Bank of Japan Working Paper Series

Estimating a Markov Switching DSGE Model with Macroeconomic Policy Interaction

Nobuhiro Abe*

Takuji Fueki**
takuji.fueki@boj.or.jp

Sohei Kaihatsu***
skaihatsu@imf.org

No.19-E-3
March 2019

Bank of Japan
2-1-1 Nihonbashi-Hongokucho, Chuo-ku, Tokyo 103-0021, Japan

* Research and Statistics Department (currently at the Personnel and Corporate Affairs Department)
** Research and Statistics Department
*** Research and Statistics Department (currently at the Strategy, Policy, and Review Department, International Monetary Fund)

Estimating a Markov Switching DSGE Model with Macroeconomic Policy Interaction*

Nobuhiro Abe[†], Takuji Fueki[‡], and Sohei Kaihatsu[§]

March 2019

Abstract

This paper estimates a Markov switching dynamic stochastic general equilibrium model (MS-DSGE) allowing for changes in monetary/fiscal policy interaction. The key feature of the model is that it seeks to quantitatively examine the impact of changes in monetary/fiscal policy interaction on economic outcomes even during a period when the ZLB is binding and unconventional monetary policy is implemented. To this end, we estimate our model using the shadow interest rate, which can be interpreted as an aggregate that captures the overall effect of unconventional monetary policies as well as conventional monetary policy. Applying our model to Japan, we identify changes in monetary/fiscal policy interaction even during the period when unconventional monetary policy has been implemented. We find that the introduction of Qualitative and Quantitative Easing (QQE) enables the Bank of Japan to actively respond to the inflation rate, which has helped to push up inflation.

JEL classification: E52, E62, C32

Keywords: Monetary policy; Inflation; Markov-switching DSGE

*The authors are grateful to Kosuke Aoki, Andrea Ferrero, Naohisa Hirakata, Hibiki Ichiue, Ryo Jinnai, Takushi Kurozumi, Kevin Lansing, Andrew Levin, Ichiro Muto, Toshitaka Sekine, Shigenori Shiratsuka, Nao Sudo, Tomohiro Sugo, Yosuke Uno, Shingo Watanabe, Fan Dora Xia, and staff members of the Bank of Japan for helpful comments. We also thank Hibiki Ichiue and Yoichi Ueno for providing the data on shadow interest rates. Any remaining errors are the sole responsibility of the authors. The views expressed in this paper are those of the authors and do not necessarily reflect the official views of the Bank of Japan or the International Monetary Fund.

[†]Personnel and Corporate Affairs Department, Bank of Japan

[‡]Research and Statistics Department, Bank of Japan (E-mail: takuji.fueki@boj.or.jp)

[§]Strategy, Policy, and Review Department, International Monetary Fund (E-mail: skaihatsu@imf.org)

1 Introduction

Over the past decades, Japan has struggled with prolonged periods of deflation or low inflation, while the United States and other major advanced economies have also experienced low inflation following the 2007/2008 global financial crisis. In order to escape from negative or low inflation, monetary and fiscal authorities have tried to stimulate the economy. As a result, we have seen dramatic changes in monetary and fiscal policy and increases in uncertainty surrounding policy conduct. For instance, to overcome the limitations of conventional monetary policy due to the zero lower bound (ZLB) on nominal interest rates, central banks in advanced economies introduced unconventional monetary policies such as quantitative easing and forward guidance on future policies. Meanwhile, fiscal positions have started to deteriorate through an expansion of fiscal expenditure to stimulate the economy. Worsening fiscal positions have in turn put great uncertainty and restrictions on further fiscal expansions, which has brought the risks linked to fiscal imbalances to the forefront of policy concerns.

These developments have led to a renewed interest in the sensitivity of the economy to changes and uncertainty in the monetary/fiscal policy mix. One of the first studies on this topic is that by Leeper (1991). This has been followed by a growing number of studies estimating Markov Switching Dynamic Stochastic General Equilibrium (MS-DSGE) models that allow for changes in the mix of monetary and fiscal policies. Such models make it possible to quantify the impact of uncertainty about the policy mix on economic outcomes. For instance, Bianchi and Ilut (2017) and Bianchi and Melosi (2017) find that changes in the monetary/fiscal policy mix play a substantial role in accounting for inflation dynamics in the United States. However, few studies have evaluated changes in the monetary/fiscal policy mix and examined how these changes have shaped economic outcomes in the period after the global financial crisis including the period following the introduction of unconventional monetary policy. This is partly because it is computationally burdensome to handle the ZLB on nominal interest rates, which explicitly introduces nonlinearity with respect to the nominal interest rate into the model.

The contribution of this paper is to fill this gap. We aim to quantitatively examine the impact of changes in monetary/fiscal policy interaction on economic outcomes even during a period when the ZLB is binding and unconventional monetary policy is implemented. In particular, our focus is on Japan. We start by trying to identify changes in monetary/fiscal policy interaction even during the period when unconventional monetary policy has been implemented. Since it has experienced a binding ZLB since the late 1990s, Japan provides a great laboratory to examine the role of changes in the policy mix at the ZLB. We then quantitatively investigate the impact of such changes on the evolution of Japan's economy. More specifically, we address the following questions: What are the causes of the prolonged deflation in Japan and what is the role of the policy mix? And has the unconventional policy pursued by the Bank of Japan helped to push up inflation?

To this end, we construct and estimate a new Keynesian model allowing for changes in the monetary and fiscal policy mix. The MS-DSGE model that we construct builds on the influential contribution of Bianchi and Ilut (2017). They develop a recurrent MS-DSGE model with monetary and fiscal policy interaction and estimate the model for the U.S. economy focusing on the period from 1954 to 2009, which does not include any periods in which the ZLB was binding. They consider three monetary/fiscal policy regimes. The first consists of active monetary and passive fiscal policy (AM/PF), where both the interest rate response to inflation and the tax response to debt are strong.[1] The second consists of passive monetary and active fiscal policy (PM/AF), where both responses are weak. Finally, the third consists of active monetary and active fiscal policy (AM/AF).

This paper differs from Bianchi and Ilut (2017) in two major respects. First, inspired by Chen et al. (2018), we consider a richer set of policy regimes and transitions across regimes. That is, we also consider the PM/PF regime, which Bianchi and Ilut (2017) do not consider in detail.[2] The PM/PF regime consists of passive monetary and passive fiscal policy, where the response to inflation of the monetary authority is weak and the response to debt of the fiscal authority is strong. This richer set of policy regimes allows us to identify the evolution of monetary and fiscal policies without restrictions.[3]

Second, and more importantly, we estimate our model using the shadow rate as an aggregate that captures both conventional and unconventional monetary policy. Specifically, following Wu and Zhang (2017), we assume the monetary authority sets the shadow nominal interest rate in response to inflation. The shadow rate essentially corresponds to the policy rate to reflect the effects of conventional monetary policy when the ZLB is not binding. However, it can be below zero when the ZLB is binding to reflect the effects of unconventional

[1] We use the terminology of Leeper (1991) in specifying policies as active or passive. We provide a detailed explanation further below.

[2] In addition, we do not restrict the transition across regimes. For example, it is not necessary to transition through the AM/AF regime when moving from the PM/AF regime to the AM/PF regime as in Bianchi and Ilut (2017).

[3] Bianchi and Ilut (2017) show that when the PM/PF regime is introduced into the model, the performance of the model in terms of the marginal likelihood deteriorates. However, their observation period does not include any periods in which the ZLB was binding. Different from their study, our analysis includes periods in which the ZLB was binding.

monetary policy. Hence, the shadow rate is informative in order to evaluate the response of monetary policy to inflation even when the ZLB is binding and unconventional monetary policy is implemented. In addition, using the shadow rate allows us to reduce the computational burden of handling the ZLB, because the shadow rate can be below zero and does not have a ZLB.

Our main findings are twofold:

- From 1998 to 2013, policy in Japan was characterized by a PM/PF regime: During the period from 1998 to 2013, the ZLB substantially constrained the Bank of Japan's ability to mitigate the impact of negative demand shocks on the economy, leading to deflation. In addition, agents' perceptions mattered: once the PM/PF regime was in place, it was expected to last, and agents believed that the negative impact of demand shocks was unlikely to be mitigated. Consequently, the PM/PF policy mix played a substantial role in the propagation of negative demand shocks and contributed to the prolonged deflation in Japan. Our results indicate that if monetary policy had been more active (i.e., unconventional policies had been implemented more aggressively), the economy would have escaped from deflation.

- We find that since the introduction of quantitative and qualitative easing (QQE) in 2013:2Q, an active monetary policy regime has been in place. This finding suggests that the introduction of QQE enables the Bank of Japan to actively respond to the inflation rate and thus has helped to push up inflation.[4]

The remainder of the paper is organized as follows. Section 2 describes the model and the policy mix structure. Section 3 presents the solution method for the MS-DSGE model and the empirical strategy. Section 4 shows the estimation results and the model dynamics. Section 5 draws on counterfactual simulations to discuss the role of the policy mix in accounting for inflation dynamics. Section 6 presents concluding remarks.

2 Model

We follow the standard New Keynesian model with independent Markov switching processes developed by Bianchi and Ilut (2017). The model allows for recurrent changes in the policy

[4] We also apply our method to the United States using the shadow federal funds rate estimated by Ichiue and Ueno (2018). The results are shown in Appendix B.

mix (ξ_t^{sp}) and volatility regimes (ξ_t^{vo}) and contains a wide range of fiscal variables such as government debt, government purchases, tax revenue, and government expenditure.

For our analysis, we add two features to the approach developed by Bianchi and Ilut (2017). First, the monetary authority sets the shadow interest rate, which can be interpreted as an aggregate that captures the overall effect of unconventional monetary policies. Second, we consider a richer set of policy regimes in that we also allow for a passive monetary/passive fiscal policy regime (PM/PF).

The economy consists of a continuum of identical households, a continuum of monopolistically competitive intermediate goods producing firms, perfectly competitive final good producing firms, a government that engages in fiscal policy, and a central bank that controls monetary policy.

2.1 Households

Households maximize the following lifetime utility function separable into consumption C_t and hours worked h_t:

$$\mathbb{E}_0 \left[\sum_{s=0}^{\infty} \beta^s e^{d_s} \left\{ \log(C_s - \Phi C_{s-1}^A) - h_s \right\} \right] \tag{1}$$

where C_t^A stands for the average level of consumption and Φ denotes the degree of external habit formation. We assume that demand (preference) d_s follows an autoregressive process: $d_t = \rho_d d_{t-1} + \sigma_{d,\xi_t^{vo}} \epsilon_{d,t}$ where $\epsilon_{d,t} \sim N(0,1)$. ξ_t^{vo} denotes the volatility regime which is in place at t. We allow for two volatility regimes, Low and High, which is discussed in detail below.

Households' budget constraint is given by

$$P_t C_t + P_t^s B_t^s + P_t^m B_t^m = P_t W_t h_t + B_{t-1}^s + (1 + \rho P_t^m) B_{t-1}^m + P_t D_t - T_t + TR_t \tag{2}$$

where P_t is the general price level, W_t is the real wage, D_t represents firms'real profits, T_t is a lump-sum tax, and TR_t stands for transfers. There are two types of government bonds: one-period government bonds B_t^s and long-term government bonds B_t^m. While the net supply of one period government bonds B_t^s is zero, that of long-term government bonds B_t^m is non-zero. Accordingly, B_t^s has a price of P_t^s, which is equal to R_t^{-1}, while B_t^m has a price of P_t^m, which has the payment structure $\rho^{T-(t+1)}$ for $T > t$ and $0 < \rho < 1$. Then, the value of long-term bonds issued in period t in future period $t+i$ can be computed as $P_{t+i}^{m-i} = \rho^i P_{t+i}^m$.

2.2 Firms

Final good producers aggregate intermediate goods which are indexed by $j \in [0,1]$:

$$Y_t = \left(\int_0^1 Y_t(j)^{1-\upsilon_t} dj\right)^{\frac{1}{1-\upsilon_t}} \tag{3}$$

Firms take input prices $P_t(j)$ and output prices P_t as given. The demand for inputs is given by the profit maximization condition:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\frac{1}{\upsilon_t}} Y_t \tag{4}$$

where the parameter $\frac{1}{\upsilon_t}$ is the elasticity of substitution across differentiated intermediate input goods. Under the assumption of free entry into the final good market, profits are zero in equilibrium, and the price of the aggregate good is given by:

$$P_t = \left(\int_0^1 P_t(j)^{\frac{\upsilon_t-1}{\upsilon_t}} dj\right)^{\frac{\upsilon_t}{\upsilon_t-1}} \tag{5}$$

We define inflation at time t as $\Pi_t = P_t/P_{t-1}$. Intermediate goods firms produce their products only with labor, $Y_t(j) = A_t h_t^{1-\alpha}(j)$. A_t is an exogenous productivity process given by $\ln(A_t/A_{t-1}) = \gamma + a_t$, where $a_t = \rho_a a_{t-1} + \sigma_{a,\xi_t^{vo}} \epsilon_{a,t}$ and $\epsilon_{a,t} \sim N(0,1)$. Intermediate goods producing firms face the following quadratic adjustment costs:

$$AC_t(j) = \frac{\varphi}{2}\left(\frac{P_t(j)}{P_{t-1}(j)} - \Pi_{t-1}^{\zeta}\Pi^{1-\zeta}\right)^2 \frac{P_t(j)}{P_t} Y_t(j) \tag{6}$$

where φ governs the price stickiness in the economy, Π is the steady state of Π_t, and the parameter ζ denotes the degree of indexation to lagged inflation. The elasticity of substitution can be converted into the mark-up $\Theta_t = \frac{1}{1-\upsilon_t}$. The rescaled mark-up $\mu_t (= \frac{\kappa}{1+\zeta\beta} \log(\Theta_t/\Theta))$ follows an autoregressive process, $\mu_t = \rho_\mu \mu_{t-1} + \sigma_{\mu,\xi_t^{vo}} \epsilon_{\mu,t}$, where $\kappa \equiv \frac{1-\upsilon}{\upsilon\phi\Pi^2}$ is the slope of the Phillips curve and $\epsilon_{\mu,t} \sim N(0,1)$. Firm j chooses its labor input $h_t(j)$ and the price $P_t(j)$ to maximize the present value of future profits:

$$\mathbb{E}_t\left[\sum_{s=t}^{\infty} Q_s \left(\frac{P_s(j)}{P_s} Y_s(j) - W_s h_s(j) - AC_s(j)\right)\right] \tag{7}$$

where Q_s is the marginal value of a unit of the consumption good to the household.

2.3 Government

The flow budget constraint of the government is given by

$$P_t^m B_t^m = B_{t-1}^m(1+\rho P_t^m) - T_t + P_t G_t + TR_t + TP_t \tag{8}$$

where $P_t^m B_t^m$ is the market value of debt, T_t represents government tax revenues, $P_t G_t$ is government goods purchases, and TR_t denotes government transfers. The term TP_t reflects measurement errors and is used to fill the gap between the market value of debt at the end of the last quarter and the sum of debt and the primary balance in this quarter. We assume this gap includes changes in the maturity structure, which we cannot rigorously take into account here. The net supply of one-period debt B_t^s is zero.

When considering the equilibrium for debt, we convert equation (8) into the share of nominal GDP:

$$b_t^m = (b_{t-1}^m R_{t-1,t}^m)/(\Pi_t Y_t / Y_{t-1}) - \tau_t + g_t + tr_t + tp_t \tag{9}$$

where $R_{t-1,t}^m = \frac{1+\rho P_t^m}{P_{t-1}^m}$ is the return on long-term bonds and it is assumed that $tp_t = \rho_{tp} tp_{t-1} + \sigma_{tp,\xi_t^{vo}} \epsilon_{tp,t}$ and $\epsilon_{tp,t} \sim N(0,1)$.

Linearized government expenditure, $E_t = P_t G_t + TR_t$, as a fraction of GDP, $\tilde{e}_t$, is divided into a short-term component, $\tilde{e}_t^S$, and a long-term component, $\tilde{e}_t^L$:

$$\tilde{e}_t^L = \rho_{e^L} \tilde{e}_{t-1}^L + \sigma_{e^L,\xi_t^{vo}} \epsilon_{e^L,t} \tag{10}$$

$$\tilde{e}_t^S = \rho_{e^S} \tilde{e}_{t-1}^S + (1-\rho_{e^S})\phi_y(\hat{y}_t - \hat{y}_t^*) + \sigma_{e^S,\xi_t^{vo}} \epsilon_{e^S,t} \tag{11}$$

where $\epsilon_{e^L,t} \sim N(0,1)$ and $\epsilon_{e^S,t} \sim N(0,1)$. We assume that the long-term component is exogenous and represents major government programs such as the pension system. As such, it does not react to business cycle fluctuations. Instead, it is the short-term component that reacts to business cycle fluctuations and hence the output gap, $\hat{y}_t - \hat{y}_t^*$. Next, we define the ratio of government transfers in total government expenditure as $\chi_t \equiv TR_t / E_t$ and assume that

$$\tilde{\chi}_t = \rho_\chi \tilde{\chi}_{t-1} + (1-\rho_\chi)\iota_y(\hat{y}_t - \hat{y}_t^*) + \sigma_{\chi,\xi_t^{vo}} \epsilon_{\chi,t} \tag{12}$$

where $\epsilon_{\chi,t} \sim N(0,1)$.

Below, we refer to $\epsilon_{\chi,t}$ as transfer shocks. Lastly, the market clearing condition is

$$Y_t = G_t + C_t \tag{13}$$

2.4 Monetary and Fiscal Rules, and Recurrent Regime Change

As noted above, this model allows for independent changes in the conduct of monetary and fiscal policy. In what follows, we first show the principal monetary and fiscal policy rules and then provide details of the regime switching parameters.

Monetary policy

The monetary policy authority sets the interest rate and follows a feedback rule, which Wu and Zhang (2017) call the shadow rate Taylor rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_{R,\xi_t^{sp}}} \left[\left(\frac{\Pi_t}{\Pi}\right)^{\psi_{\pi,\xi_t^{sp}}} \left(\frac{Y_t}{Y_t^*}\right)^{\psi_{y,\xi_t^{sp}}}\right]^{(1-\rho_{R,\xi_t^{sp}})} e^{\sigma_{R,\xi_t^{vo}}\epsilon_{R,t}} \tag{14}$$

where R_t is the gross nominal interest rate, R denotes the steady-state gross nominal interest rate, and $\epsilon_{R,t} \sim N(0,1)$. Π represents the steady-state aggregate inflation rate. Note that the monetary policy response parameters $\rho_{R,\xi_t^{sp}}$, $\psi_{\pi,\xi_t^{sp}}$, and $\psi_{y,\xi_t^{sp}}$ could be switched. ξ_t^{sp} represents the monetary/fiscal policy regime which is in place at t. There are four monetary/fiscal policy regimes, which is discussed in detail below.

In a departure from Bianchi and Ilut's (2017) setup, where R_t represents the policy interest rate, in our model R_t represents the shadow interest rate, which can be negative when the ZLB is binding and unconventional policy is implemented. In other words, R_t essentially corresponds to the policy rate (the call rate in Japan's case) when the ZLB is not binding but can be below zero when the ZLB is binding and in this case reflects the effects of unconventional monetary policy. Thus, like Wu and Zhang (2017), we can incorporate both conventional and unconventional policy by using the shadow rate.

Fiscal policy

The government adjusts taxes according to the following rule:

$$\tilde{\tau}_t = \rho_{\tau,\xi_t^{sp}}\tilde{\tau}_{t-1} + (1-\rho_{\tau,\xi_t^{sp}})[\delta_{b,\xi_t^{sp}}\tilde{b}_{t-1}^m + \delta_e\tilde{e}_t + \delta_y(\hat{y}_t - \hat{y}_t^*)] + \sigma_{\tau,\xi_t^{vo}}\epsilon_{\tau,t} \tag{15}$$

where $\tilde{\tau}_t$ is the deviation of the tax-to-GDP ratio from its own steady state and $\epsilon_{\tau,t} \sim N(0,1)$. Taxes respond not only to the debt $\delta_{b,\xi_t^{sp}}$ but also to government expenditure δ_e and the GDP gap δ_y. Note that, like the monetary policy response parameters, the fiscal policy response parameters ρ_τ, ξ_t^{sp}, and $\delta_{b,\xi_t^{sp}}$ could be switched.[5]

Policy mix

Following Leeper (1991), the general criteria on parameter values regarding the existence and uniqueness of a solution to the model in the absence of policy regime switches are as follows:

- Regime I: Passive monetary and active fiscal policy; i.e., $\psi_\pi < 1$ and $\delta_b < \beta^{-1} - 1$.
- Regime II: Passive monetary and passive fiscal policy; i.e., $\psi_\pi < 1$ and $\delta_b > \beta^{-1} - 1$.
- Regime III: Active monetary and active fiscal policy; i.e., $\psi_\pi > 1$ and $\delta_b < \beta^{-1} - 1$.
- Regime IV: Active monetary and passive fiscal policy; i.e., $\psi_\pi > 1$ and $\delta_b > \beta^{-1} - 1$.

Let us consider these regimes in more detail. In Regime I, the passive monetary and active fiscal (PM/AF) regime, taxes are not sufficiently adjusted to prevent the government debt burden from being financed through future taxes, and monetary policy does not satisfy the Taylor principle. Under this regime, the fiscal authority weakly responds to debt. In other words, the tax response rate to debt is smaller than the steady state quarterly real interest rate $\beta^{-1} - 1$. Next, in Regime II, both fiscal and monetary policy are passive (PM/PF) and the economy is subject to multiple equilibria. This is because the level of debt does not directly affect inflation dynamics (Bhattarai et al. (2014)). In Regime III, both fiscal and monetary policy are active (AM/AF), and no stationary equilibrium exists, which means the transversality condition is violated, as both fiscal and monetary authorities try to determine the price level without paying attention to the debt level. Finally, in Regime IV, consisting of active monetary and passive fiscal policy (AM/PF), the Taylor principle is satisfied and the fiscal authority strongly adjusts taxes in order to keep debt stable. This is the regime usually assumed in the standard new Keynesian literature.

In our model, monetary and fiscal policy regimes change freely and independently of each other. Therefore, our model allows different combinations of active and passive monetary

[5]We assume that the inflation target and the target for the government debt-to-GDP ratio are constant over time. As highlighted by Bianchi (2013), it is difficult to distinguish a change in a particular target from a change in the policy response parameters, unless we have some additional information to identify a change in a particular target. Hence, following studies such as Bianchi and Ilut (2017), we assume that what changes is the response with which policy makers try to achieve the target (goal), not the target itself, to reduce the difficulties of identifying policy regimes.

and fiscal policies at different points in time. As outlined above, the PM/PF regime leaves the equilibrium undetermined in the absence of policy regime switches. In addition, an AM/AF regime means that either no equilibrium exists or, if it does exist, the equilibrium is explosive and non-stationary. However, when regime changes are modeled as independent Markov switching processes as in our model, the PM/PF regime does not necessarily leave the equilibrium indeterminate, as is mentioned by Chen et al. (2018). Similarly, the AM/AF regime does not necessarily violate the transversality condition, because agents correctly assign a positive probability to returning to a regime that prevents the government debt from accumulating in an explosive manner.

Transition matrices

In addition to the four policy regimes outlined above (PM/AF, PM/PF, AM/AF, and AM/PF), we allow two volatility regimes, Low and High. Here, we describe the transition matrices governing the probability of transition from one regime to another. In our model, agents are aware of the possibility of a switch to another regime or staying in the current regime and thus take the possibility of regime changes into account when forming expectations and making decisions. Therefore, the transition probability matrices play an important role in determining the economic outcomes. Specifically, the transition probability matrices look as follows.

$$H^{sp} = \begin{bmatrix} H^{sp}_{11} & H^{sp}_{12} & H^{sp}_{13} & H^{sp}_{14} \\ H^{sp}_{21} & H^{sp}_{22} & H^{sp}_{23} & H^{sp}_{24} \\ H^{sp}_{31} & H^{sp}_{32} & H^{sp}_{33} & H^{sp}_{34} \\ H^{sp}_{41} & H^{sp}_{42} & H^{sp}_{43} & H^{sp}_{44} \end{bmatrix} \tag{16}$$

$$H^{vo} = \begin{bmatrix} H^{vo}_{11} & H^{vo}_{12} \\ H^{vo}_{21} & H^{vo}_{22} \end{bmatrix} \tag{17}$$

where for H^{sp} subscripts 1, 2, 3, and 4 correspond to the PM/AF, PM/PF, AM/AF, and AM/PF regime, respectively. For the stochastic volatilities, H^{vo}, subscripts 1 and 2 correspond to the Low and High volatility regime, respectively.[6]

[6] As highlighted by Sims and Zha (2006) and Cogley and Sargent (2006), accounting for the stochastic volatility of exogenous shocks is essential when trying to identify policy regime shifts.

3 Estimation

We employ the maximum likelihood (ML) method to estimate the structural parameters of the model. Parameters that are not estimated are calibrated in the standard fashion.

3.1 Data

We estimate the model using quarterly data for Japan for the period from 1982:2Q to 2017:1Q. It thus includes the period when ZLB was binding, which was from 1999:2Q onward.[7] The data consist of 140 time series, including real GDP growth, the consumer price index (all items less fresh food and energy), the interest rate (the call rate up to 1991:Q1 and then the shadow rate), the debt-to-GDP ratio, the ratio of government purchases to GDP, the government expenditure-to-GDP ratio, and the government tax revenue-to-GDP ratio. Our data sources are listed in Appendix A.

Shadow rate

For our analysis, we make use of the shadow rate calculated by Ueno (2017) to grasp the response of monetary policy to inflation even during the period when unconventional policy has been implemented in Japan.[8] The shadow rate used in this paper is shown in Figure 1. The shadow rate essentially corresponds to the call rate when the ZLB is not binding but goes below zero when the ZLB is binding, which reflects the effects of unconventional monetary policy. This shows that the shadow rate can be interpreted as an aggregate that captures both conventional and unconventional monetary policy. Hence, the shadow rate is informative to evaluate changes in the response of monetary policy to inflation even when the ZLB is binding and unconventional monetary policy is implemented.[9]

In addition, using the shadow rate has another advantage. The ZLB on nominal interest rates explicitly introduces nonlinearity with respect to nominal interest rates into the model, making it computationally burdensome to deal with the ZLB. However, the shadow rate does not have a ZLB and can go below zero, which reflects the effects of unconventional monetary policy. Hence, using the shadow rate as an aggregate that captures both conventional and

[7] We follow an official statement of the Bank of Japan to identify the date when nominal interest rates hit the ZLB.

[8] Admittedly, the estimation results for the shadow rate are highly dependent on the theoretical assumptions underlying the estimation. Therefore, while we use the shadow rate calculated by Ueno (2017) as our benchmark, we also check the robustness of our results using the shadow rate estimated below Krippner (2016). Doing so indicates that our results presented below are robust.

[9] Wu and Xia (2016), for example, argue that their estimated shadow federal funds rate can be used to illustrate the effects of unconventional monetary policy on the macroeconomy. Wu and Zhang (2017) propose a comprehensive framework to evaluate both conventional and unconventional monetary policies using the shadow federal funds rate.

unconventional monetary policy, we can reduce the computational burden in dealing with this nonlinearity.[10]

3.2 Model Solution

We follow Bianchi and Ilut (2017) to solve the model. When a solution exists, we can obtain the solution using the following regime-switching vector auto-regression:

$$S_t = T(\xi_t^{sp}, \theta^{sp}, H^{sp})S_{t-1} + R(\xi_t^{sp}, \theta^{sp}, H^{sp})Q(\xi_t^{vo}, \theta^{vo}, H^{vo})\varepsilon_t \tag{18}$$

where S_t represents the vector of variables in our model and $\varepsilon_t \sim N(0, I)$. θ^{sp} is a vector of the structural parameters which could be switched, and θ^{vo} is a vector of the volatility parameters. $T(\xi_t^{sp}, \theta^{sp}, H^{sp})$ and $R(\xi_t^{sp}, \theta^{sp}, H^{sp})$ take four sets of values corresponding to the four policy regimes. In addition, $Q(\xi_t^{vo}, \theta^{vo}, H^{vo})$ take two sets of values corresponding to the two volatility regimes. Note that $T(\xi_t^{sp}, \theta^{sp}, H^{sp})$, $R(\xi_t^{sp}, \theta^{sp}, H^{sp})$, and $Q(\xi_t^{vo}, \theta^{vo}, H^{vo})$ are characterized by the structural parameters (θ^{sp}) and the volatility parameters (θ^{vo}). Moreover, note that the probabilities of moving across regimes (H^{sp} and H^{vo}) are also included. Hence, the possibility of regime change also matters when agents form expectations and make decisions, which means that agents' beliefs likely play a significant role in determining the law of motion of the economy.

3.3 Model Estimation

We conduct the maximum likelihood estimation of the non-calibrated structural parameters of the model following Davig and Leeper (2006). Specifically, we combine the law of motion with a system of observation equations as follows:

$$X_t = D + ZS_t \tag{19}$$

where X_t represents observable variables and D is a constant. S_t means the vector of variables in our model. Z maps S_t into the observables.

Given the above system of stochastic difference equations describing the equilibrium dy-

[10] While central banks cannot directly set a negative shadow rate in practice, they can achieve one through unconventional monetary policy tools. Wu and Zhang (2017), for example, show that the impact of unconventional policies such as quantitative easing can be mapped in the standard New Keynesian model similar to changes in the shadow rate. We implicitly assume the same mapping equivalence in this paper. The estimated shadow rate can be interpreted as an aggregate that captures both conventional and unconventional monetary policy and is informative in order to identify the response of monetary policy to inflation even when the ZLB binds.

namics of the model, it is straightforward to numerically evaluate the likelihood function of the data given the vector of estimated parameters, which we denote by $L(Y|\Theta)$, where Y is the data sample and Θ is the vector of parameters to be estimated. The likelihood $L(Y|\Theta)$ is computed using the modified Kalman filter described in Kim and Nelson (1999). We use the minimization algorithm "csminwel" by C. Sims to find the estimates.

4 Estimation Results

This section presents our estimation results. Specifically, Section 4.1 reports the parameter estimates obtained using our general regime switching DSGE framework. Section 4.2 then presents the identified regimes, while Section 4.3 shows the impulse response functions. Finally, Section 4.4 provides a historical decomposition of inflation dynamics into the contribution of various shocks.

4.1 Parameter Estimates

Table 1 shows the values assigned to the calibrated parameters. The values are more or less in line with those used by Bianchi and Ilut (2017), Fueki et al. (2016), and Sugo and Ueda (2008). We set the income share of capital in total output, α, to 0.33, implying a labor income share of 0.67. The discount factor β is 0.9985, and the parameter determining the maturity structure of government bonds is calibrated to match the average maturity of government bonds from 1982 to 2016, which is about six years.

The parameter estimates are presented in Table 2. While our estimates of the structural parameters are more or less in line with other studies, two sets of parameters are worthy of note: the policy parameters, and the transition matrix governing the probability of transition from one policy regime to another.

Starting with the policy parameters, note that they allow for recurrent regimes changes in our model, where monetary and fiscal policy can change independently of each other. Turning to monetary policy behavior, there are two regimes: a regime in which monetary policy responds strongly to inflation (active policy), and a regime in which it does not respond strongly enough to achieve the inflation target (passive policy). In other words, the shadow rate reacts stronger to both inflation ($\psi_{\pi,AM} = 2.150$) and the output gap ($\psi_{y,AM} = 0.569$) under the active regime than under the passive regime ($\psi_{\pi,PM} = 0.389$, $\psi_{y,PM} = 0.246$). Similarly, there are two fiscal policy regimes: one in which tax policy is active and responds strongly to debt, and one in which tax policy is passive and responds weakly to debt. In the passive regime, the tax response rate to debt is larger ($\delta_{b,PF} = 0.028$) than in the active regime. Note that under the active policy regime the response of taxes to debt is restricted to zero, as in Bianchi and Ilut (2017).

Turning to the transition probabilities, Figure 2 provides a graphic representation of the transition probabilities shown in the lower part of the Table 2. Reviewing the properties of the estimated transition matrix, it should be noted that there are also important differences in the duration of the regimes. Specifically, note that the two polar cases of the AM/PF regime and the PM/AF regime are persistent, while the AM/AF regime is the most transient regime, as in Bianchi and Ilut (2017). Moreover, the estimation results have two implications. First, when the AM/PF regime is in place, there is a positive probability of movement to the PM regime in the next period. In other words, even if the active monetary policy regime is in place, agents might not believe they will be in the AM/PF regime in the future and they expect the Bank of Japan to move to a passive policy with some positive probability. Second, and more interestingly, the PM/PF regime is also persistent. This indicates that, when the PM/PF regime is in place, the probability of going to the AM regime is low and agents therefore are less likely to expect that AM regime will be in place in the future.

4.2 Identified Regimes

Figure 3 presents the smoothed probabilities assigned to the four policy regimes. Throughout the first half of the observation period, fiscal policy was active. Fiscal policy then switched from an active regime to a passive regime in 1998. On the other hand, monetary policy remained passive. This may reflect the fact that the ZLB was binding and that the lack of unconventional monetary policy tools did not allow the Bank to strongly respond to falling inflation. Hence, the late 1990s to 2013 were a period in which both policies were passive.

Since the ZLB did not allow the Bank of Japan to strongly respond to inflation, it was not until the beginning of 2013 that monetary policy became active. The switch may reflect the introduction of QQE. On the other hand, fiscal policy remained passive and accommodated the switch in the conduct of monetary policy. Hence, we find that since then an AM/PF policy mix has been in place.

4.3 Impulse Response Functions

In order to improve our understanding of differences in the propagation of shocks across the different regimes, it is useful to look at impulse response functions. When computing the impulse response functions, we assume that no regime shifts occur and a particular regime is in place over the entire horizon. However, when making decisions, agents take into account the possibility that regime shifts may occur in the future based on the estimated transition probabilities. The dynamics will therefore differ from those that would be obtained if we used a DSGE model without regime shifts, as highlighted by Sims (2016).

The first column of Figure 4 reports the impulse responses to an exogenous monetary tightening. The solid blue line, the dot-dash black line, the dotted green line, and the dashed red line respectively represent the PM/AF, PM/PF, AM/AF, and AM/PF regimes. The initial shock is equal to a one standard deviation monetary policy shock under the low volatility regime. The responses under the three regimes also considered by Bianchi and Ilut (2017) – i.e., the PM/AF, AM/AF, and AM/PF regimes - are all consistent with their results.

To start with, note that the policy regime matters: the responses differ substantially both qualitatively and in size across the policy regimes. In particular, the ability of a central bank to control inflation is substantially reduced under the AF regimes (that is, the AM/AF regime and the PM/AF regime). The mechanism through which a central bank loses the ability to control inflation under the AF regimes is as follows. Monetary tightening increases the real cost of debt and the recession associated with monetary tightening increases the debt burden. Under the AF regimes, agents expect that there will be no offsetting increase in current or future tax obligations despite the fact that the government debt burden will increase. Households will therefore assume that the sustainability of government debt is not assured and try to substitute out of government debt into goods. Households' consumption path therefore shifts upward. Higher demand for goods will push up the price level. On the other hand, under the AM/PF regime inflation is well anchored. With respect to the PM/PF regime, the responses to monetary tightening look qualitatively similar to those under the AM/PF regime given our estimated parameters, although the responses across the two regimes slightly differ in size.

Turning to the second column of Figure 4, this shows the responses to a negative demand shock. The initial shock is equal to a one standard deviation demand shock under the low volatility regime. We find that, across all regimes, such a shock leads to a reduction in real activity and an initial decline in inflation in line with the standard predictions of new-

Keynesian models and the results obtained by Bianchi and Ilut (2017). However, when the PM/AF and AM/AF regimes are in place, this initial decline is soon followed by a rise in inflation. The reason is that the decline in real activity will lead to an inflationary increase in the fiscal burden only when agents expect that a non-AF regime will prevail for many periods.

In addition, what is worth noting is that the propagation of a negative demand shock is strongest under the PM/PF regime. Specifically, there is a strong and persistent decline in the inflation rate. However, under the PM/PF regime, there is no strong monetary policy response to stimulate the economy. As a result, monetary policy provides little stabilization in response to the negative impact of a demand shock on inflation.

It should be highlighted that the impulse responses to a negative demand shock depend on agents' beliefs about being in or moving to the AM/PF regime in the future. In our model, agents take the possibility of regime changes into account when forming expectations and making decisions. Therefore, changes in the probability of staying in or a switch to the AM/PF regime play a role in determining economic outcomes. To examine the role played by agents' beliefs in stabilizing the economy in the wake of a negative demand shock, we investigate the response to a negative demand shock under the AM/PF regime. Specifically, we examine what happens if the transition probabilities from the AM/PF regime to another are changed from the estimated probabilities. In this counterfactual scenario, we set the probability of staying in the AM/PF regime to one, which implies agents believe that the AM/PF regime will be in place forever. We refer to this counterfactual scenario as the fully credible AM/PF regime. Note that the differences between the responses under the estimated transition probabilities and those under the counterfactual scenario (the fully credible AM/PF regime) should quantitatively reflect the role played by agents' beliefs in the propagation of a negative demand shock.

The results are shown in Figure 5. The solid blue line, the dot-dash black line, and the dashed red line respectively represent the fully credible AM/PF regime, the PM/PF regime, and the AM/PF regime. The vertical difference between the solid blue line and the dashed red line represents the impact of agents' belief about being in the AM/PF regime, in which inflation is anchored. The results imply that negative demand shocks have a much smaller impact on inflation and output under the fully credible AM/PF regime scenario. The reason is that agents believe that the central bank will actively mitigate the negative impact of demand shocks in the future. This result illustrates the important role that agents' belief about being in an active monetary policy regime plays in stabilizing the economy in the wake of a negative demand shock.

4.4 Historical Decomposition

What factors have played a role in determining inflation dynamics in Japan during the observation period? To answer this question, Figure 6 presents a historical decomposition of CPI inflation (less fresh food and energy) in Japan. Specifically, inflation dynamics are broken down into the contribution of monetary policy, fiscal policy, demand, mark-ups, and technology shocks. Fiscal policy shocks consist of changes in transfers, the tax-to-GDP ratio, short-term expenditure, long-term expenditure, and term premiums. The results in Figure 6 clearly show that demand shocks have played a substantial role in driving inflation dynamics in Japan. As seen in the impulse responses to demand shocks, this is because negative demand shocks were propagated strongly and persistently under the PM/PF policy mix. To highlight the importance of demand shocks in accounting for the evolution of Japan's economy, Figure 7 plots the paths of real GDP growth and CPI inflation (less fresh food and energy) that would be obtained if all shocks other than demand shocks were excluded. Their paths track the data well.

5 Counterfactual Simulations

In this section, we examine the role of the policy regime in the evolution of Japan's economy, in particular inflation dynamics, through the lens of our model.

As shown above, the key factor responsible for the prolonged deflation is negative demand shocks. The issue therefore is how policymakers can reduce the negative impact of demand shocks in order to escape from the prolonged deflation. We therefore explore whether changes in the policy mix would help to reduce the negative impact of demand shocks on inflation or not. To address this question, we examine two types of simulations. First, we investigate what would have happened under alternative policy mix scenarios. This is a standard counterfactual simulation. We use the structural shocks extracted from the estimates to simulate the economy but assume alternative (counterfactual) changes in the monetary and fiscal policy mix.

Second, and more interestingly, we ask what would have happened if the probabilities of transition from one policy regime to another had been different from the estimated probabilities. As in the first type of simulation, we simulate the economy using the structural shocks extracted from the estimates. Bianchi and Ilut (2017) call this latter type of simulation "beliefs counterfactual" simulation. This exercise allows us to study how changes in agents' perceptions about the policy mix change the impact of a negative demand shock.

5.1 Inflation Dynamics during the 2000s Had the Policy Mix been Different

Focusing on the period from the late 1990s to 2013, we simulate the path of Japan's economy assuming the same sequence of demand shocks. However, we assume that the policy mix, and in particular the monetary policy response, as well as agents' beliefs with regard to policy regime changes had been different. Specifically, we assume that monetary policy had been active. Thus, we assume that the AM/PF regime instead of the PM/PF regime was in place since 1998. In addition, consistent with this first assumption, we also assume that agents regard the AM/PF regime as the only possible one. That is, agents fully believe that the policy regime is AM/PF. In practical terms, this implies that the Bank of Japan had started with unconventional monetary policy in 1998 (rather than in 2001, as it actually did), and had pursued it more aggressively than it actually did. Moreover, agents believed that the Bank would conduct active monetary policy forever.

The results of this simulation are presented in Figure 8. The dashed blue line shows the paths of real GDP growth, CPI inflation (less fresh food and energy), and interest rates had the fully credible AM/PF regime been in place from 1998 onward. The results clearly indicate that inflation would have been much higher had the AM/PF regime been in place. There are two reasons. The first is the active response of monetary policy: the Bank of Japan would have tried to mitigate the effects of negative demand shocks. That is, the Bank would have tried to lower the shadow rate to stimulate the economy by implementing unconventional policy. The second reason is agents' beliefs about being in the AM/PF regime, which are also key in mitigating the impact of negative demand shocks, as discussed in the impulse response analysis. These findings imply that if the monetary policy response had been different, the deflation of the 2000s would not have occurred.

5.2 Revisiting QQE

Next, we try to illustrate the impact of the changes in the policy mix brought about by the introduction of QQE (from 2013:2Q). As above, we conduct our simulation assuming the same sequence of demand shocks; this time, however, we assumed that monetary policy did not switch to an active policy regime and examine the path of the economy in the absence of QQE. That is, we assume that the PM/PF regime before 2013:Q2 remained in place. Figure 9 compares the course of the economy in the benchmark model (represented by the solid red line) and the counterfactual scenario assuming that the PM/PF regime had remained in place (represented by the solid blue line). As can be seen, the inflation rate would have been lower had the PM/PF policy mix remained in place. This clearly indicates that the introduction of QQE has helped to push up inflation.

Finally, we look at the beliefs counterfactual simulation. Specifically, we ask whether inflation would have been higher had the probability of being in the AM/PF regime been one. This scenario implies that agents fully believe that the AM/PF regime will last forever. In Figure 9, the path of the economy in the benchmark model (represented by the solid red line) is compared with the course of the economy in the beliefs counterfactual scenario in which agents regard the AM/AF regime as the only possible regime (represented by the dotted blue line). The figure clearly indicates that inflation would have increased by more than it did in the benchmark case, indicating that agents' beliefs about being the in AM/PF regime play an important role. In other words, inflation would be higher if agents more strongly believed that they were in an AM/PF regime. This implies that the Bank of Japan could have pushed up inflation if it had managed to convince agents that it would conduct active monetary policy forever.

6 Conclusion

This paper investigated the role played by monetary-fiscal policy interaction in the behavior of inflation in Japan, focusing in particular on the prolonged deflation observed in Japan. We found that Japan's policy regime during the period was characterized by the combination of passive monetary (PM) and passive fiscal (PF) policy and that this played a substantial role in propagating negative demand shocks, leading to prolonged deflation. In addition, we found that the extent to which agents believe that the AM/PF regime remains in place is also key in stabilizing the economy in the wake of negative demand shocks and, in particular, in pushing up inflation.

However, an important issue remains for future analysis. This paper assumes that the probabilities of transition from one policy regime to another are time-invariant. That is, it is assumed that agents' beliefs about the policy do not change over time. However, it may be reasonable to assume that agents' beliefs evolve based on events . For instance, observing that the Bank of Japan has started to respond strongly to inflation, agents may have become more confident that the AM regime will remain in place. Agents may therefore have updated their beliefs and started to assign a higher probability to being in the AM regime in the future. Therefore, an interesting task for the future is to endogenize how agents update their beliefs regarding the policy response and to examine the macroeconomic consequences of dynamic changes in agents' beliefs.

References

Bhattarai, Saroj, Jae Won Lee, and Woong Yong Park, "Inflation Dynamics: The Role of Public Debt and Policy Regimes," *Journal of Monetary Economics*, 2014, *67*, 93–108.

Bianchi, Francesco, "Regime Switches, Agents' Beliefs, and Post-World War II U.S. Macroeconomic Dynamics," *Review of Economic Studies*, 2013, *80* (2), 463–490.

_ **and Cosmin Ilut**, "Monetary/Fiscal policy mix and agents' beliefs," *Review of Economic Dynamics*, 2017, *26*, 113–139.

_ **and Leonardo Melosi**, "Escaping the Great Recession," *American Economic Review*, 2017, *107* (4), 1030–1058.

Chen, Xiaoshan, Eric M. Leeper, and Campbell Leith, "US Monetary and Fiscal Policies - Conflict or Cooperation?," 2018. Mimeo.

Cogley, Timothy and Thomas J. Sargent, "Drifts and Volatilities: Monetary Policies and Outcomes in the Post WWII U.S.," *Review of Economic Dynamics*, 2006, *8*, 262–302.

Davig, Troy and Eric M. Leeper, "Fluctuating Macro Policies and the Fiscal Theory," *NBER Macroeconomics Annual*, 2006, *21*, 247–315.

Fueki, Takuji, Ichiro Fukunaga, Hibiki Ichiue, and Toyoichiro Shirota, "Measuring Potential Growth with an Estimated DSGE Model of Japan's Economy," *International Journal of Central Banking*, 2016, *12*, 1–32.

Ichiue, Hibiki and Yoichi Ueno, "A Survey-based Shadow Rate and Unconventional Monetary Policy Effects," 2018. IMES Discussion Paper Series.

Kim, Chang-Jin and Charles R. Nelson, *State-Space Models with Regime Switching*, Cambridge, MA: MIT Press, 1999.

Krippner, Leo, "Documentation for measures of monetary policy," 2016. Mimeo.

Leeper, Eric M., "Equilibria under 'active' and 'passive' monetary and fiscal policies," *Journal of Monetary Economics*, 1991, *27*, 129–147.

Sims, Christopher A., "Fiscal policy, monetary policy and central bank independence," 2016. Kansas Citi Fed Jackson Hole Conference.

— **and Tao Zha**, “Were There Regime Switches in U.S. Monetary Policy?,” *American Economic Review*, 2006, *96* (1), 54–81.

Sugo, Tomohiro and Kozo Ueda, “Estimating a dynamic stochastic general equilibrium model for Japan,” *Journal of the Japanese and International Economies*, 2008, *22*, 476–502.

Ueno, Yoichi, “Term Structure Models with Negative Interest Rates,” 2017. IMES Discussion Paper Series.

Wu, Jing Cynthia and Fan Dora Xia, “Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound,” *Journal of Money, Credit and Banking*, 2016, *48* (2).

— **and Ji Zhang**, “A Shadow Rate New Keynesian Model,” 2017. Chicago Booth Working Paper No. 16-18.

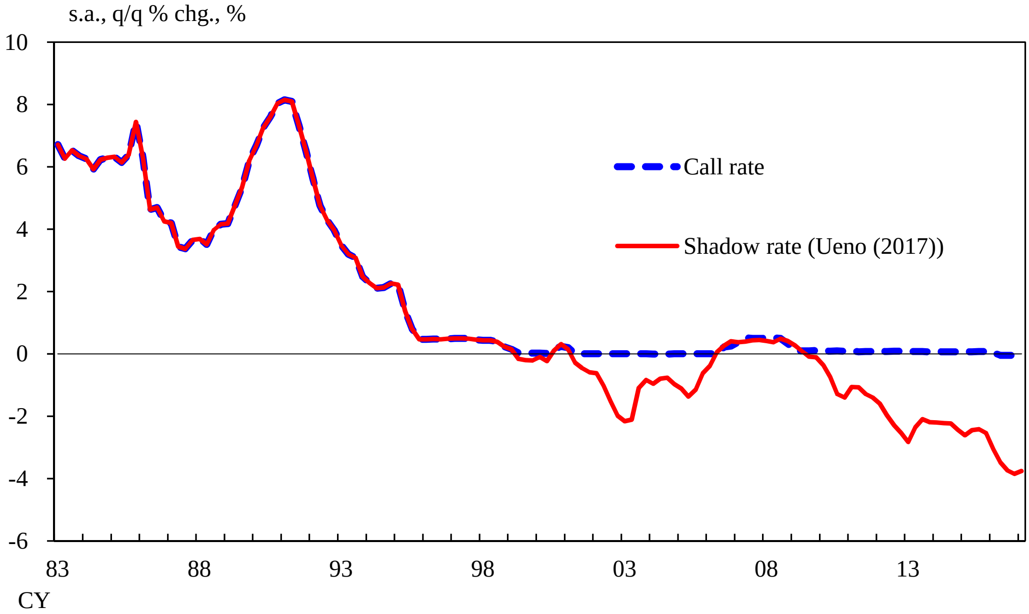
Table 1: Calibrated Parameters

Parameter		Value
Capital share	α	0.3300
Discount rate	β	0.9985
Persistence of long term-expenditure	ρ_{e^L}	0.9900
S.D. of long term-expenditure	$100\sigma_{e^L}$	0.1000
Parameter for maturity structure	ρ	0.9583

Table 2: Estimated Parameters

Parameter		Value
Monetary policy response to inflation (PM)	$\psi_{\pi,PM}$	0.389
Monetary policy response to inflation (AM)	$\psi_{\pi,AM}$	2.150
Monetary policy response to output (PM)	$\psi_{y,PM}$	0.246
Monetary policy response to output (AM)	$\psi_{y,AM}$	0.569
Monetary policy rule smoothing (PM)	$\rho_{R,PM}$	0.843
Monetary policy rule smoothing (AM)	$\rho_{R,AM}$	0.936
Fiscal policy response to debt (AF)	$\delta_{b,AF}$	0.000
Fiscal policy response to debt (PF)	$\delta_{b,PF}$	0.028
Fiscal policy rule smoothing (AF)	$\rho_{\tau,AF}$	0.926
Fiscal policy rule smoothing (PF)	$\rho_{\tau,PF}$	0.992
Fiscal policy response to output	δ_y	1.461
Fiscal policy response to expenditure	δ_e	0.639
Transfer response to output	ι_y	0.135
Short-term expenditure response to output	ϕ_y	-0.472
Degree of lagging in inflation	ζ	0.327
Degree of external habit	Φ	0.292
Slope of Phillips curve	κ	0.003
Transfer smoothing	ρ_χ	0.990
Persistence of neutral technology shocks	ρ_a	0.535
Persistence of preference shocks	ρ_d	0.976
Short-term expenditure smoothing	ρ_{e^S}	0.921
Persistence of mark-up shocks	ρ_μ	0.033
Persistence of term premium shocks	ρ_{tp}	0.837
Steady state		
Inflation rate	100π	0.421
Neutral technological change	$100ln(\gamma)$	0.450
Debt-to-GDP ratio (annualized)	b^m	0.524
Purchase to GDP ratio	g	0.093
Tax-to-GDP ratio	τ	0.195
S.D. of monetary shocks (Low)	$100\sigma_{R,1}$	0.080
S.D. of monetary shocks (High)	$100\sigma_{R,2}$	0.080
S.D. of transfer shocks (Low)	$100\sigma_{\chi,1}$	2.823
S.D. of transfer shocks (High)	$100\sigma_{\chi,2}$	27.808
S.D. of neutral technology shocks (Low)	$100\sigma_{a,1}$	0.715
S.D. of neutral technology shocks (High)	$100\sigma_{a,2}$	2.073
S.D. of tax shocks (Low)	$100\sigma_{\tau,1}$	0.541
S.D. of tax shocks (High)	$100\sigma_{\tau,2}$	0.831
S.D. of preference shocks (Low)	$100\sigma_{d,1}$	4.269
S.D. of preference shocks (High)	$100\sigma_{d,2}$	8.840
S.D. of short-term expenditure (Low)	$100\sigma_{e^S,1}$	0.472
S.D. of short-term expenditure (High)	$100\sigma_{e^S,2}$	2.796
S.D. of term premium shocks (Low)	$100\sigma_{tp,1}$	1.221
S.D. of term premium shocks (High)	$100\sigma_{tp,2}$	3.512
S.D. of mark-up shocks (Low)	$100\sigma_{\mu,1}$	0.129
S.D. of mark-up shocks (High)	$100\sigma_{\mu,2}$	0.077
Transition Probability		
from PM/AF to PM/AF	H_{11}^{sp}	0.998
from PM/PF to PM/PF	H_{22}^{sp}	0.974
from AM/AF to AM/AF	H_{33}^{sp}	0.925
from AM/PF to AM/PF	H_{44}^{sp}	0.974
from PM/AF to PM/PF	H_{21}^{sp}	0.002
from PM/AF to AM/AF	H_{31}^{sp}	0.000
from PM/PF to PM/AF	H_{12}^{sp}	0.000
from PM/PF to AM/AF	H_{32}^{sp}	0.000
from AM/AF to PM/AF	H_{13}^{sp}	0.075
from AM/AF to PM/PF	H_{23}^{sp}	0.000
from AM/PF to PM/AF	H_{14}^{sp}	0.002
from AM/PF to PM/PF	H_{24}^{sp}	0.021
from Low volatility to Low volatility	H_{11}^{vo}	0.88
from High volatility to High volatility	H_{22}^{vo}	0.18

Figure 1: Interest Rates



Sources: Bank of Japan; Ueno (2017).

Figure 2: Estimated Transition Probability

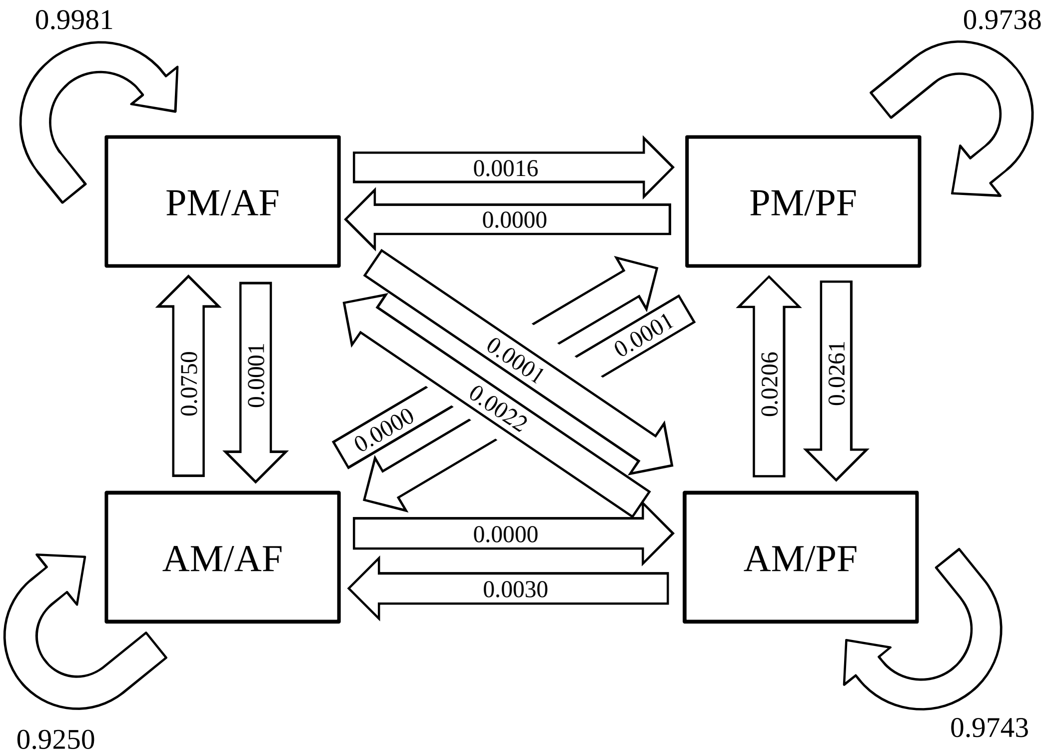
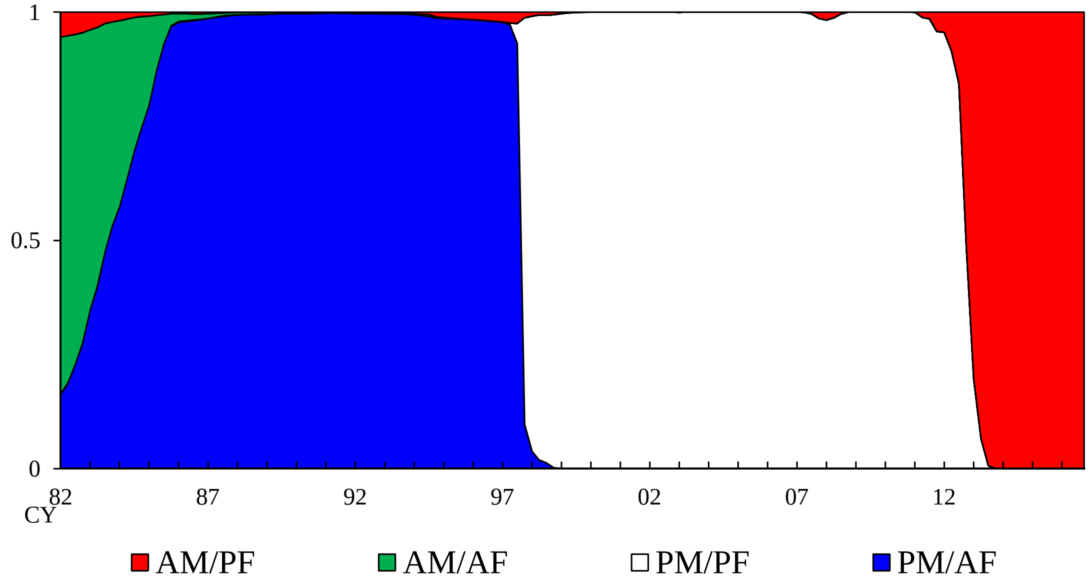
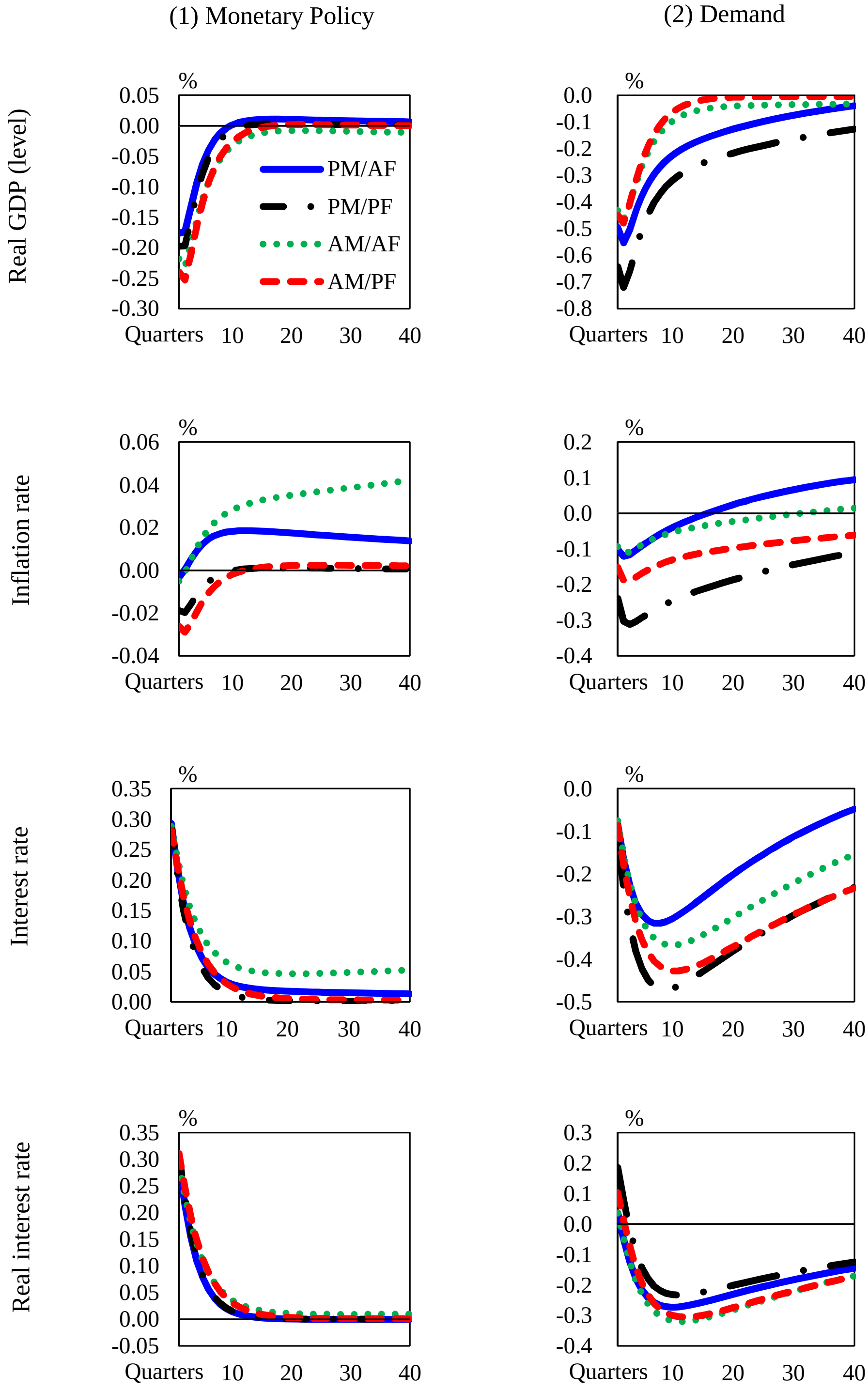


Figure 3: Probability of Policy Regimes



Note: This figure shows the smoothed probabilities given to the four policy regimes.
AM/PF: Active monetary policy/passive fiscal policy regime
AM/AF: Active monetary policy/active fiscal policy regime
PM/PF: Passive monetary policy/passive fiscal policy regime
PM/AF: Passive monetary policy/active fiscal policy regime

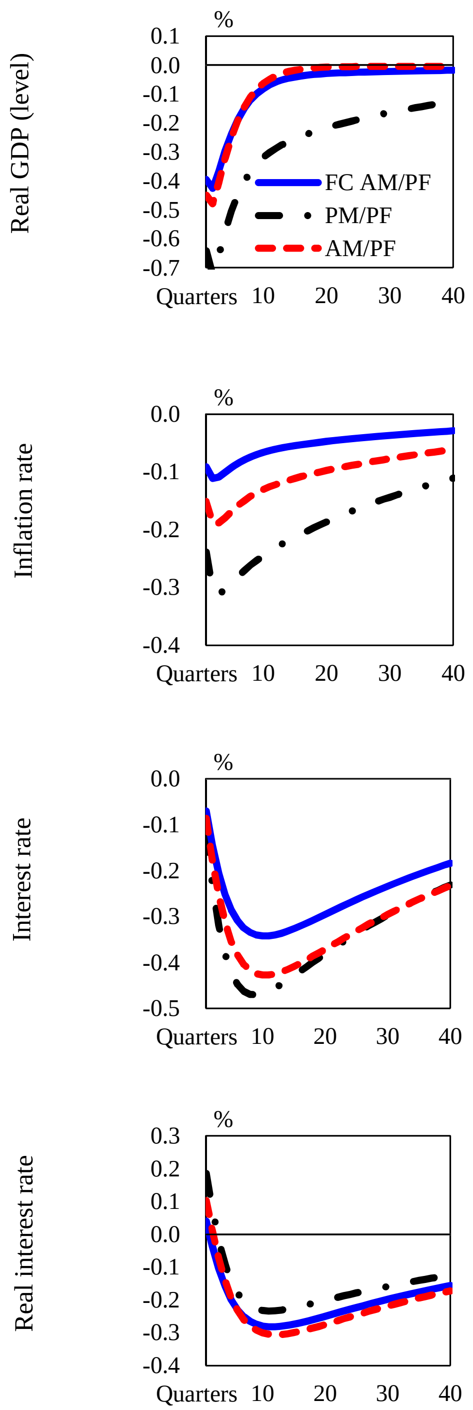
Figure 4: Impulse Responses



Note: The first column shows the impulse response functions to an exogenous monetary tightening, while the second column shows those to a demand shock. The horizontal axes show the number of quarters after the shock. The solid blue line, the dot-dash black line, the dotted green line, and the dashed red line represent the PM/AF regime, the PM/PF regime, the AM/AF regime, and the AM/PF regime, respectively. The initial shock is equal to a one standard deviation shock under the low volatility regime.

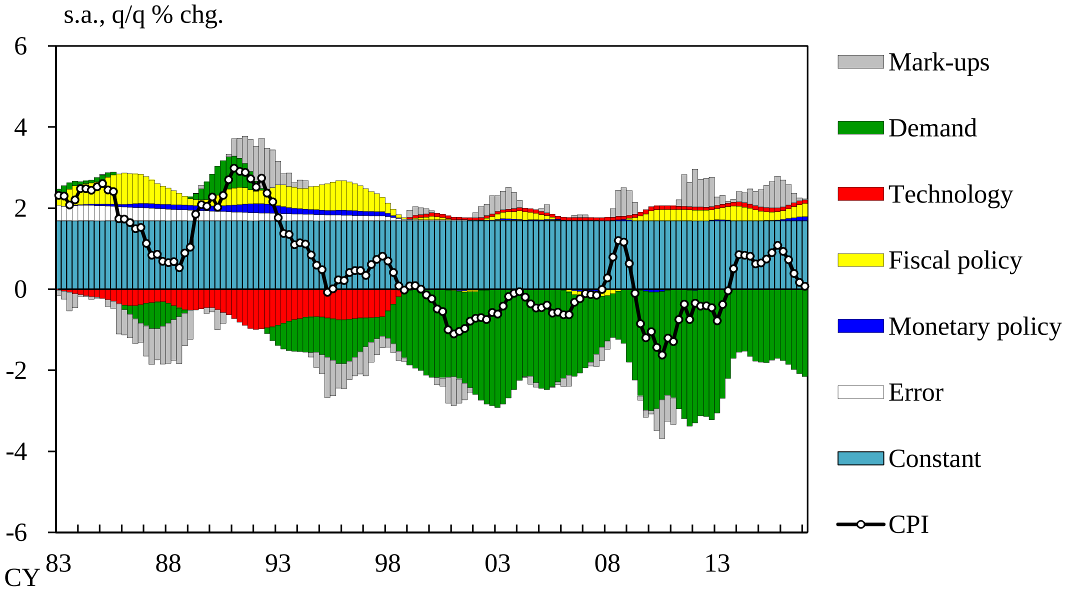
Figure 5: Influence of Agents' Beliefs on Impulse Responses

Impulse responses to a demand shock under the fully credible AM/PF regime,
the PM/PF regime, and the AM/PF regime



Note: "FC AM/PF" stands for the fully credible AM/PF regime. We assume that the AM/PF policy mix is the only possible regime, and agents regard the regime which is in place as lasting forever. The solid blue line, the dot-dash black line, and the dashed red line represent the fully credible AM/PF regime, the PM/PF regime, and the AM/PF regime, respectively.
The horizontal axes show the number of quarters after the shock. The vertical difference between the solid blue line and the dashed red line represents the effect of agents' beliefs about being in the AM/PF regime. The initial shock is equal to a one standard deviation shock under the low volatility regime.

Figure 6: Historical Decomposition of Inflation

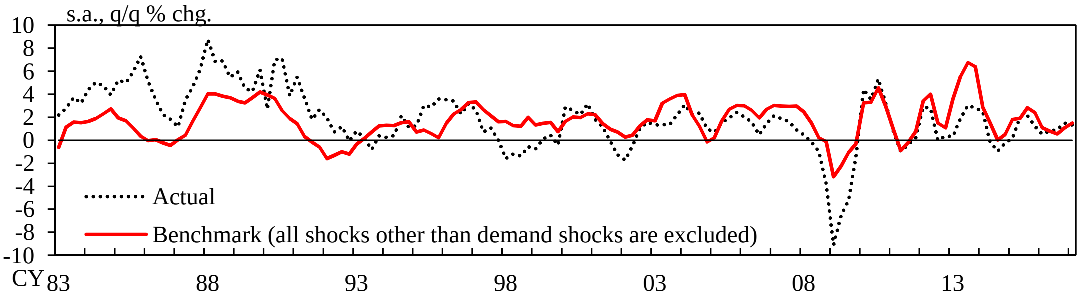


Note: This figure shows the historical decomposition of changes in the CPI (less fresh food and energy, four-quarter backward moving average). Changes in the CPI are broken down into the contribution of monetary policy, fiscal policy, demand, mark-ups, and technology shocks. Fiscal policy shocks consist of changes in transfers, the tax-to-GDP ratio, short-term expenditure, long-term expenditure, and term premiums.

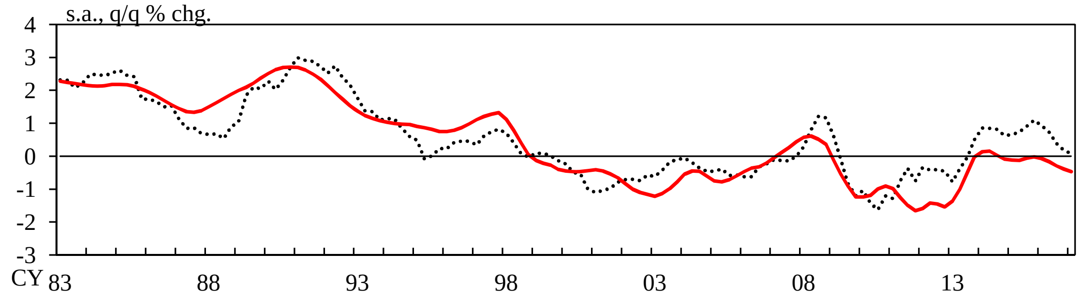
Figure 7: Historical Decomposition

Contribution of demand shocks

(1) Real GDP



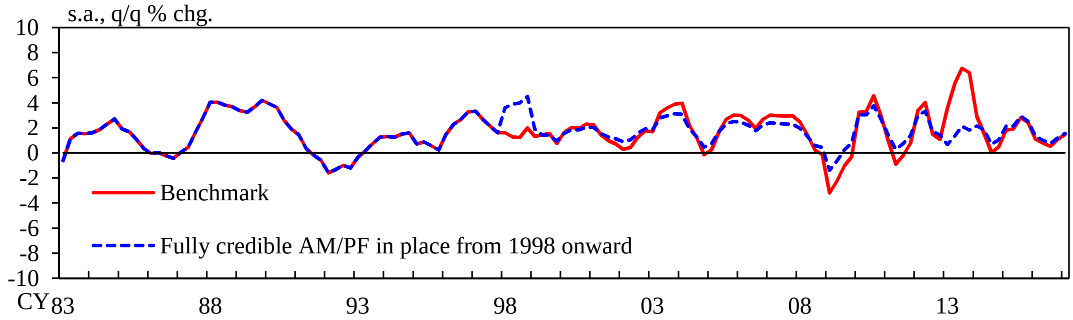
(2) CPI (less fresh food and energy)



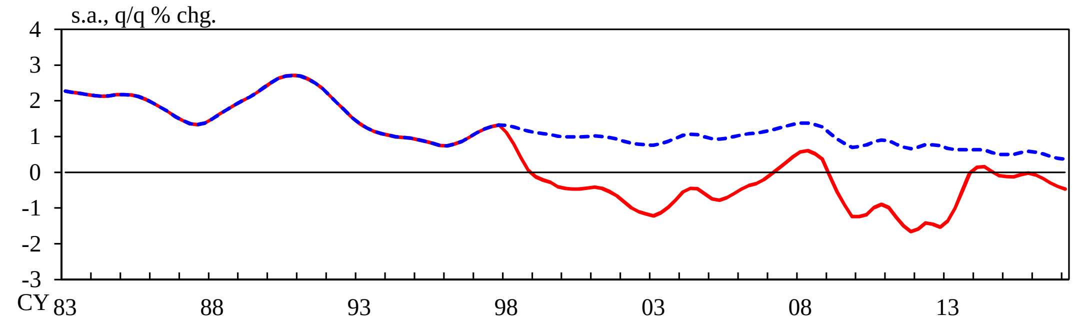
Note: The dotted line represents actual observations. We set all shocks other than demand shocks to zero to find the contribution of demand shocks to the benchmark results (solid red line). The lower panel shows the four-quarter backward moving average.

Figure 8: Counterfactual Simulation (1)

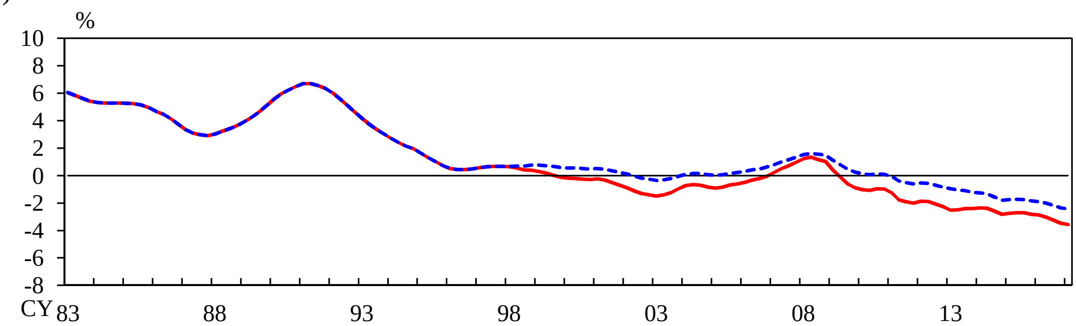
(1) Real GDP



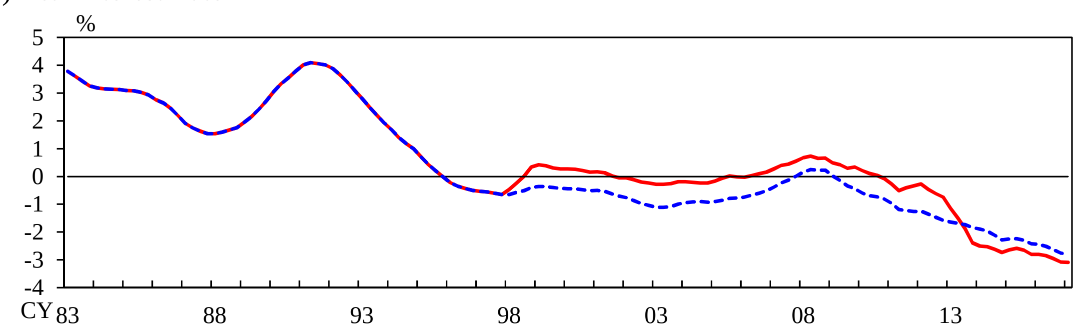
(2) CPI (less fresh food and energy)



(3) Interest Rate



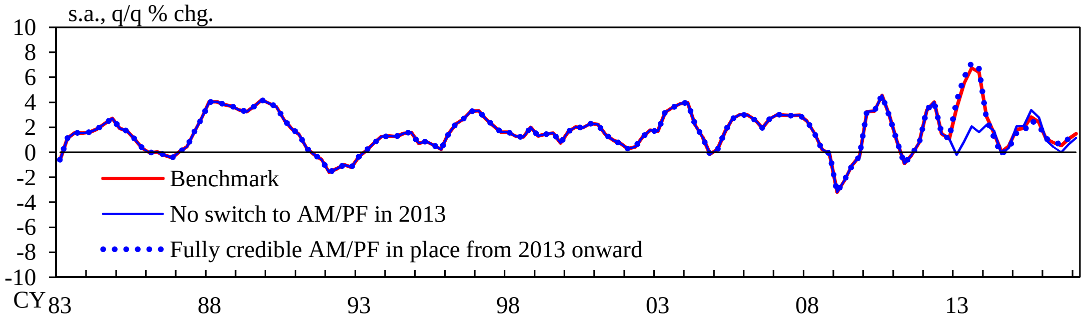
(4) Real Interest Rate



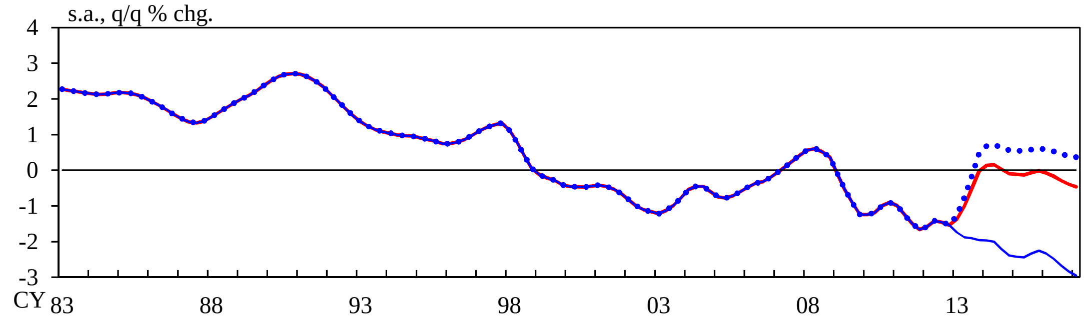
Note: We consider the following scenario relative to the benchmark result in which all shocks other than demand shocks are excluded (solid red line):
Fully credible AM/PF in place from 1998 onward (dashed blue line): From 1998 onward, we simulate the path of Japan's economy assuming the AM/PF policy mix is the only possible one and agents regard the regime as lasting forever. As in the benchmark, we exclude all shocks other than demand shocks.

Figure 9: Counterfactual Simulation (2)

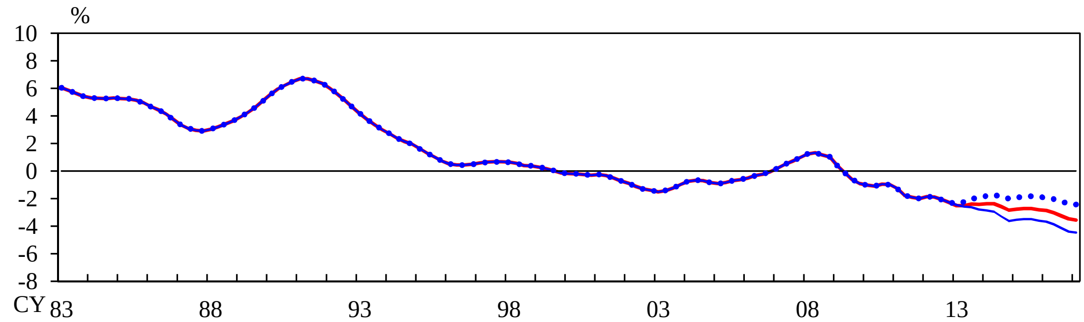
(1) Real GDP



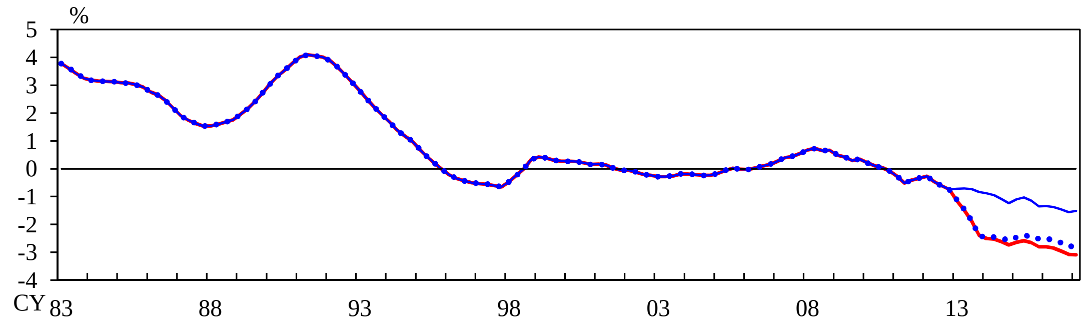
(2) CPI (less fresh food and energy)



(3) Interest Rate



(4) Real Interest Rate



Note: We consider the following scenarios relative to the benchmark result in which all shocks other than demand shocks are excluded (solid red line):

No switch to AM/PF in 2013 (solid blue line): The PM/PF regime remained in place.

Fully credible AM/PF in place from 2013 onward (dotted blue line): From 2013 onward, we simulate the path of Japan's economy assuming the AM/PF policy mix is the only possible one and agents regard the regime as lasting forever. As in the benchmark, we exclude all shocks other than demand shocks.

Appendixes

Appendix A

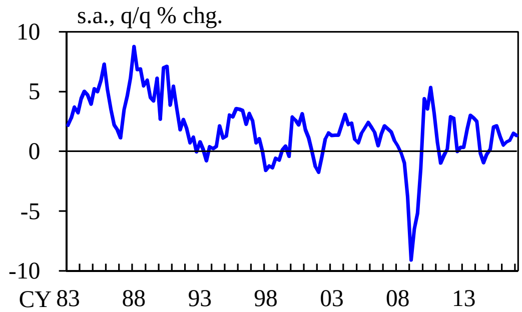
In this appendix, we provide details of our dataset. Our dataset covers the following seven observable variables: real output growth (y_t), the rate of consumer price inflation (π_t), the nominal rate of interest (R_t), the debt-to-GDP ratio (B_t/GDP_t), the ratio of government purchases to GDP (G_t/GDP_t), the government expenditure-to-GDP ratio (E_t/GDP_t), and the ratio of government tax revenues to GDP (T_t/GDP_t). Details of the data sources are provided below. In Appendix Figure A.1, we show developments in variables used in the analysis.

Appendix A. Table: Data Sources

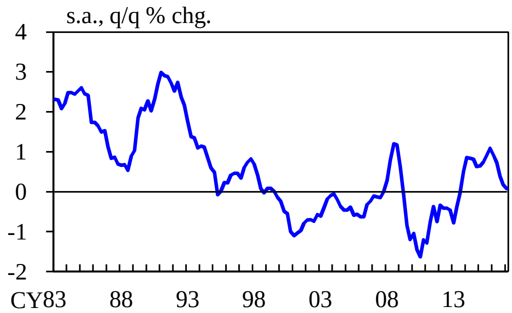
Variables	Sources
Real GDP Growth	Cabinet Office, "National Accounts"
Consumer Price Index (less fresh food and energy)	Ministry of Internal Affairs and Communications, "Consumer Price Index"
Interest Rate	Bank of Japan "Call Rate" from 1982/2Q to 1999/1Q
	Ueno (2017) "Shadow Rate" from 1999/2Q to 2017/1Q
Government Debt	Cabinet Office, "National Accounts"
	Closing Balance Sheet Account
	Liabilities
Government Purchases	Cabinet Office, "National Accounts"
	Income and Outlay Accounts - General Government
	Collective Consumption Expenditure
	Consumption of Fixed Capital (Less)
	Closing Balance Sheet Account - General Government
	Net Purchases of Non-produced assets (Natural resources)
	Gross Capital Formation - General Government
	Gross fixed capital formation
	Changes in inventories
Government Expenditure	Sum of 'Government Purchase' and 'Government Transfer'
Government Purchase	see the above
Government Transfer	Cabinet Office, "National Accounts"
	Income and Outlay Accounts - General Government
	Individual consumption expenditure
	Social benefits other than social transfers in kind, payable
	Other current transfers, payable less receivable
	Net social contributions, receivable (less)
	Subsidies, payable
	Capital Account - General Government
	Capital transfers, payable less receivable
Government Taxes	Cabinet Office, "National Accounts"
	Income and Outlay Accounts - General Government
	Taxes on production and imports, receivable
	Property income receivable less payable
	Current taxes on income, wealth, etc., receivable

Appendix Figure A.1: Developments in Variables Used in the Analysis

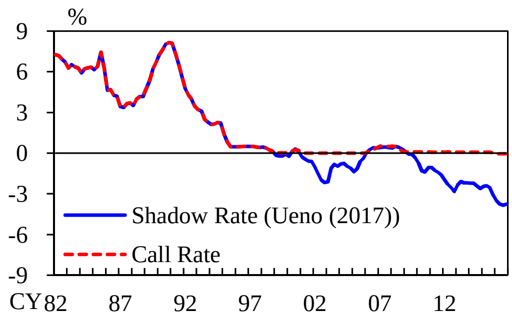
(1) Real GDP Growth



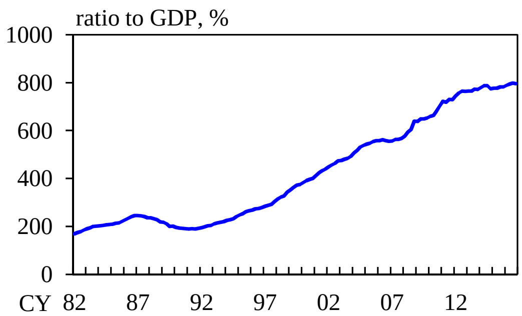
(2) CPI (Less Fresh Food and Energy)



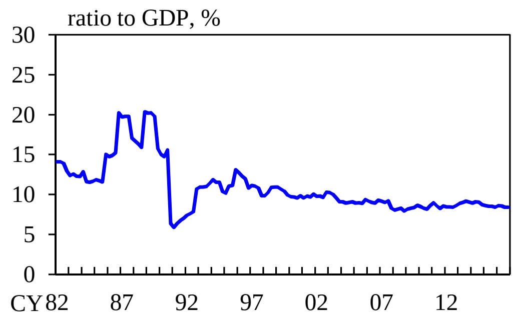
(3) Interest Rate



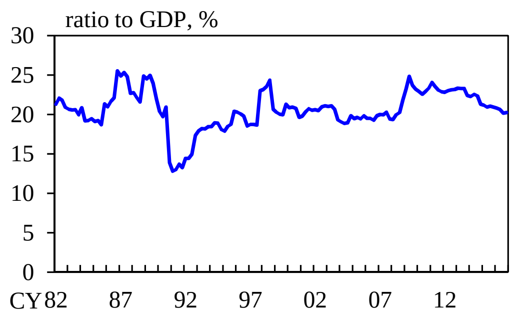
(4) Government Debt



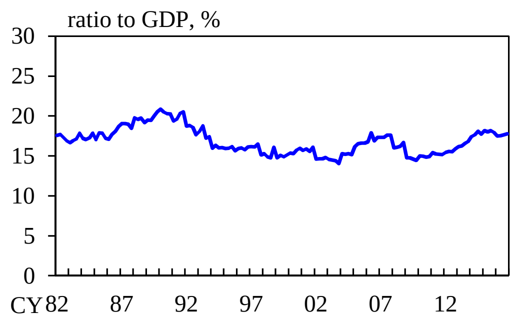
(5) Government Purchases



(6) Government Expenditure



(7) Government Taxes

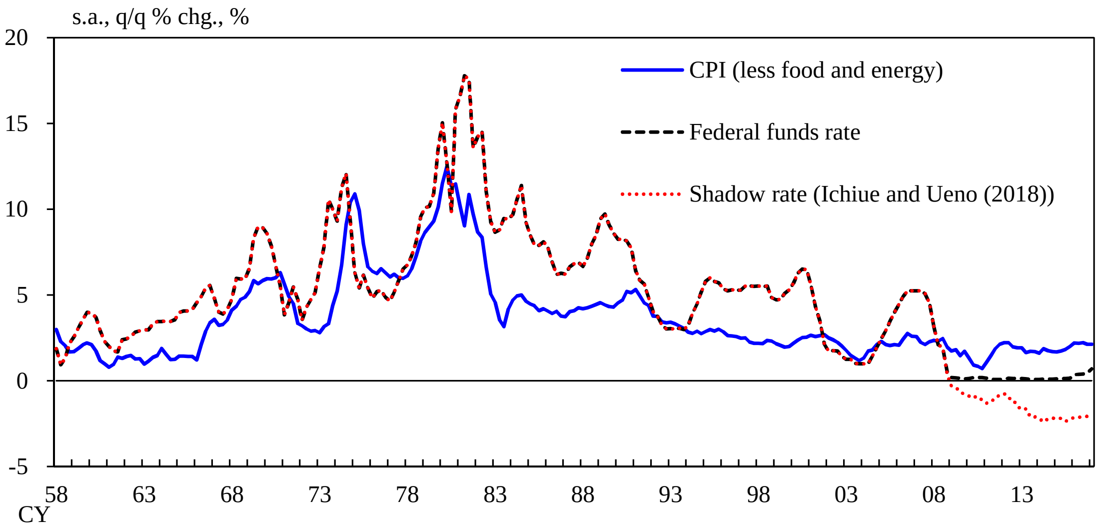


Note: The panels for real GDP growth and changes in the CPI (less fresh food and energy) show four-quarter backward moving averages.

Appendix B

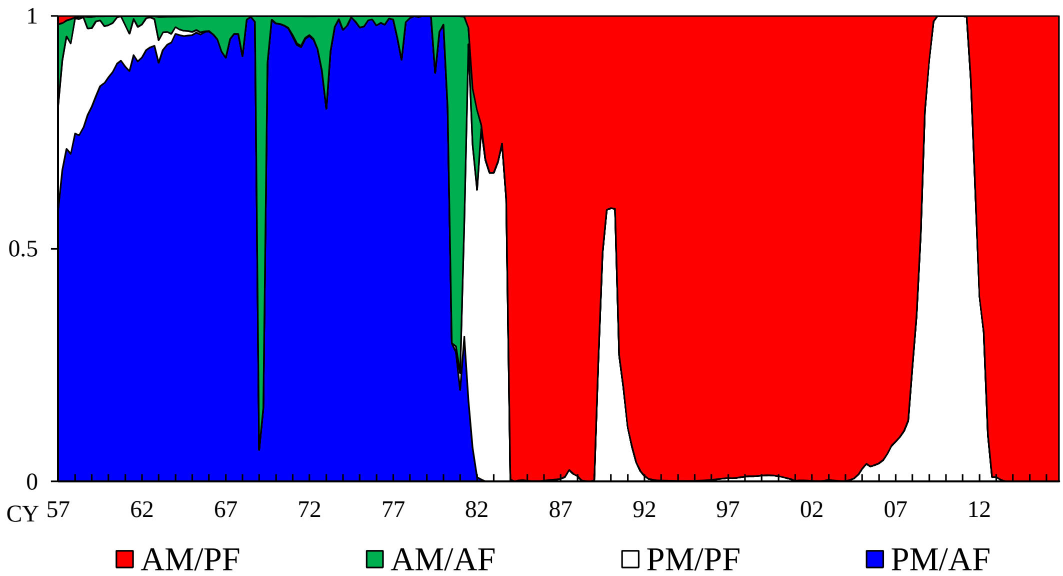
We also apply our approach to the United States. In a departure from Bianchi and Ilut's (2017) study, we seek to grasp changes in monetary/fiscal policy interaction even during the period when the ZLB is binding and unconventional monetary policy is implemented. The results are shown in Appendix Figure B.1. To estimate our model, we used the same seven observable variables as for Japan. However, it should be noted that we use the shadow federal funds rate estimated by Ichiue and Ueno (2018). In addition, our analysis spans the period from 1957:2Q to 2017:1Q, while Bianchi and Ilut's (2017) observation period is from 1954:4Q to 2009:3Q. The estimation results are shown in Appendix Figure B.2 and indicate that the identified regimes are almost the same as those identified by Bianchi and Ilut (2017) from 1954:4Q to 2009:3Q. However, for the period after the global financial crisis, which they do not cover, we find that the policy regime was also PM/PF, just like in Japan. Therefore, it would be interesting to examine the role played by the PM/PF regime in the evolution of the U.S. economy after the financial crisis, focusing in particular on the behavior of inflation. We leave this analysis for future work.

Appendix Figure B.1: Inflation and Interest Rates (U.S.)



Note: CPI (less food and energy) represents the four-quarter backward moving average of the rate of change in the CPI.

Appendix Figure B.2: Probability of Policy Regimes (U.S.)



Note: This figure shows the smoothed probabilities given to the four policy regimes.
AM/PF: Active monetary polcy/passive fiscal policy regime
AM/AF: Active monetary polci/active fiscal policy regime
PM/PF: Passive monetary policy/passive fiscal policy regime
PM/AF: Passive monetary policy/active fiscal policy regime