taxation rule are explained in Section 2.6.

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

Next Central bank conducts its monetary policy by the "Taylor (1993) rule."[8] This policy's details are mentioned in Section 2.6. Last, the following is the market clearing condition for the final good:

$$y_t = c_t + i_t + gt \ . \quad (41)$$

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 implementing the log linearization of 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 $\lambda_t \equiv \Lambda_t z_t^{\theta}$. See Appendix 1 for details of the detrended equations.

After log-linearizing the equilibrium conditions, the system of these equations was converted to the following version:[9]

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

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

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

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

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

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

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

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

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

$$\widehat{\pi_t} = \frac{\beta}{z^\theta}E_t\widehat{\pi_{t+1}} + \frac{(1-\eta)\left(1-\frac{\beta\eta}{z^\theta}\right)}{\eta}\left[(1-\alpha)\widehat{wd_t} + \alpha\widehat{r_t^k}\right] \quad (49)$$
(see Equations (35) and (36)).

$$\widehat{yd_t} = \alpha\widehat{kd_{t-1}} - z_t^z + (1-\alpha)\widehat{l_t} \text{ (see Equations (25) and (38)).} \quad (50)$$

$$z_t^z + \widehat{l_t} - \widehat{kd_{t-1}} = \widehat{r_t^k} - \widehat{wd_t} \text{ (see Equation (37)).} \quad (51)$$

$$\widehat{kd_t} = \frac{1-\delta}{z}\widehat{kd_{t-1}} - \frac{1-\delta}{z}z_t^z + \frac{z-(1-\delta)}{z}\widehat{\imath d_t} \text{ (see Equations (4) and (23)).} \quad (52)$$

$$\widehat{bd_t} = \frac{R}{z}\widehat{bd_{t-1}} + \frac{R}{z}\frac{bd}{yd}\widehat{r_{t-1}} - \frac{R}{z}\frac{bd}{yd}\widehat{\pi_t} - \frac{R}{z}\frac{bd}{yd}z_t^z + \widehat{gd_t} - \widehat{\tau d_t} \quad (53)$$
(see Equation (40)).

$$\widehat{yd_t} = \frac{cd}{yd}\widehat{cd_t} + \frac{id}{yd}\widehat{\imath d_t} + \widehat{gd_t} \text{ (see Equation (41)).} \quad (54)$$

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

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

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

$$\widehat{r_t} = \rho_r \widehat{r_{t-1}} + \phi_\pi \widehat{\pi_t} + \phi_y \widehat{yd}_t + \varepsilon_{rt}. \quad (58)$$

Here 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 those steady-state values. (2) The variables without subscription 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 $\widehat{r_t} = \widehat{R_t}$ is held. (5) Equation (49) is the New Keynesian Philips Curve (NKPC). (6) In Equation (53), the following definitions are used: $\widehat{bd}_t \equiv (bd_t - bd)/yd$; $\widehat{gd}_t \equiv (gd_t - gd)/yd$; $\widehat{\tau d}_t \equiv (\tau d_t - \tau d)/yd$. (6) Equation (55) represents the lump-sum taxation rule. If $(R - \phi_b)/z < 1$, 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 the i.i.d. normal distribution with standard deviation σ_x.

I also explained the derivation manners for the steady-state values needed in the Bayesian estimation of parameters and simulation analysis in Appendix 2.[10]

3. Data and Estimation Methods

3.1 Data

To estimate the structural parameters of the model (Section 2) by a Bayesian technique, I used the following nine Japanese quarterly time series as observable variables: (1) the net

[10] See Sims (2001) for the procedures that derive the rational expectation solution of a DSGE model.

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 deviation rate of the net nominal “inflation rate” from the steady-state value (dev_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 were seasonally adjusted using X12-ARIMA, and (2) the necessary steady-state values were estimated using the Hodrick-Prescott (HP) filter.[11] (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 a reminder of GDP minus “consumption” and “government spending.”

I also prepared two analysis (estimation) terms to consider the changes of Japan’s socio-economic state for the past five decades. The first term from 1972Q3 to 2001Q1 was set as one that was not effectively influenced by quantitative easing (QE) policy. The second term from 1985Q1 to 2023Q1 was set as one that was influenced by the economic conditions after the Plaza Accord (including monetary-easing policies since the late 1990s).

3.2 Measurement (observation) equations

The measurement (observation) equations, which correspond to the nine quarterly time series

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

explained in Section 3.1, are shown below:

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

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

$$\text{gr\_}i_t\text{\_}obs = \text{log}z + z_t^z + \widehat{id}_t - \widehat{id_{t-1}} + \nu_{it}, \tag{61}$$

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

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

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

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

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

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

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 the i.i.d. normal distribution with standard deviation σ_x.

3.3 Preliminary setting

In utilizing Bayesian estimation, I planned to focus on the estimations of the important structural parameters for monetary and fiscal policies to investigate the effects of those policies on the economy after the estimations. 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 determined the values of gd/yd and bd/yd, which have to be exogenously given, as in Table 2, based on the actual average values and the relatively new values during each analysis term.

Subsequently, 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

In conducting Bayesian estimation, I used Dynare (Ver. 5.5) software for MATLAB. Given the prior distributions of the structural parameters and the parameter values except for the estimated parameters, Dynare calculates posterior distributions of the structural parameters using a Metropolis-Hastings Markov chain Monte Carlo (MCMC) algorithm. I sampled two separate chains of 500,000 replications by chain to confirm the convergence of the parameter estimation, although I discarded the former half of the sample as the burn-in period. Then, based on the posterior draws, I closely examined the parameter-estimation results, implemented variance-decomposition analysis, and derived the Bayesian impulse responses to the structural (monetary and fiscal policy) shocks.[12]

[Tables 1-3 near here]

4. Estimation Results and Discussion

4.1 Estimation results of structural parameters

Table 4 shows the estimation results of the structural (deep) parameters and explains the following. (1) The share of *non-Ricardian* households in the population probably increased over time, as expected. (2) The BOJ tended to emphasize the inflation rate more than the output gap. However, it more weakly responded to the inflation rate in the second term than

[12] See e.g., An and Schorfheide (2007) for details of Bayesian estimation using a Metropolis-Hastings MCMC algorithm.

in the first. This result seems consistent with the fact that the BOJ has been engaged in monetary-easing policies since the late 1990s along a long-lasting deflation trend (Fig. 2). (3) The estimated 90% interval of ϕ_y indicates that the BOJ did not fully consider the state of the output gap, i.e., seemingly concentrating on the price-level issue in the second term. (4) In both analysis terms, there probably exists a positive (gross) trend rate of neutral technological changes. However, technological evolution has been weakened as time passes. (5) Based on the parameter estimates, $(R - \phi_b)/z < 1$ is held in both analysis periods in terms of a 90% confidence interval. Therefore, the Japanese government has sustainably managed its finances through the entire analysis term.

4.2 Comparison with previous studies

I compared the estimation results of this study with those of previous studies in Table 5 and assessed my study's performance as follows. Note that since all the models in Table 5 have some different aspects, this comparison 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) The parameter estimates (except ω and ρ_z) tend to have similar values among all of the studies. (3) This study's ω estimates are relatively smaller than those of the other studies except Eguchi (2011). However, this study's results probably capture a situation where the Japanese government's income redistribution policies can sooth unfair wealth distribution to some extent (Fig. 3).[13]

4.3 Variance-decomposition analysis

Subsequently, I indicated the variance-decomposition results regarding endogenous-variable variations by the analysis term in Table 5, which shows the following. (1) Many endogenous-

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

variable variations can be attributed to a production-technology shock. (2) In the second term, the interest-rate shock became a more influential factor for the variations of the *non-Ricardian* household's consumption, labor supply, wage rate, capital rental cost, and inflation rate than in the first term. This fact is consistent with BOJ's monetary-easing policy, which was expanded in the late 1990s. (3) Output responded more to interest-rate changes in the second term. (4) The production-technology shock mainly influences not the *non-Ricardian* households' but the *Ricardian* households' consumption through both terms. (5) The *non-Ricardian* households' consumption responds more to taxation than the *Ricardian* households. (6) Government spending was more affected by outstanding government bonds in the first term. On the other hand, the importance of the interest rate for government-bond accumulation emerged in the second term. (7) In the second term, the government-spending influence on firms' value grew. (8) In the second term, the relationship between the production-technology state and tax revenues strengthened.

4.4 Bayesian impulse responses to structural shocks

Finally, Figs. 4-11 show the Bayesian impulse responses of endogenous variables (including a part of the observation variables) to the lump-sum tax, the nominal interest rate, government spending, and production-technology shocks, the magnitude of which is estimated one standard deviation of each shock. These figures indicate the following. Note that instead of % expressions, this study uses the bare values of each growth rate, the deviation rate, and the difference. (1) The lump-sum tax shock increases $\widehat{kd}_t$ and decreases $\widehat{bd}_t$. (2) The nominal interest-rate shock increases $\widehat{bd}_t$ and $\widehat{\tau d}_t$. (3) The government-spending shock decreases $\widehat{cd_t^{rc}}$, $\widehat{m}_t$, and $\widehat{kd}_t$ and increases $\widehat{bd}_t$ and $\widehat{\tau d}_t$. Although the estimated model in the second term slightly explains the consumption growth, a crowding-in effect, caused by increased government spending, the estimated models cannot fully indicate the above effect. (4) The production-technology shock decreases $\widehat{yd}_t$, $\widehat{cd_t^{rc}}$, $\widehat{m_t}$, $\widehat{kd}_t$, $\widehat{bd}_t$, and $\widehat{\tau d}_t$ and increases $\widehat{r_t}$.

Here I add some explanations about the above findings. Items (2) and (3) can be directly understood. Regarding Item (1), my presumption is as follows. First, the increase of tax revenues causes a decrease in outstanding government bonds, and consequently, *Ricardian* households increase their share of investment to private firms in their financial portfolios instead of purchasing government bonds. Regarding Item (4), the following mechanism probably exists. A positive shock of the labor-augmenting production technology modeled in this study (see Equation (29)) shrinks capital stock supply/demand in the short run. The capital-stock decrease from this shrink induces a decrease of the output, the *Ricardian* households' consumption, money demand, and tax revenue in turn. However, the falling government-bond purchases induced by the output shrink gives a favorable effect to the situation of $\widehat{bd}_t$.

[Tables 4-6 and Figs. 4-11 near here]

5. Concluding Remarks

Considering Japan's lackluster economy for almost last 30 years, I investigated Japan's economic structural changes since the 1970s by making a medium-scale NK DSGE model, which features *non-Ricardian* households, sticky goods prices, and investment-adjustment cost and also detrends real economic variables. Using a Bayesian technique, I estimated my DSGE model over two terms: 1972Q3-2001Q1 and 1985Q1-2023Q1.

The following is the main knowledge I gleaned through this study. (1) The share of *non-Ricardian* households in the population probably increased over time, as expected. (2) The BOJ tended to emphasize the inflation rate more than the output gap. However, it more weakly responded to the inflation rate in the second term. This result is consistent with the fact that the BOJ has been engaged in monetary-easing policies since the late 1990s to extricate Japan from the long-lasting deflation and achieve a moderate inflation. (3) Based on the parameter estimates, the Japanese government has sustainably managed its finances through the entire analysis term. (4) Many endogenous-variable variations can be attributed to the production-technology shock. (5) In the second term, the interest-rate shock became a more influential factor for the variations of the *non-Ricardian* households' consumption, labor supply, wage rate, capital rental cost, inflation rate, and the government-bond accumulation than in the first term: these findings are related to Item (2) above.

Although I have shed light on the structural changes of the Japanese economy, some tasks remain. First, even though the BOJ started a negative-interest policy in 2016 (Fig. 2), it is more receptive to establishing a DSGE model that addresses the zero lower bound constraint on the policy-target interest rate, which several central banks of developed countries have faced since 2000s, as argued by Kulish et al. (2017). Second, as revealed in Iwasaki et al. (2021) and Zhang et al. (2021), the issues of downward wage rigidity and labor market friction must be considered. Third, it is crucial to consider plural types of government expenditure and tax, as Kotera and Sakai (2018) have done.

Appendix 1: Detrended equations

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

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

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

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

$cd_t^{nrc}=wd_tl_t^{nrc}-\tau d_t^{nrc}$ (see Equation (16)) (A1-5)

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

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

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

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

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

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

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

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

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

Appendix 2: Steady-state values

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

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

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

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

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 $yd = \int_0^1 yd\, dj$.

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

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 $yd = \int_0^1 yd\, dj$. Eventually, the final version of wdl/cd is derived from Equations (A2-5) - (A2-7).

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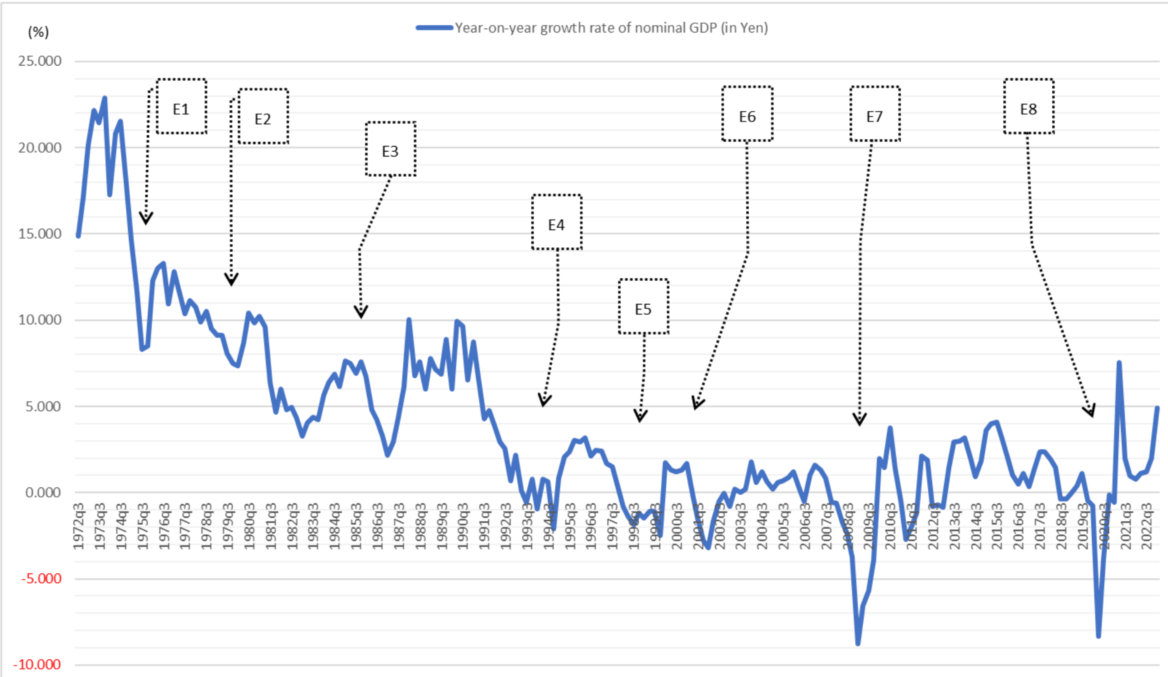
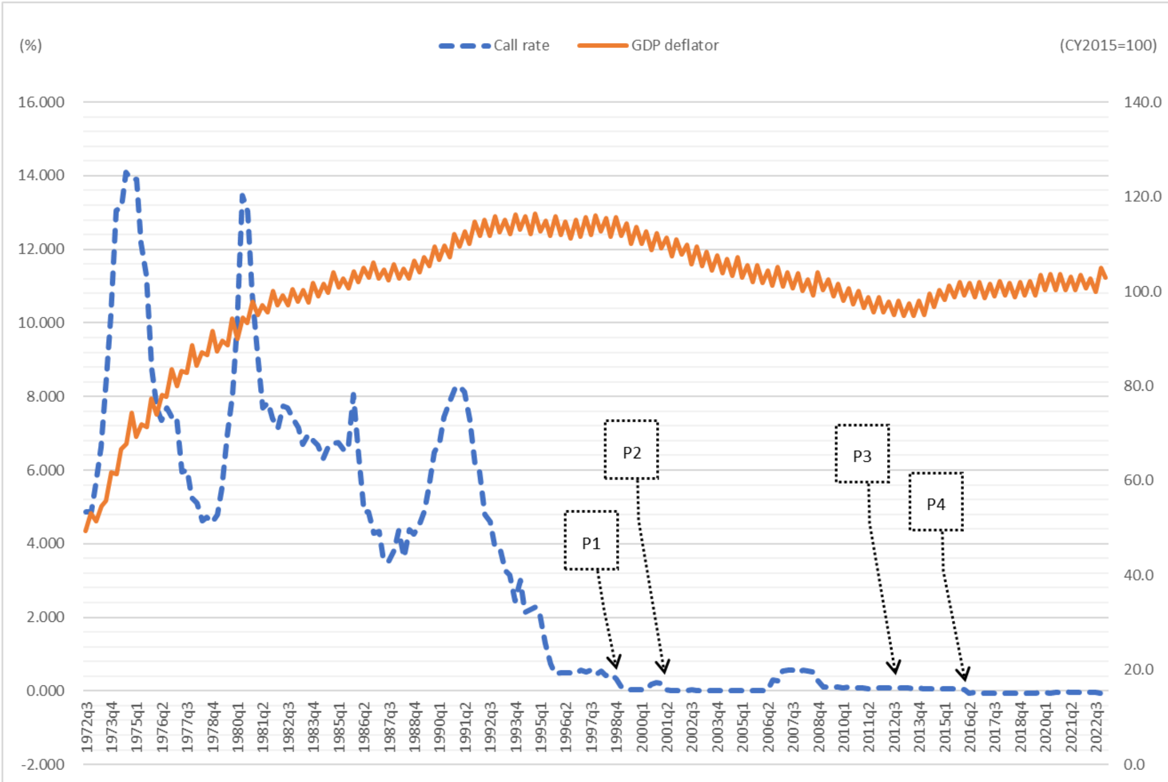
Tables and Figs



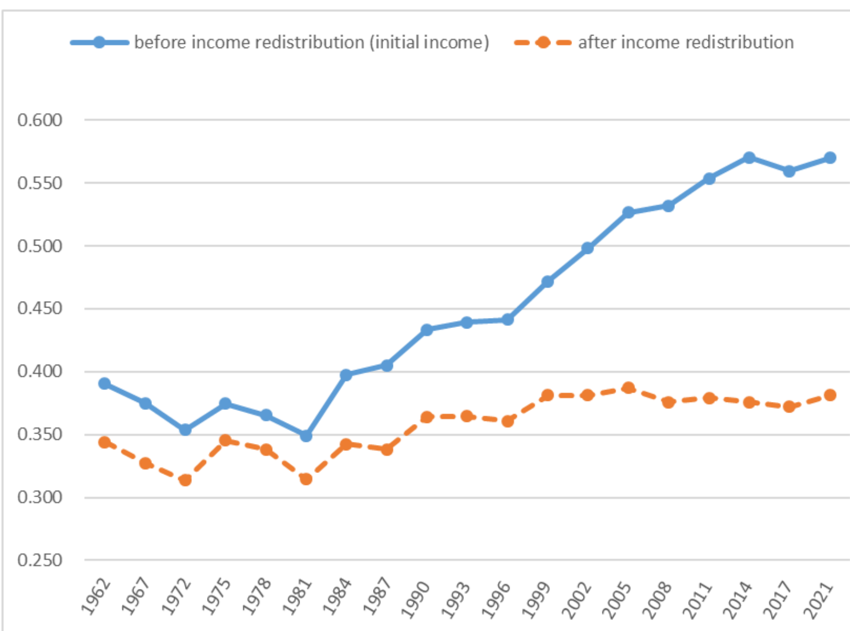
Legends: E1: First oil crisis; E2: Second oil crisis; E3: Plaza Accord; E4: Heisei-era depression; E5: Second Heisei-era depression; E6: IT bubble burst; E7: Global financial crisis; E8: New COVID-19 shock.
Source: By author using data in Table 1.

Fig. 1 Changes of 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.
Source: By author using data in Table 1.

Fig. 2 Changes of Call rate and GDP deflator in Japan



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

Fig. 3 Changes of 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 b. GDP deflator	National Accounts (Cabinet Office) https://www.esri.cao.go.jp/jp/sna/menu.html (Accessed on March 8, 2024.)	
2	**gr_ct_obs**	a. Private final consumption expenditure b. GDP deflator	National Accounts (Cabinet Office) See Item 1	
3	**gr_it_obs**	a. Private final consumption expenditure b. GDP deflator	National Accounts (Cabinet Office) See Item 1	
4	**gr_wt_obs**	a. Wage index b. Salary paid on a fixed basis c. GDP deflator	Monthly Labor Statistics Survey (Ministry of Health, Labour and Welfare) https://www.mhlw.go.jp/toukei/list/30-1k.html#01 (Accessed on March 8, 2024.) 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/2.html (Accessed on March 8, 2024.)	Calculated quarterly figures by averaging monthly figures every quarter.
6	**dev_gt_obs**	a. Government final consumption expenditure b. Government gross fixed capital formation c. Government changes in inventories e. GDP f. GDP deflator	National Accounts (Cabinet Office) See Item 1	
7	**dev_bt_obs**	a. Government outstanding net-financial liabilities b. GDP c. GDP deflator	Flow of Fund Statistics (Bank of Japan) https://www.stat-search.boj.or.jp/ (Accessed on March 8, 2024.) See Item 1	Estimated the figures of outstanding net-finacial liabilities before 1998Q4 following Yoshida (2021).
8	**dev_πt_obs**	a. GDP deflator	National Accounts (Cabinet Office) See Item 1	
9	**dif_rt_obs**	a. Unsecured overnight call rate b. GDP c. GDP deflator	(Bank of Japan) See Item 7 See Item 1	Calculated quarterly figures by averaging monthly figures every quarter ; used "unconditional call rate" before 1985Q2.

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

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

	β	θ	ζ	φ	α	δ	κ	ψ
Both analysis terms	0.996	1.500	2.000	2.000	0.330	0.060	7.000	11.000
	gd/yd	bd/yd						
First term	0.230	2.500						
Second term	0.290	5.500						

Note: First term and Second term indicate 1972Q3-2001Q1 and 1985Q1-2023Q1.

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	0.100
ϕ_{π}	Normal	1.050	1.050	0.200	0.200
ϕ_{y}	Normal	0.100	0.100	0.100	0.100
ϕ_{b}	Normal	0.030	0.030	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	0.850	0.100	0.100
logz	Normal	0.010	0.010	0.010	0.010
$\sigma_{s\tau}$	Inv. Gamma	0.050	0.020	Inf	Inf
σ_{sg}	Inv. Gamma	0.050	0.020	Inf	Inf
σ_{sr}	Inv. Gamma	0.050	0.020	Inf	Inf
σ_{sz}	Inv. Gamma	0.050	0.020	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	0.020	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 1972Q3-2001Q1 and 1985Q1-2023Q1.
(2) Each σ with subscript s indicates standard deviation of concerned exogenous structural shocks.

Table 4 Posterior Distributions of Parameters

Parameter	Distribution	Mean		90% interval	
		First term	Second term	First term	Second term
ω	Beta	0.046	0.177	[0.020, 0.073]	[0.102, 0.254]
ϕ_π	Normal	1.711	1.055	[1.438, 1.978]	[0.726, 1.380]
ϕ_y	Normal	0.258	0.102	[0.102, 0.417]	[-0.062, 0.270]
ϕ_b	Normal	0.035	0.030	[0.020, 0.050]	[0.014, 0.046]
ρ_g	Beta	0.716	0.630	[0.633, 0.800]	[0.466, 0.794]
ρ_z	Beta	0.457	0.500	[0.319, 0.598]	[0.331, 0.662]
ρ_r	Beta	0.833	0.851	[0.677, 0.994]	[0.712, 0.995]
logz	Normal	0.010	0.003	[0.009, 0.011]	[0.002, 0.004]
z		1.010	1.003	[1.009, 1.011]	[1.002, 1.004]
$\sigma_{s\tau}$	Inv. Gamma	0.022		[0.011, 0.032]	
σ_{sg}	Inv. Gamma	0.008		[0.007, 0.009]	
σ_{sr}	Inv. Gamma	0.007		[0.006, 0.008]	
σ_{sz}	Inv. Gamma	0.007		[0.006, 0.008]	
σ_y	Inv. Gamma	0.010	0.014	[0.009, 0.012]	[0.012, 0.015]
σ_c	Inv. Gamma	0.012	0.015	[0.010, 0.013]	[0.013, 0.016]
σ_i	Inv. Gamma	0.021	0.036	[0.017, 0.024]	[0.033, 0.040]
σ_w	Inv. Gamma	0.041	0.012	[0.036, 0.046]	[0.011, 0.014]
σ_g	Inv. Gamma	0.019	0.020	[0.017, 0.022]	[0.018, 0.022]
σ_π	Inv. Gamma	3.955	4.038	[3.524, 4.384]	[3.658, 4.415]
σ_r	Inv. Gamma	0.017	0.007	[0.015, 0.019]	[0.006, 0.007]
σ_l	Inv. Gamma	0.007	0.005	[0.006, 0.008]	[0.005, 0.006]
σ_b	Inv. Gamma	0.653	0.067	[0.581, 0.723]	[0.060, 0.073]

Notes: Identical as Table 3.

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

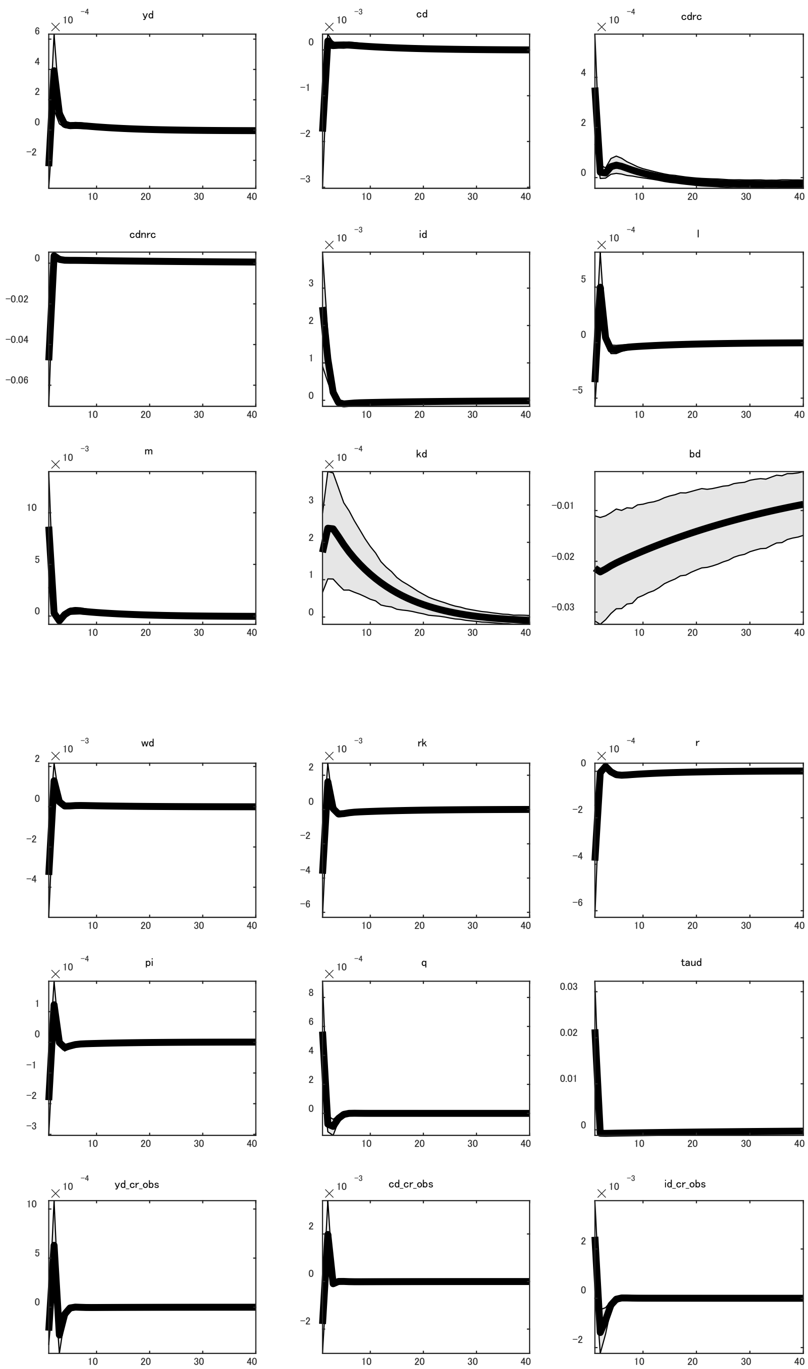
	This study		Hirose and Kurozumi (2012)	Eguchi (2011)	Iwata (2009)	Sugo and Ueda (2008)	Forni et al. (2009)
Region	Japan		Japan	Japan	Japan	Japan	Euro
Term	1972Q3-2001Q1	1985Q1-2023Q1	1981Q1-1998Q4	1992Q1-2001Q4	1980Q1-1998Q4	1981Q1-1995Q4	1980Q1-2005Q4
Parameter							
ω	0.046	0.177		0.043	0.248		0.340
ϕ_π	1.711	1.055	1.683	1.602	1.533	0.606	1.720
ϕ_y	0.258	0.102	0.079	0.201	0.254	0.110	0.130
ϕ_b	0.035	0.030		0.035			
ϕ_{cb}					0.013		0.500
ϕ_{lb}					0.005		0.280
ϕ_{kb}					0.123		0.570
ρ_g	0.716	0.630		0.616	0.736	0.892	
ρ_z	0.457	0.500	0.067	0.757	0.518	0.949	
ρ_r	0.833	0.851		0.864	0.934	0.842	0.920
z	1.010	1.003	1.004				

Note: Subscript, 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 (%)

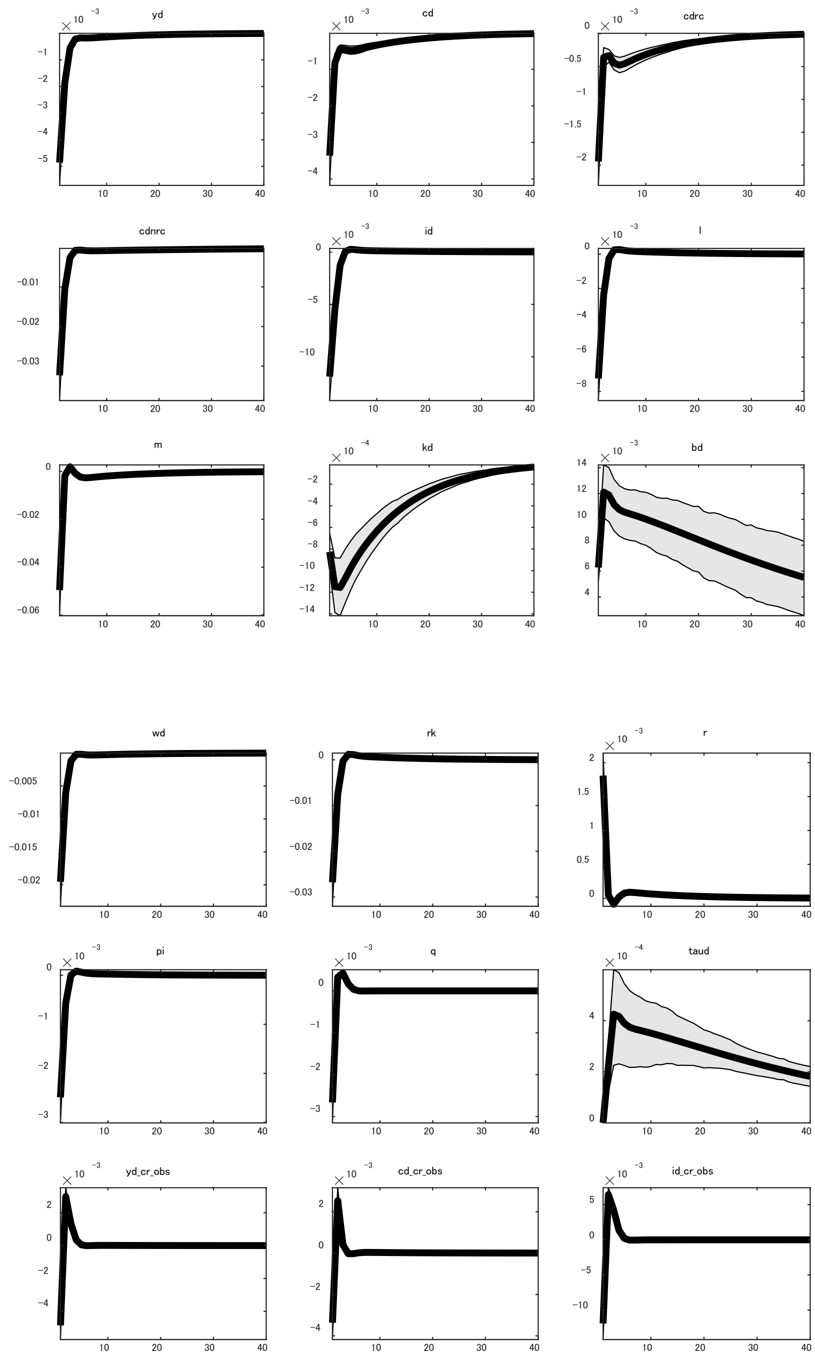
First term	Structural shocks				Second term	Structural shocks			
Endogeneous variables	Tax ε_τ	Interest rate ε_r	Government spending ε_g	Production technology ε_z	Endogeneous variables	Tax ε_τ	Interest rate ε_r	Government spending ε_g	Production technology ε_z
yd	0.17	20.30	8.17	71.36	yd	0.93	30.15	7.13	61.79
cd	0.91	3.71	16.29	79.10	cd	4.14	32.00	5.30	58.56
cd^{rc}	0.04	1.44	15.82	82.69	cd^{rc}	0.08	0.51	3.94	95.47
cd^{nrc}	56.47	29.11	6.83	7.59	cd^{nrc}	10.63	66.46	9.73	13.18
id	0.75	16.57	63.46	19.21	id	2.55	3.77	54.46	39.22
l	0.26	37.39	15.18	47.16	l	1.50	53.80	11.50	33.20
m	0.41	13.21	11.65	74.73	m	1.29	4.02	9.90	84.79
kd	0.03	0.78	8.88	90.32	kd	0.05	0.09	3.80	96.06
bd	20.43	7.00	59.98	12.60	bd	2.12	26.16	30.19	41.53
wd	1.91	58.89	5.73	33.47	wd	4.27	67.70	7.93	20.10
r^k	0.74	33.44	5.84	59.98	r^k	2.91	54.99	7.35	34.76
r	0.66	14.44	11.02	73.88	r	1.86	2.75	10.84	84.55
π	0.44	54.68	1.93	42.95	π	1.38	76.39	3.43	18.80
q	2.74	59.14	31.95	6.18	q	12.14	18.02	50.35	19.49
gd	0.00	0.00	100.00	0.00	gd	0.00	0.00	100.00	0.00
τd	91.03	0.79	6.76	1.42	τd	38.21	16.52	19.06	26.21

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).



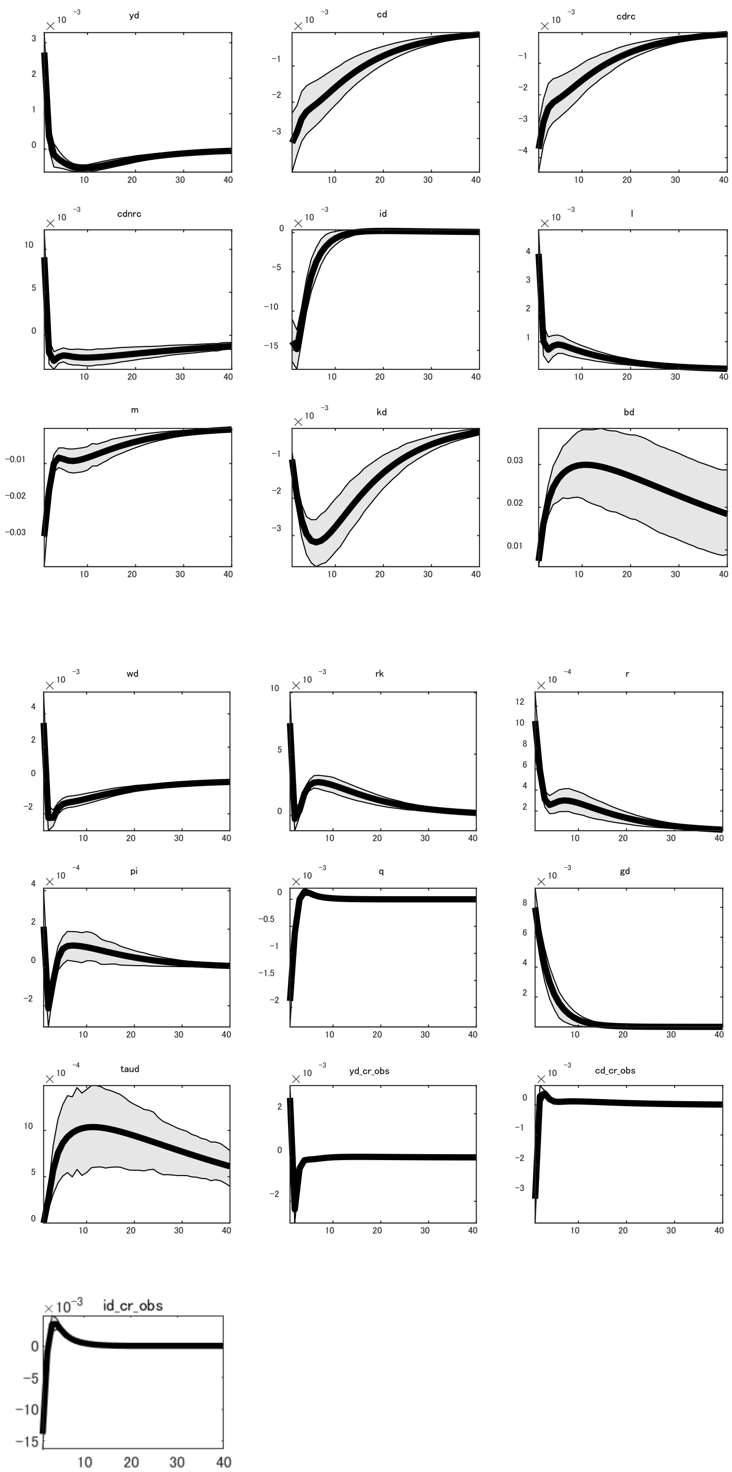
Notes: (1) cdrc, cdnrc, rk, pi, and taud respectively indicate cd^{rc}, cd^{nrc}, r^k, π, and τd. (2) Endogenous variables denote those with hats in Equations (42)-(58). (3) yd_cr_obs, yd_cr_obs, and yd_cr_obs respectively indicate gr_y_t_obs, gr_c_t_obs, and gr_i_t_obs.

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



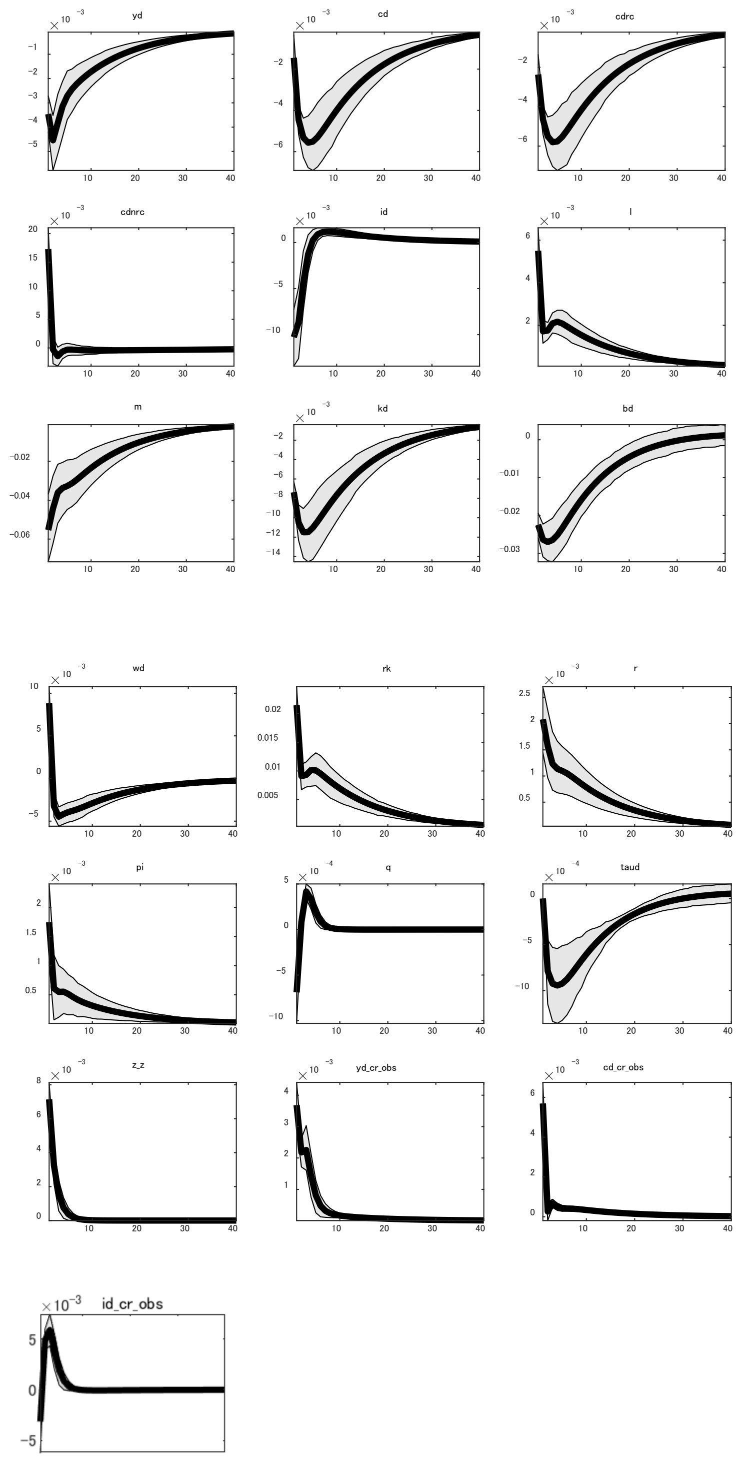
Notes: Identical as Fig. 4.

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



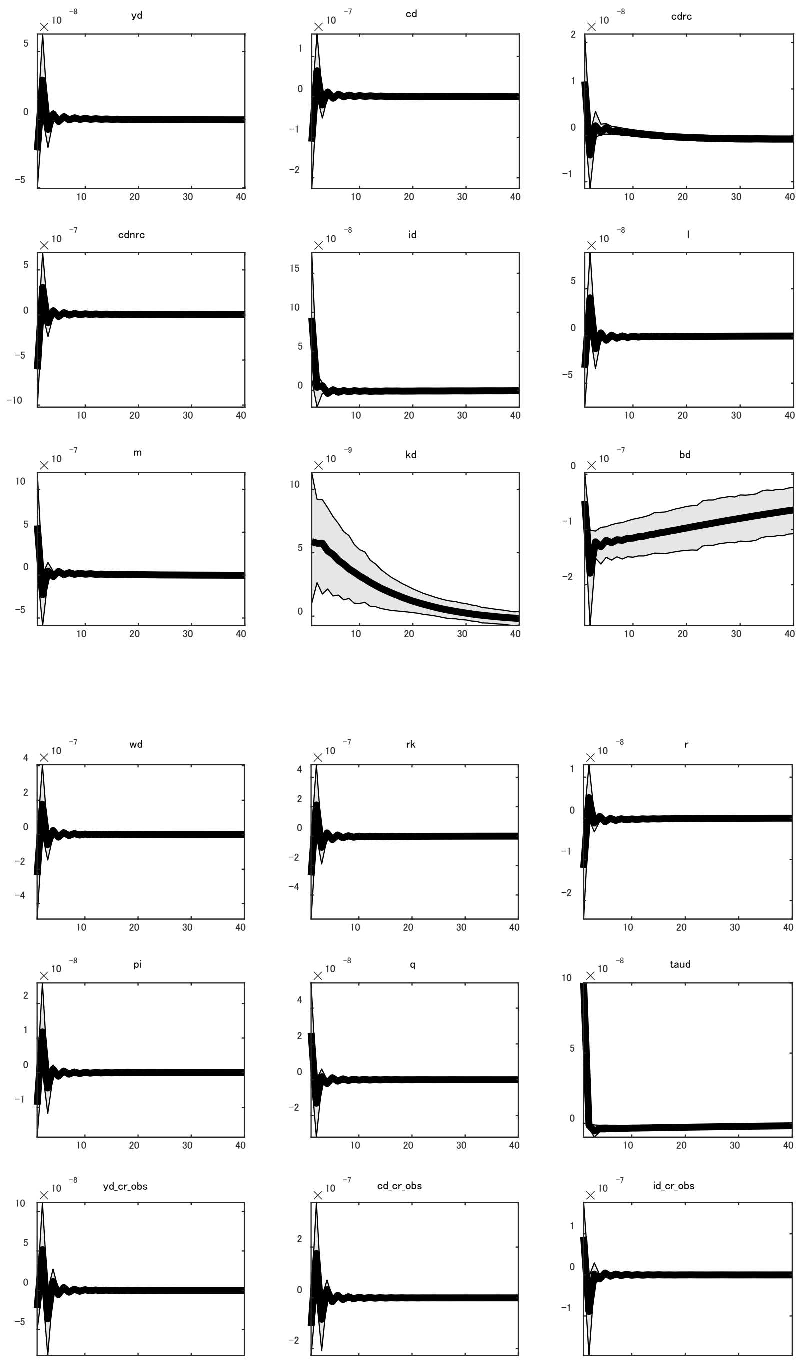
Notes: Identical as Fig. 4.

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



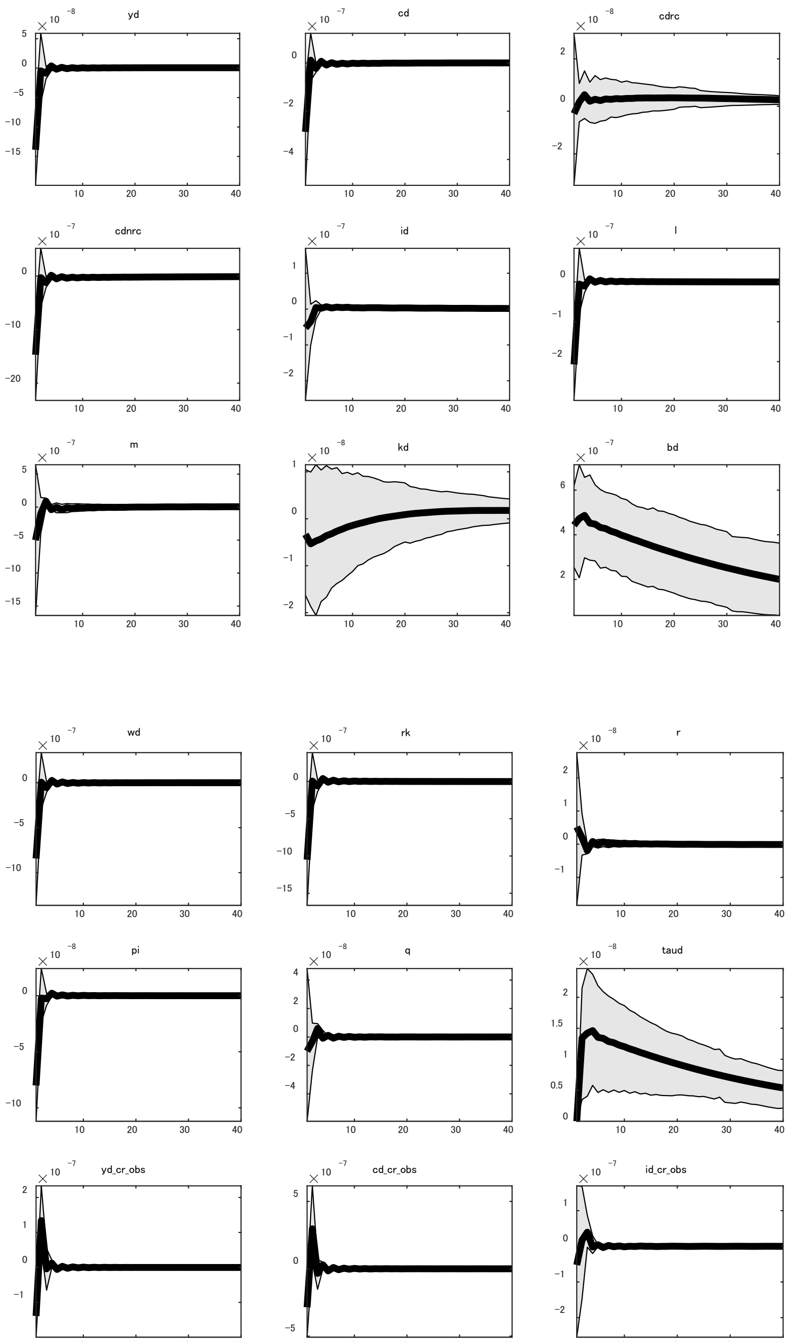
Notes: Identical as Fig. 4. In addition, z_z indicates z_t^z.

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



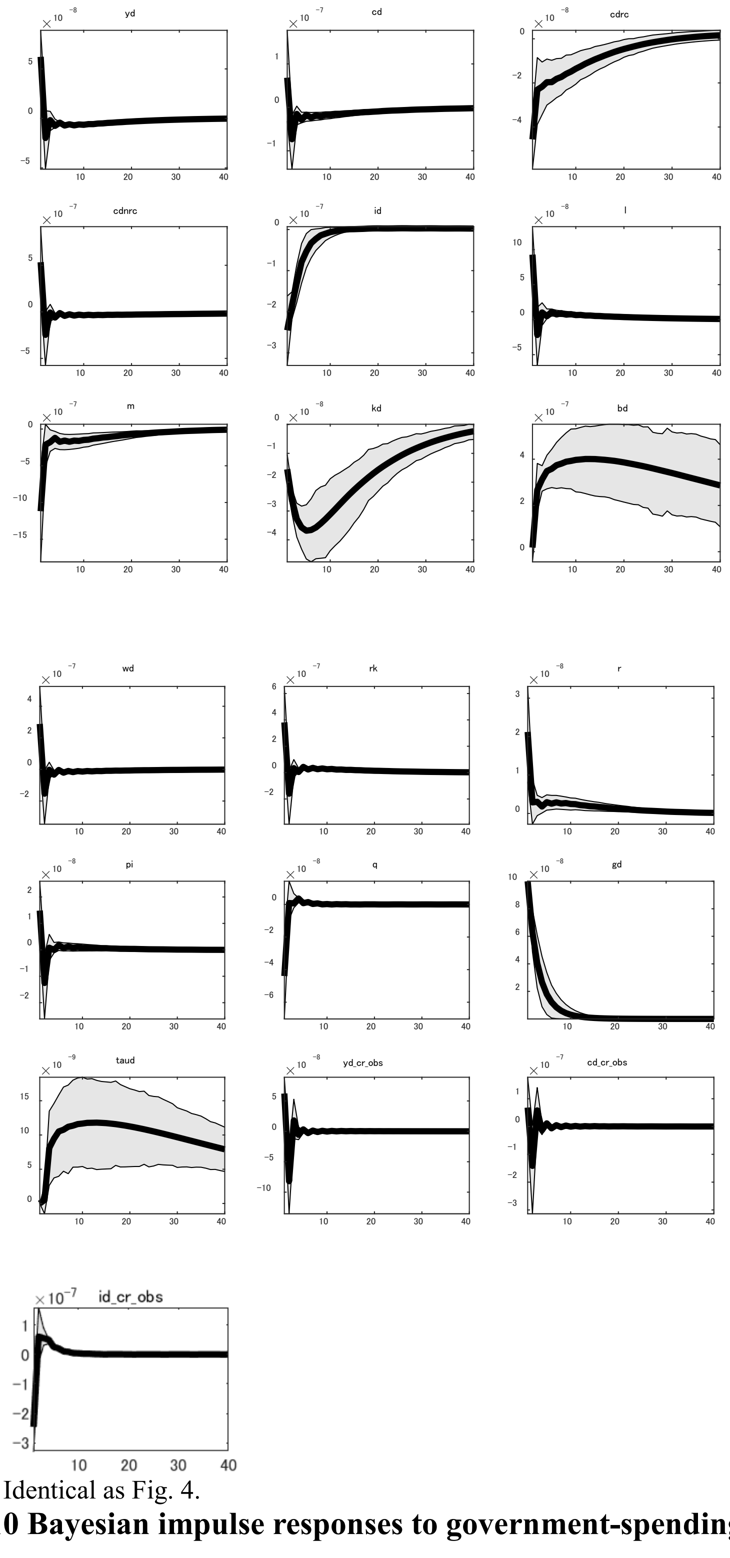
Notes: Identical as Fig. 4.

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



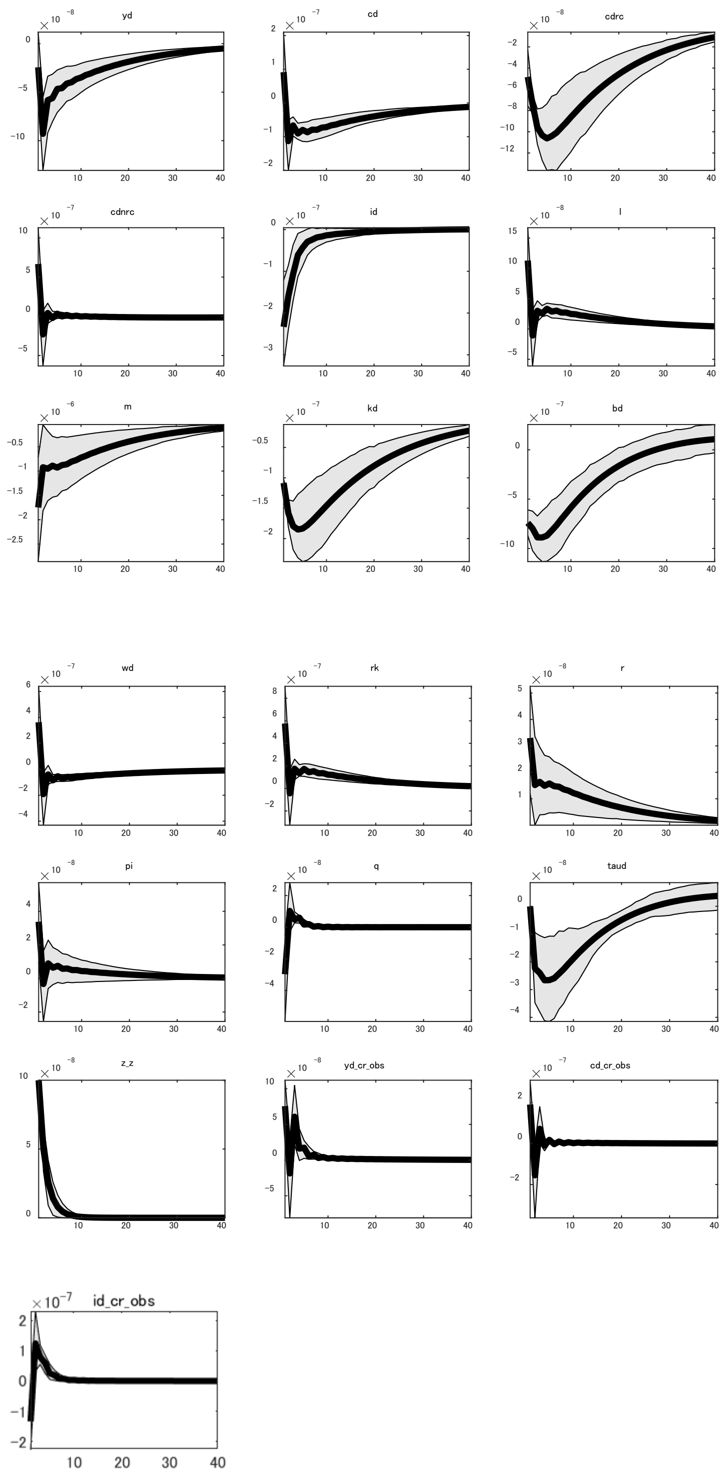
Notes: Identical as Fig. 4.

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



Notes: Identical as Fig. 4.

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



Notes: Identical as Fig. 4. In addition, z_z indicates z_t^z.

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