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The Effects of Asset Purchases and Normalization of US Monetary Policy

Naoko Hara*, Ryuzo Miyao**, and Tatsuyoshi Okimoto***

Abstract

This paper examines changes in the effects of unconventional monetary policies in the US. To this end, we estimate a Markov-switching VAR model with absorbing regimes to capture possible structural changes. Our results detect regime changes around the beginning of 2011 and the middle of 2013. Before 2011, the US large-scale asset purchases (LSAPs) had relatively large impacts on the real economy and prices, but after the middle of 2013, their effects were weaker and less-persistent. In addition, after the middle of 2013, which includes the monetary policy normalization period, the asset purchase (or balance sheet) shocks had slightly weaker effects than during the early stage of the LSAPs but stronger effects than during the late stage of the LSAPs, while interest rate shocks had insignificant effects on the real economy and prices. Finally, our results suggest that the positive responses of durables and capital goods expenditures to interest rate shocks weakened the negative impacts of interest rate hikes after the middle of 2013 including the period of monetary policy normalization.

Keywords: Quantitative easing; Unconventional monetary policy; LSAP; MSVAR

JEL classification: C32, E21, E52

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1 Introduction

After the global financial crisis (GFC) erupted and short-term interest rates fell close to zero, central banks in advanced economies, most notably in the US, adopted large-scale asset purchases (LSAPs) as an unconventional policy tool to stabilize the financial system and spur economic recovery. Such asset purchase programs are typically called “quantitative easing (QE),” and the Bank of England, the Bank of Japan and the European Central Bank all followed a similar approach in providing ample monetary accommodation. A policy of adjusting the size and composition of their balance sheets appears to have been added to the toolkit of major central banks.

Despite its widespread use in the crisis and recession phases, how well the balance sheet policy works, particularly in normal economic conditions, remains open to question. Critics argue that these measures have significant effects only when financial markets are under severe stress and that their effectiveness may diminish when economic and financial conditions move from crisis to normal conditions (e.g. [Goodhart and Ashworth \(2012\)](#) and [Borio and Zabai \(2018\)](#)). The policy transmission mechanism could also be weaker in an economic recovery when interest rates are persistently low, partly due to post-crisis headwinds such as substantial deleveraging and heightened uncertainty (e.g. [Borio and Hofmann \(2017\)](#), [Hesse et al. \(2018\)](#)). Meanwhile, policymakers tend to offer a more positive assessment of the efficacy of LSAPs as a policy tool to respond to future economic downturns (e.g. [Yellen \(2016\)](#) and [Bernanke \(2017\)](#)). In addition, based on simulations, [Kiley \(2018\)](#) suggests that active QE improves economic performance given that equilibrium real interest rates become lower and that interest rates are near their effective lower bound. Now that the post-crisis headwinds have dissipated and normalization of monetary policy is well underway, it is an opportune time to reinvestigate the macroeconomic effects of LSAPs and possible shifts in their effects in the US.

Against this background, this paper empirically examines changes in the effects of unconventional monetary policies (UMPs) in the US. To this end, we build on a benchmark vector autoregression (VAR) analysis with a combination of zero and sign restrictions, based on [Weale and Wieladek \(2016\)](#) and [Hesse et al. \(2018\)](#), and estimate a Markov-switching VAR (MSVAR) model with absorbing states to capture possible structural changes. This is relevant because the Federal Reserve (Fed) undertook the LSAPs starting in December 2008 and expanded or modified the program several times thereafter. Partly because of these

LSAPs, the US economy experienced not only a quick recovery but also solid growth, forcing the Fed to consider tapering the LSAPs. In speeches given in May and June 2013, former Fed chair Ben Bernanke hinted at reducing the size of the third-round of the LSAP, causing the taper tantrum, and this may have altered market expectations of aggressive monetary accommodation in the future (that is, a possible beginning of monetary policy normalization). Indeed, the Fed ended the LSAPs in December 2014 and started raising the federal funds (FF) rates in December 2015. Our regime-shift analysis incorporates these developments in assessing the efficacy of UMPs.

One of the challenges of estimating a MSVAR model is that there may be no single monetary policy measure which can capture the full range of US UMPs over the last decade. We employ the shadow rate (SR) of [Wu and Xia \(2016\)](#) as a single monetary policy measure to deal with this issue. As we will see below, the SR can arguably capture the easing of monetary policy during QE, decreasing significantly between 2009 and 2014, even when the FF rate remained at the effective lower bound. In addition, the SR was mostly increasing after early 2014, indicating a movement towards the normalization of US monetary policy. Therefore, it is not unreasonable to assume that the SR can describe the monetary policy stance of the Fed over the last decade.

Our model has at least three notable features. Firstly, the analysis allows us to detect the timing of breaks in the policy effects formally. Either two or three regimes are assumed for the period of January 2009 - September 2018 to accommodate multiple regime changes. Secondly, two primary regimes corresponding to before and after the middle of 2013 – emerge from the Markov-switching model. For each regime, the macroeconomic effects are further investigated with relevant policy measures. Thirdly, we examine components of GDP (non-durable, service, and durable consumption, as well as capital investment) as alternative indicators of real economic activity to discuss possible factors that generate different policy effects for each regime.

The main findings of this paper can be summarized as follows. The MSVAR analysis detects regime changes around the beginning of 2011 and the middle of 2013. Before 2011, the LSAPs had relatively large impacts on the real economy and prices, but after the middle of 2013, their effects were weaker and less-persistent. In addition, after the middle of 2013, which include the monetary policy normalization period, the asset purchase or balance sheet shocks had slightly weaker effects than during the early stage of the LSAPs but stronger effects than during the late stage of the LSAPs. This suggests that asset purchases can be

used at least as a secondary tool to respond to future downturns. On the other hand, interest rate shocks had insignificant impacts on the real economy and prices. Finally, our results using the components of GDP indicate that a positive response of durable and capital goods expenditures to interest rate shocks weakened the negative impacts of interest rate hikes after 2013 including the period of monetary policy normalization.

The remainder of this paper is organized as follows. Section 2 briefly reviews the US UMPs and the related literature, while Section 3 introduces our empirical methodology. Section 4 summarizes the empirical results based on the MSVAR model using the SR as a policy measure. Section 5 analyzes each regime in detail using more appropriate policy measures for each regime. Finally, Section 6 concludes the paper.

2 Related Literature

There is a vast literature on the LSAPs since the GFC. Various papers propose theoretical frameworks to explain the effectiveness of asset purchases by the central bank. They suggest that asset purchases are particularly effective when financial markets are disrupted. In other words, their effectiveness may become weaker as financial markets return to normal. For example, [Curdia and Woodford \(2011\)](#) construct a New Keynesian model with imperfect financial intermediation and lending to the private sector by the central bank and find that asset purchases targeted at specific types of assets can be stimulative, particularly during a period of financial market turmoil. [Gertler and Karadi \(2013\)](#) extend a New Keynesian framework to introduce a central bank that purchases government bonds as well as private securities and compare the effectiveness of different QE programs. They find that a purchase of private securities is more stimulative than that of government bonds. Moreover, they find that the LSAP is more effective the longer the time expected at the effective lower bound. [Bauer and Rudebusch \(2014\)](#) find evidence of signaling effects from asset purchases that effectively lower expectations on future short-term interest rates.

In contrast, there seems to be no conclusive empirical evidence of changes in the effectiveness of the LSAPs on the macroeconomy. Many studies find a decline in the effect of monetary policy on financial markets during the zero lower bound (ZLB) period (e.g. [Krishnamurthy and Vissing-Jorgensen \(2011\)](#), [Krishnamurthy and Vissing-Jorgensen \(2013\)](#), [D'Amico and King \(2013\)](#)), although some studies also find that the announcement of an LSAP has significant effects on the financial markets ([Ihrig et al. \(2018\)](#), [Swanson \(2018\)](#)). As

for the macroeconomic effects, [Haldane et al. \(2016\)](#) find that an increase in asset purchases can be more stimulative when financial markets are disrupted. In a similar vein, [Hesse et al. \(2018\)](#) report that the stimulative effects of the LSAPs have been declining in the post-GFC period. They also argue that anticipated asset purchases can have substantial stimulative effects even in the later stages of an LSAP.

Since the LSAPs and the zero interest rate policy were conducted simultaneously, a growing number of studies devote much attention to evaluating the effectiveness of multiple monetary policy measures in a unified way. Against this background, SR term structure models have been developed to deal with the ZLB by a number of studies, including [Ichiue and Ueno \(2013\)](#), [Krippner \(2013\)](#), [Bauer and Rudebusch \(2016\)](#), and [Wu and Xia \(2016\)](#). More specifically, [Bullard \(2012\)](#), [Krippner \(2013\)](#), and [Wu and Xia \(2016\)](#) claim that the SR can be used as a single measure of both conventional and unconventional monetary policy stances. For example, [Wu and Xia \(2016\)](#) estimate the effectiveness of monetary policy from 1990 to 2013 using their SR and find an expansionary monetary policy shock is highly stimulative during the ZLB period. Furthermore, [Bauer and Rudebusch \(2016\)](#) suggest that the SR can capture monetary policy expectations. In this study, we use the SR data computed according to the method of [Wu and Xia \(2016\)](#),¹ and extend the existing empirical studies in a few ways. Firstly, by expanding the sample period up to September 2018, we analyze the effectiveness of the US UMPs over both LSAP and normalization periods. Secondly, we consider regime changes in the effects of the US UMPs, allowing for the possibility of a difference in the effects of UMPs during the LSAP and normalization regimes. Thirdly, we use the estimated SVAR model to compare the effectiveness of the policy rate and LSAPs during both the LSAP and normalization regimes, as detected by the model.

Other studies related to ours include those on the state-dependence of monetary policy effectiveness. For example, [Lo and Piger \(2005\)](#) find that policy shocks are more stimulative in recessions and that the asymmetry may not be caused by either the direction or size of the policy shock. In contrast, [Tenreyro and Thwaites \(2016\)](#) provide empirical evidence that a change in the FF rate is less effective in recessions, particularly for durable goods consumption and business investment. [Berger and Vavra \(2015\)](#) extend a standard incomplete market model to incorporate fixed costs into households' durable goods consumption adjustment. They find that durable expenditures are less responsive to economic shocks during recessions in the presence of adjustment costs to households' durable purchases. In other words, durable

¹The data are available at <http://faculty.chicagobooth.edu/jing.wu/research/data/WX.html>

expenditures can be more sensitive to shocks in an economic recovery. [Suzuki \(2016\)](#) provides empirical evidence of this by using the US Consumer Expenditure Survey. He reports that the fixed costs of adjustment on households’ durable goods consumption are larger than those on non-durable goods consumption. In this study, we investigate the state-dependence of policy effectiveness potentially arising from households’ durables consumption adjustment. Specifically, we introduce durable and non-durable goods as well as services into our VAR model and analyze changes in the policy effects on these types of goods before and after the start of US monetary policy normalization.

3 Methodology

This paper employs a MSVAR model with absorbing regimes to examine possible permanent regime changes in the effects of US UMPs. This is relevant because the US UMPs have evolved significantly over the last decade, as we briefly discussed in the introduction. In this section, we introduce our baseline model, followed by the MSVAR model and its estimation.

3.1 Baseline Model

The baseline model is taken from [Weale and Wieladek \(2016\)](#) and [Hesse et al. \(2018\)](#). Both studies employ the following VAR model estimated on monthly data:

$$\mathbf{Y}_t = \boldsymbol{\alpha} + \sum_{k=1}^L \mathbf{A}_k \mathbf{Y}_{t-k} + \boldsymbol{\varepsilon}_t, \quad \boldsymbol{\varepsilon}_t \sim \text{iid } N(\mathbf{0}, \boldsymbol{\Sigma}) \quad (1)$$

where \mathbf{Y}_t is a vector of endogenous variables, $\boldsymbol{\alpha}$ is a vector of constants, \mathbf{A}_k is the array of coefficients associated with the corresponding vector of variables for lag k . The endogenous variables comprise the logarithm of monthly (seasonally adjusted) real gross domestic product (GDP), the logarithm of the (seasonally adjusted) consumer price index (CPI), a measure of the policy instrument which is discussed in detail below, the yield on the 10-year government bond and the logarithm of the real stock price index (deflated by the CPI). For our empirical analysis, L is set to two, following [Weale and Wieladek \(2016\)](#) and [Hesse et al. \(2018\)](#).

One of the difficulties with assessing the effects of the US UMPs over the last decade is that there may be no single variable which can capture the US UMPs during this period. During the GFC the Fed lowered the FF rate effectively to zero and introduced the LSAP program in December 2008. Since then, the Fed has been using asset purchases as one of its policy instruments. Because of this, [Weale and Wieladek \(2016\)](#) and [Hesse et al. \(2018\)](#) use

the announcement of asset purchases as a policy measure. In addition, the Fed started raising the FF rate in December 2015, making it an active policy tool during the normalization of US monetary policy. The dynamics of these two policy measures are displayed in Figure 1. As can be seen, the cumulative amount of asset purchases announced has been constant since 2014, while the FF rate was essentially at its lower bound with little fluctuation before December 2015. As a consequence, econometrically it might not be appropriate to use either of them as a policy measure throughout the entire sample period.

To overcome this problem, we adopt the SR of [Wu and Xia \(2016\)](#) as a single monetary policy measure over the last decade. Figure 1 also plots the SR along with the two other policy measures. As can be seen, even though the FF rate was almost constant at the effective lower bound until the end of 2015, the SR decreased significantly between 2009 and 2014, reflecting the increase in the cumulative amount of asset purchases announced. On the other hand, the SR was mostly increasing after early 2014, indicating a movement towards the normalization of US monetary policy. Thus, it seems not unreasonable to assume that the SR can describe the monetary policy stance of the Fed over the last decade as discussed by [Krippner \(2013\)](#) and [Wu and Xia \(2016\)](#). Therefore, we will use the SR as a single policy instrument for our analysis in the next section.

Another issue for the VAR analysis is how to identify monetary policy shocks. In this paper, following [Hesse et al. \(2018\)](#), we use a combination of zero and sign restrictions to identify monetary policy shocks. More specifically, we assume that outputs and prices do not respond contemporaneously to any shocks, including monetary policy shocks, other than aggregate demand and supply shocks. This is a classical assumption used in the block-recursive identification of [Christiano et al. \(1999\)](#) and not unreasonable given the sticky nature of output and prices. In addition, we assume that a contractionary monetary policy shock increases the SR and long-term bond yield and reduces real stock prices. Our identification assumptions are essentially the same as those of [Hesse et al. \(2018\)](#) and similar to one of the identification schemes of [Weale and Wieladek \(2016\)](#). All sign restrictions are imposed upon impact and one month thereafter.

3.2 MSVAR Model

The US UMPs have evolved greatly over the last decade, including the introduction of the LSAP and the start of monetary policy normalization. Therefore, it is important to consider possible regime changes to assess the effects of the UMPs. To this end, we incorporate

Markov-switching into the baseline model, following [Sims and Zha \(2006\)](#), among others.

Our baseline VAR model (1) is extended as:

$$\mathbf{Y}_t = \boldsymbol{\alpha}(s_t) + \sum_{k=1}^L \mathbf{A}_k(s_t) \mathbf{Y}_{t-k} + \boldsymbol{\varepsilon}_t, \quad \boldsymbol{\varepsilon}_t \sim \text{iid } N(\mathbf{0}, \boldsymbol{\Sigma}(s_t)) \quad (2)$$

where s_t is a latent variable that takes a value from $1, 2, \dots, K$, with K being the number of regimes. In other words, this model allows us to specify different VAR models for different regimes. [Hamilton \(1989\)](#) proposes modeling the stochastic process of s_t using a Markov chain.

The Markov chain is a simple model that describes the dynamics of a discrete random variable. The law of regime evolution is governed by the transition probability matrix \mathbf{P} , where the (i, j) element of \mathbf{P} , p_{ij} , indicates $Pr[s_t = i | s_{t-1} = j]$. The expected duration of each regime and inferences about s_t can be calculated based on this matrix. Although the Markov chain is a simple model, it can describe various patterns of regime transitions. Specifically, we can capture permanent structural changes by imposing zero restrictions on the elements of matrix \mathbf{P} . Below is an example of a transition matrix of a three-regime model with absorbing regimes:

$$\mathbf{P} = \begin{pmatrix} p_{11} & 0 & 0 \\ 1 - p_{11} & p_{22} & 0 \\ 0 & 1 - p_{22} & 1 \end{pmatrix}. \quad (3)$$

With this transition probability matrix, the regime dynamics are assumed to start from Regime 1. The regime can shift from Regime 1 to Regime 2 but not to Regime 3, due to the restriction that $p_{31} = 0$. Once the regime moves from Regime 1 to Regime 2, it can shift to Regime 3 but it will never return to Regime 1 because $p_{12} = 0$. Finally, once the model reaches Regime 3, it will stay in Regime 3 for the remainder of the sample period, since the zero restrictions on p_{13} and p_{23} prevent a regime change from Regime 3 to Regime 1 or Regime 2. Therefore, by imposing restrictions on \mathbf{P} in this manner, we can model two permanent structural changes within the sample period.

We will use the transition matrix (3) for the three-regime model in Section 4. The restrictions are reasonable for our purpose of studying the changes in the effects of the US UMPs, corresponding to their evolution over the last decade. In other words, we assume that there are permanent regime shifts along with changes in the US UMPs employed. As will be discussed in the next section, Regimes 1 and 2 are identified with the periods corresponding to the early and late stages of the LSAPs and Regime 3 with the period corresponding to the

normalization of monetary policy. Note that this does not necessarily mean that the policy effects have to be very different in each regime, since we do not impose any restrictions on the VAR parameters and they could be similar across regimes. We will examine the differences in the policy effects systematically based on the impulse response functions in the following two sections.

3.3 Estimation

MSVAR models are most commonly estimated by the Bayesian Markov chain Monte Carlo (MCMC) approach, or more specifically a Gibbs sampler, which is what we employ in this paper. One of the reasons for employing this approach is that the popular maximum likelihood estimation is difficult to apply to MSVAR models due to the large number of parameters. Bayesian methods conduct statistical inference based on the posterior distribution calculated from the prior distribution and the observed data. Although the analytical calculation of the posterior distribution is often impossible, MCMC methods can still provide feasible algorithms for sampling from the posterior distribution by constructing a Markov chain that has the desired posterior distribution as its stationary distribution. Thus, after enough iterations, we should be able to generate a sample from the desired posterior distribution which we can use for statistical inference.

In what follows, we briefly explain the Gibbs sampling procedure for a two-regime MSVAR model with an absorbing regime. For details of the algorithm as well as an extension to the three-regime case, see Chib (1996, 1998) and Krolzig (1997). Let T denote the number of observations, and $\boldsymbol{\theta}$ be the set of parameters to estimate. To use the Gibbs sampler we divide $\boldsymbol{\theta}$ into four blocks as $\boldsymbol{\theta} = [\boldsymbol{\theta}'_1, \boldsymbol{\theta}'_2, \boldsymbol{\theta}'_3, \boldsymbol{\theta}'_4]'$. In this case $\boldsymbol{\theta}_1 = [s_{25}, s_{26}, \dots, s_{T-24}]'$,² $\boldsymbol{\theta}_2 = p_{11}$, $\boldsymbol{\theta}_3 = [\text{vech}(\boldsymbol{\Sigma}(1))', \text{vech}(\boldsymbol{\Sigma}(2))']'$, and $\boldsymbol{\theta}_4 = [\boldsymbol{\beta}(1)', \boldsymbol{\beta}(2)]'$, where $\boldsymbol{\beta}(j)$ is a column vector of the form $\boldsymbol{\beta}(j) = [\boldsymbol{\alpha}, \text{vec}(\mathbf{A}_1(j))', \dots, \text{vec}(\mathbf{A}_L(j))']'$. Furthermore, let $\tilde{\mathbf{Y}}_t = \{\mathbf{Y}_{-L+1}, \mathbf{Y}_{-L+2}, \dots, \mathbf{Y}_t\}$ and $p(\boldsymbol{\theta}|\tilde{\mathbf{Y}}_T)$ be the desired posterior distribution. Then the Gibbs sampler allows us to generate random samples from $p(\boldsymbol{\theta}|\tilde{\mathbf{Y}}_T)$ as follows:

1. Set initial values $\boldsymbol{\theta}^{(0)}$ and set $j = 0$.

²We assume that each regime has more than 24 months, or 2 years, of observations to avoid detecting a very short regime and guarantee the estimation precision of the parameters of each regime. In other words, we assume that $s_1 = s_2 = \dots = s_{24} = 1$ and $s_{T-23} = s_{T-22} = \dots = s_T = 2$ for the two-regime model. Strictly speaking, $\{s_t\}_{t=25}^{T-24}$ are the latent variables, not the parameters. However, since they are estimated from the data, they are usually treated as unknown parameters in the Bayesian framework.

2. Draw $\boldsymbol{\theta}_1^{(j+1)}$ from $p\left(\boldsymbol{\theta}_1 \mid \boldsymbol{\theta}_2^{(j)}, \boldsymbol{\theta}_3^{(j)}, \boldsymbol{\theta}_4^{(j)}, \tilde{\mathbf{Y}}_T\right)$.
3. Draw $\boldsymbol{\theta}_2^{(j+1)}$ from $p\left(\boldsymbol{\theta}_2 \mid \boldsymbol{\theta}_1^{(j+1)}, \boldsymbol{\theta}_3^{(j)}, \boldsymbol{\theta}_4^{(j)}, \tilde{\mathbf{Y}}_T\right)$.
4. Draw $\boldsymbol{\theta}_3^{(j+1)}$ from $p\left(\boldsymbol{\theta}_3 \mid \boldsymbol{\theta}_1^{(j+1)}, \boldsymbol{\theta}_2^{(j+1)}, \boldsymbol{\theta}_4^{(j)}, \tilde{\mathbf{Y}}_T\right)$.
5. Lastly draw $\boldsymbol{\theta}_4^{(j+1)}$ from $p\left(\boldsymbol{\theta}_4 \mid \boldsymbol{\theta}_1^{(j+1)}, \boldsymbol{\theta}_2^{(j+1)}, \boldsymbol{\theta}_3^{(j+1)}, \tilde{\mathbf{Y}}_T\right)$
6. Set $\boldsymbol{\theta}^{(j+1)} = \left[\left(\boldsymbol{\theta}_1^{(j+1)}\right)', \left(\boldsymbol{\theta}_2^{(j+1)}\right)', \left(\boldsymbol{\theta}_3^{(j+1)}\right)', \left(\boldsymbol{\theta}_4^{(j+1)}\right)' \right]'$
7. If $j + 1 = N$, then stop the algorithm. Otherwise, repeat the algorithm from step 2.

Here N is the number of iterations and we discard the first N_0 samples. Thus, $\left\{\boldsymbol{\theta}^{(j)}\right\}_{j=N_0+1}^N$ are the samples that can be considered to follow $p(\boldsymbol{\theta} \mid \tilde{\mathbf{y}}_T)$ approximately.³ For the prior distributions of the unknown parameters, we assume the conjugate diffuse priors. Specifically, we use the uniform distribution between 0 and 1 for the prior of the transition probability, p_{11} , and the Normal-Wishart diffuse priors for steps 4 and 5.

4 Results with the SR as a Policy Measure

In this and the following section, we discuss our empirical results. In this section, we use the entire sample to observe possible changes in the effects of monetary policy over the last decade. For this purpose, we use the SR as a single monetary policy measure. Based on the results of this section, we will analyze each regime more carefully using more direct monetary policy measures in the following section.

4.1 Data

Our empirical analysis is based on monthly data of real GDP, the CPI, the SR, the US 10-year government bond yield and real stock prices, with the sample period lasting from January 2009 to September 2018. Monthly real GDP data were obtained from Macroeconomic Advisors, while the SR was taken from Wu's website. We also obtained 12-month FF futures data from Bloomberg. Other data were downloaded from the Federal Reserve Economic Data (FRED) database.

³In this paper, we set $N = 30,000$ and $N_0 = 20,000$.

The cumulative asset purchases announced series was constructed in a similar manner to [Weale and Wieladek \(2016\)](#) and [Hesse et al. \(2018\)](#). Specifically, we calculated the cumulative sum of asset purchase announcements by adding up the Fed’s announced purchases of Treasuries, mortgage-backed securities (MBS) and agency debt under the three LSAPs (LSAP1, LSAP2, and LSAP3). In addition, we included asset purchases associated with the maturity extension program (MEP). Finally, we divided the cumulative sum of asset purchase announced by the nominal GDP of the previous quarter to mitigate the possible endogeneity problem.⁴

4.2 Results of the Two-Regime Model

We start by estimating the two-regime MSVAR model, assuming one permanent structural change. Figure 2 plots the smoothed probabilities of Regime 2. As can be seen, the two-regime model detects a structural change around July 2013, immediately after speeches by former Fed chair Ben Bernanke about a possible end to QE in the US on May 22nd and June 19th, 2013. At that time, financial markets appeared not to be prepared for the tapering of QE. As a consequence, the US Treasury yields surged and more than two trillion dollars was lost on international stock markets within four weeks, an event which is sometimes called the taper tantrum. In other words, our results suggest that after the taper tantrum, the economic regime might have shifted to a new regime as the market became aware of the possible termination of massive monetary easing.

In order to see the change in the effects of monetary policy that occurred along with this regime change, Figure 3 plots the impulse responses of each variable to a contractionary monetary policy shock, defined as a one-standard-deviation increase in the SR along with 68% credible intervals for each regime. The results of Regime 1, shown in Panel (a), indicate fairly standard responses of each variable to a contractionary monetary policy shock. Specifically, a contractionary monetary policy shock significantly reduces real output and prices and its effects are relatively persistent. On the other hand, as can be seen from Panel (b) of Figure 3, the impacts of the same shock on the real economy and prices during Regime 2 are somewhat weaker and less persistent. In other words, our results suggest that the normalization of US monetary policy has had only marginal effects on the real economy and inflation.

⁴For this calculation, we used monthly nominal GDP obtained by linearly interpolating quarterly nominal GDP.

4.3 Results of the Three-Regime Model

There is controversy about whether the effects of LSAPs have declined or not. For example, while [Weale and Wieladek \(2016\)](#) confirm that including LSAP1 or not does not change the effectiveness of LSAPs, [Hesse et al. \(2018\)](#) suggest that the effects of the later LSAP seem to be weaker. Therefore, it might be instructive to consider multiple regime shifts to examine a possible change in the effects of the LSAPs. In addition, the actual FF rate hikes started in December 2015, which might have shifted the economy to a new regime, giving us another motivation to accommodate multiple regime changes. To see when an additional regime shift can be observed and examine the possible changes in the effects of UMPs along with regime changes, we report the results of the three-regime MSVAR model in this subsection.

Figure 4 plots the smoothed probabilities of Regimes 2 (solid line) and 3 (broken line). The results indicate an additional regime shift around the beginning of 2011 in addition to a break in July 2013. Thus, the three-regime model detects some changes during the LSAPs rather than during the normalization period after the middle of 2013. We note that the beginning of the second regime is fairly close to the start of the second subsample of [Hesse et al. \(2018\)](#).

To visualize the variations in the effects of UMPs that occur along with these regime changes, Figure 5 summarizes the impulse responses of each variable to a contractionary monetary policy shock for each regime. The impulse responses of Regime 1, shown in Panel (a) are standard, persistently depressing real output and prices. On the other hand, as shown in Panel (b), the same shock in Regime 2 seems to have a larger impact on output and a similar impact on prices in short-run, but the effects disappear quickly, within six months. Thus, our findings are consistent with those of [Weale and Wieladek \(2016\)](#) in the short-run and similar to those of [Hesse et al. \(2018\)](#) in the long-run. Finally, and not surprisingly, the responses of Regime 3, shown in Panel (c), are essentially the same as those of Regime 2 of the two-regime model.

5 Analysis of Each Regime with More Relevant Policy Measures

The results of the previous section provide clear evidence of a regime shift around the middle of 2013. In this section, we conduct further analyses of each regime. More specifically, given the results of the previous section, we divide the sample into two subsamples: January

2009 to June 2013 and September 2013 to September 2018.⁵ One advantage in considering subsamples separately is that we can use more relevant measures of monetary policy for each regime instead of the SR, enabling a more precise assessment of the effects of the US UMPs based on similar VAR models, but with more appropriate policy measures.

5.1 Results of the First Subsample

We start by estimating a two-regime MSVAR model using the first subsample, since the results of the three-regime MSVAR model detected a regime shift around the beginning of 2011. For this period, the asset purchases can be considered as the unique active monetary policy instrument, since the FF rate was essentially at the lower bound with little fluctuation during the entire period. More specifically, following [Weale and Wieladek \(2016\)](#) and [Hesse et al. \(2018\)](#), we use the cumulative amount of asset purchases announced divided by the nominal GDP of the previous quarter as the policy instrument.

Figure 6 plots the smoothed probabilities of Regime 2, showing a similar regime shift around the beginning of 2011 to the one found in the previous section. Thus, there may have been some change in the propagation mechanism of monetary policy shocks around this period. To investigate this point more closely, Figure 7 depicts the impulse responses along with 68% credible intervals of each regime. As can be seen, the impulse responses of Regime 1 shown in Panel (a) exhibit the proper responses to monetary policy shocks, while those of Regime 2 in Panel (b) suggest that the effects of monetary policy shocks became weaker and less persistent. These findings are partially consistent with those of [Weale and Wieladek \(2016\)](#) in the short-run and similar to those of [Hesse et al. \(2018\)](#) in the long-run.

These findings might reflect the state-dependence of the effectiveness of monetary policy. [Berger and Vavra \(2015\)](#) prove that expenditures on durable goods are less responsive to economic shocks during recessions in the presence of adjustment costs on durable goods consumption. This implies that durable expenditures respond to shocks more in an economic recovery. Against that background, we examine the state-dependence of policy effectiveness potentially arising from households' durable consumption adjustments. To this end, we replace GDP with non-durable consumption, service consumption, durable consumption and capital goods new orders,⁶ and estimate the same two-regime MSVAR model.

⁵The second subsample starts from September 2013, since we use the first two months of data for the lags of the VAR model.

⁶More specifically, we use the manufacturers' new orders for nondefense capital goods excluding aircraft.

The impulse response of each variable for each regime is illustrated in Figure 8. As can be seen from Panel (a), each GDP component responds significantly and persistently negatively to a monetary policy shock in Regime 1. In contrast, a monetary policy shock in Regime 2 has smaller and less persistent effects on each GDP component, with the exception of the effect on durable consumption, which is larger but still less persistent in Regime 2 than in Regime 1. In other words, our results indicate that the monetary policy effects in Regime 2 seem to be smaller for a wide range of consumption types. The larger but less persistent responsiveness of durable consumption might imply state-dependence of monetary policy effectiveness arising from adjustment costs on durable goods consumption.

5.2 Results of the Second Subsample

In this subsection, we document the results of the second subsample from September 2013 to September 2018. In this period, there are arguably two active policy instruments: the Fed's asset purchases, or balance sheet, and the FF rate. Therefore, we extend the benchmark 5-variate VAR model to 6-variate VAR model to incorporate both monetary policy measures. For the balance sheet, we use the Fed's total assets divided by the nominal GDP of the previous quarter. This policy instrument is slightly different from the cumulative amount of asset purchases announced used in the previous subsection, as there were not many announcements of changes in the Fed's balance sheet during this regime. For the FF rate, we use the implied FF rate based on 12-month FF futures price data, since the actual FF rate exhibited little fluctuation before the Fed started raising the FF rate in December 2015. To identify a monetary shock for each measure, we use the same sign restrictions as above. More specifically, we assume that a contractionary balance sheet policy shock reduces the Fed's total assets and real stock prices and increases long-term bond yields, while the interest rate policy shock increases the FF rates and long-term bond yields and reduces real stock prices.

Figure 9 summarizes the impulse responses of each variable to each contractionary monetary policy shock based on the 6-variate VAR model. Specifically, Panel (a) plots the impulse responses of each variable to an unexpected decrease in the size of the Fed's balance sheet. The results indicate that real output responds significantly negatively to quantitative tightening. Although the effects are slightly smaller than those of Regime 1 of the first subsample (Figure 7(a)), they are still larger and more persistent than those of Regime 2 of the first subsample (Figure 7(b)).

In contrast, Panel (b) of Figure 9 suggests that neither real output nor the price level shows a strong response to an unexpected increase in the FF rate. In other words, our results indicate that during the normalization period FF rate hikes had only marginal effects.

As for the size of the balance sheet, Bullard (2019) points out that unanticipated announcements of a balance sheet reduction during 2017 seem to have had a smaller economic impact than earlier balance sheet expansions. Based on this fact, he concludes that the signaling effects from the asset purchases suggested by Bauer and Rudebusch (2014) can induce asymmetric effects between an expansion and a reduction of the central bank’s balance sheet. Our findings suggest that a decline in the signaling effect might be less obvious if we look at the subsample after the taper tantrum triggered by Bernanke’s speeches in 2013. Regarding the policy rates, the results are consistent with Lo and Piger (2005), who find that policy shocks are more stimulative in recessions.

To obtain some insight into the possible reasons for the differences in the effects of monetary tightening between the two instruments, we conduct a similar exercise to that performed earlier and replace GDP with non-durable consumption, service consumption, durable consumption and capital goods new orders, and estimate the same 6-variate VAR model with two monetary policy instruments. Figure 10 plots the impulse responses of each variable for each instrument. As can be seen, regardless of the policy measure, a monetary policy tightening shock significantly reduces non-durable and service consumption in the long-run, although the effects are not statistically significant. In addition, both measures significantly dampen capital goods new orders in the short-run. On the other hand, durable consumption responds significantly positively to a FF rate shock in the short-run, raising durable consumption even in the long-run, although the positive responses are insignificant in the long-run. One possible explanation for these unusual responses is that in the normalization period the tightening of monetary policy produces an expectation of further monetary policy tightening with future interest rate hikes, inducing consumers to buy durables before the interest rate rise occurs. In fact, in January 2012 the Fed publicly started to report a “dot plot,” which shows the Federal Open Market Committee (FOMC) member’s projections for future interest rates in subsequent years and in the longer run, making it easier to predict the future interest rate hikes. For example, as of March 2014, FOMC participants largely anticipated several interest rates hikes both in 2015 and 2016, leading the median target federal funds rate to 2.25% by the end of 2016. Since the dot plots usually show diversified projections, particularly in the monetary normalization period, an interest rate hike could

reduce the uncertainty about the future path of the FF rates, yielding stronger anticipation of future interest rate hikes. As a consequence, in the case of FF rate shocks, the positive effects on durables offset the negative effects on other goods, rendering the responses on GDP insignificant.

What do the findings of this paper imply for the conduct of monetary policy going forward? The empirical results indicate that unexpected expansions or reductions in the size of the Fed’s balance sheet had relatively clear macroeconomic effects not just in the early stage of the LSAP but also in the period from September 2013 to September 2018, including the period of monetary policy normalization. Given that the present economic structure remains essentially unchanged, this suggests that the balance sheet policy is likely to remain in the policy toolkit for the Fed to use in response to future economic downturns, as [Yellen \(2016\)](#) anticipates. Our results also support [Kiley \(2018\)](#)’s argument that QE can play a useful role in offsetting the adverse effects of the effective lower bound when the equilibrium real interest rate is low. We should note that our sample periods are relatively short, because we focus on the period since the Great Recession. Although it is a caveat when interpreting our results, in sum, the findings of this paper generally support the case for an active balance sheet policy, at least as a secondary tool in ordinary times.⁷

6 Conclusion

Over the last decade, US monetary policy has evolved significantly. In response to the GFC, the Fed lowered the policy rate to the effective lower bound, introduced the LSAP in December 2008 and expanded the LSAP on two occasions. With the help of these policy initiatives, the US economy recovered and grew steadily, causing former Fed chair Ben Bernanke to suggest a possible tapering of the LSAPs and the beginning of monetary policy normalization in May and June 2013, which induced the taper tantrum. The Fed eventually ended the LSAPs in December 2014 and started raising the FF rate in December 2015.

Against this background, this paper empirically assessed the effects of the US UMPs over the last decade. Given the evolution of the US UMPs, it is crucial to consider possible regime shifts. To this end, we estimated a MSVAR model by incorporating Markov-switching into the benchmark VAR model based on [Weale and Wieladek \(2016\)](#) and [Hesse et al. \(2018\)](#).

⁷This view seems consistent with a recent announcement by the Fed. In January 2019 Fed chair Jerome Powell announced publicly at the American Economic Association Meetings that the Fed would not hesitate to make changes to the balance sheet reduction plan if necessary.

To overcome the problem that there may be no single monetary policy measure during this period, we adopted the SR of [Wu and Xia \(2016\)](#) as an appropriate monetary policy indicator over the last decade.

Our estimation of the MSVAR model detected a regime shift around the middle of 2013, immediately after the taper tantrum triggered by Bernankes speeches. In addition, the three-regime MSVAR model detected an additional regime change around the beginning of 2011, suggesting a possible change in the effects of the LSAPs.

We further investigated the details of each regime with relevant policy measures based on subsamples before and after the middle of 2013. Our analysis indicated that in the early stage of LSAPs, that is, before 2011, the US LSAPs had relatively large impacts on the real economy and prices, but their effects during the late stage of the LSAPs were weaker and less persistent. Our results also suggest that the effects of the asset purchase or balance sheet shocks were slightly weaker after the middle of 2013 including the monetary policy normalization period than during the early stage of the LSAPs, but stronger than during the late stage of the LSAPs. In contrast, the real economy and prices showed no significant responses to interest rate shocks. Additional analysis using GDP components demonstrated that negative responses of nondurable and service consumption and capital goods expenditure to interest rate shocks were somewhat offset by the positive impacts of the interest rate hike on durable consumptions after the middle of 2013. These findings seem to support the view that LSAPs will retain a useful role for central banks to use in responding to future economic downturns, at least as a secondary tool.

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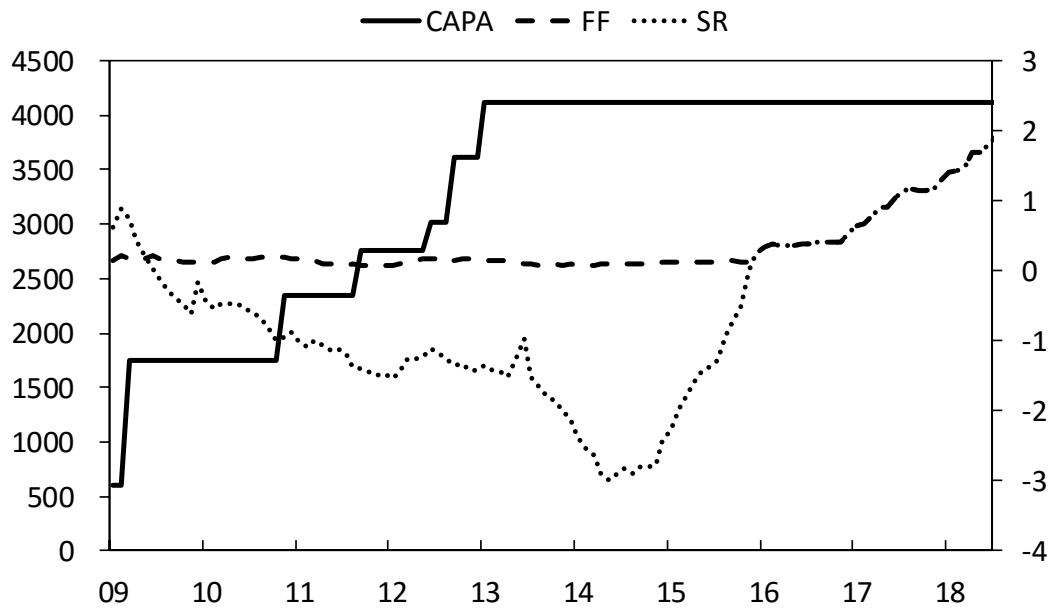


Figure 1. Cumulative sum of asset purchases announced, Federal Funds rate, and the Wu-Xia shadow rate from January 2009 to September 2018.

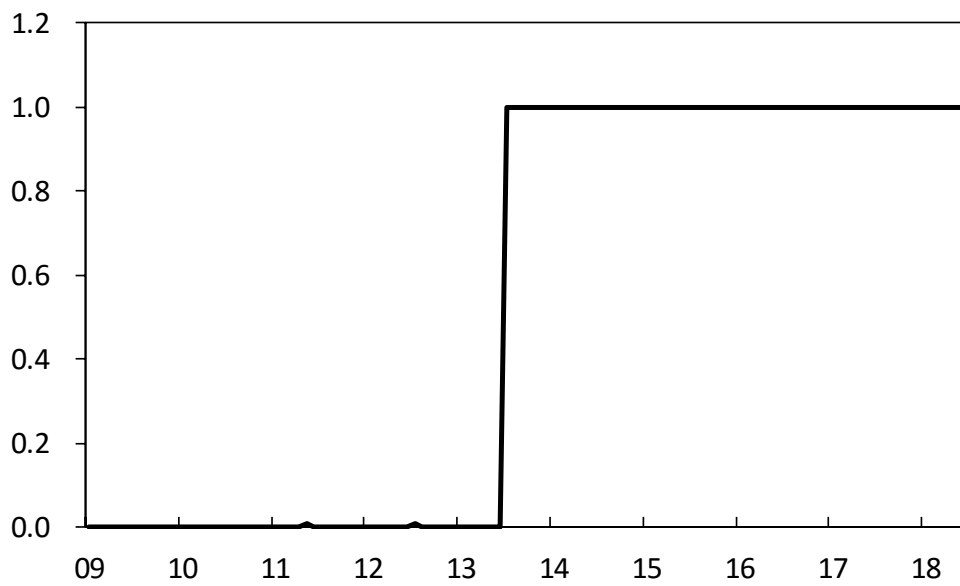


Figure 2. Smoothed probabilities of Regime 2 from Equation (2) with $K = 2$. The sample period is January 2009 to September 2018.

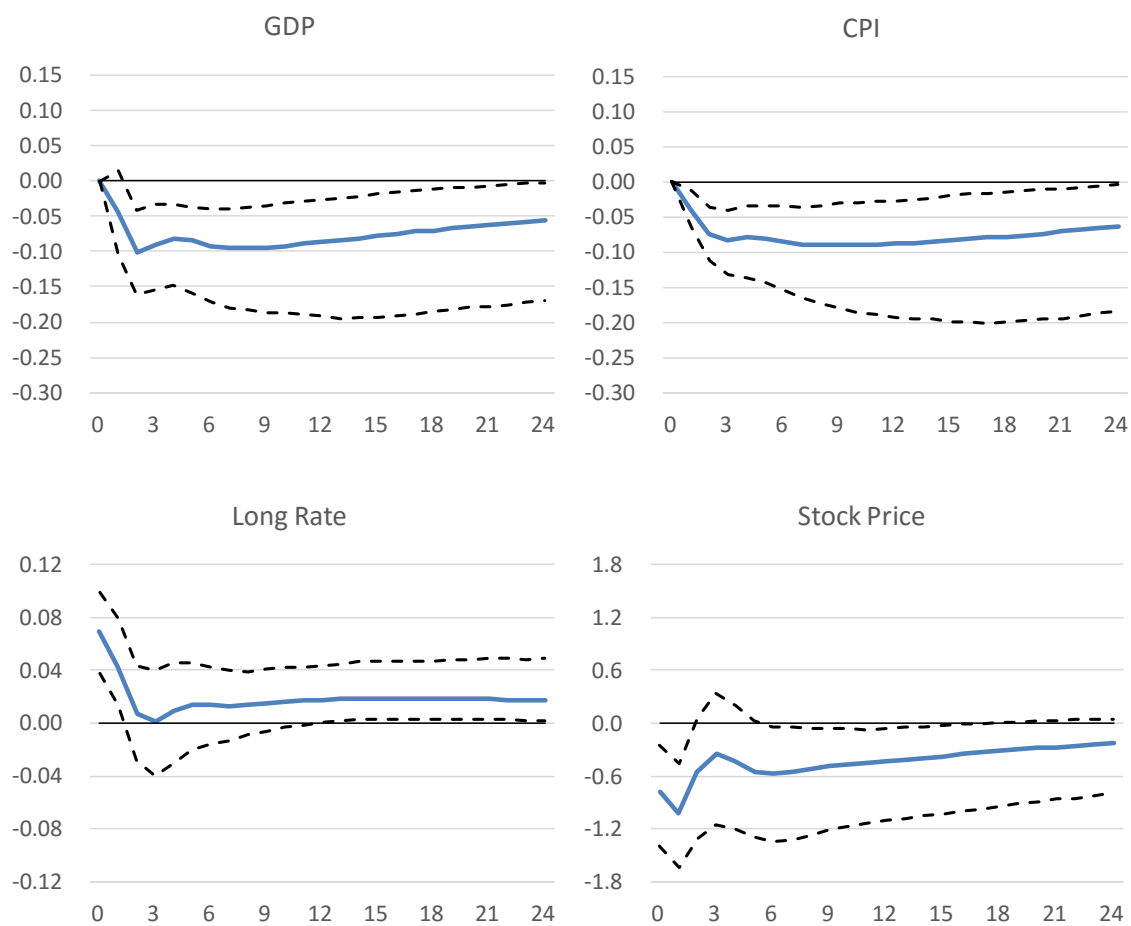


Figure 3 (a). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to a contractionary monetary policy shock under Regime 1. The results are obtained from estimating Equation (2) with $K = 2$. The sample period is January 2009 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

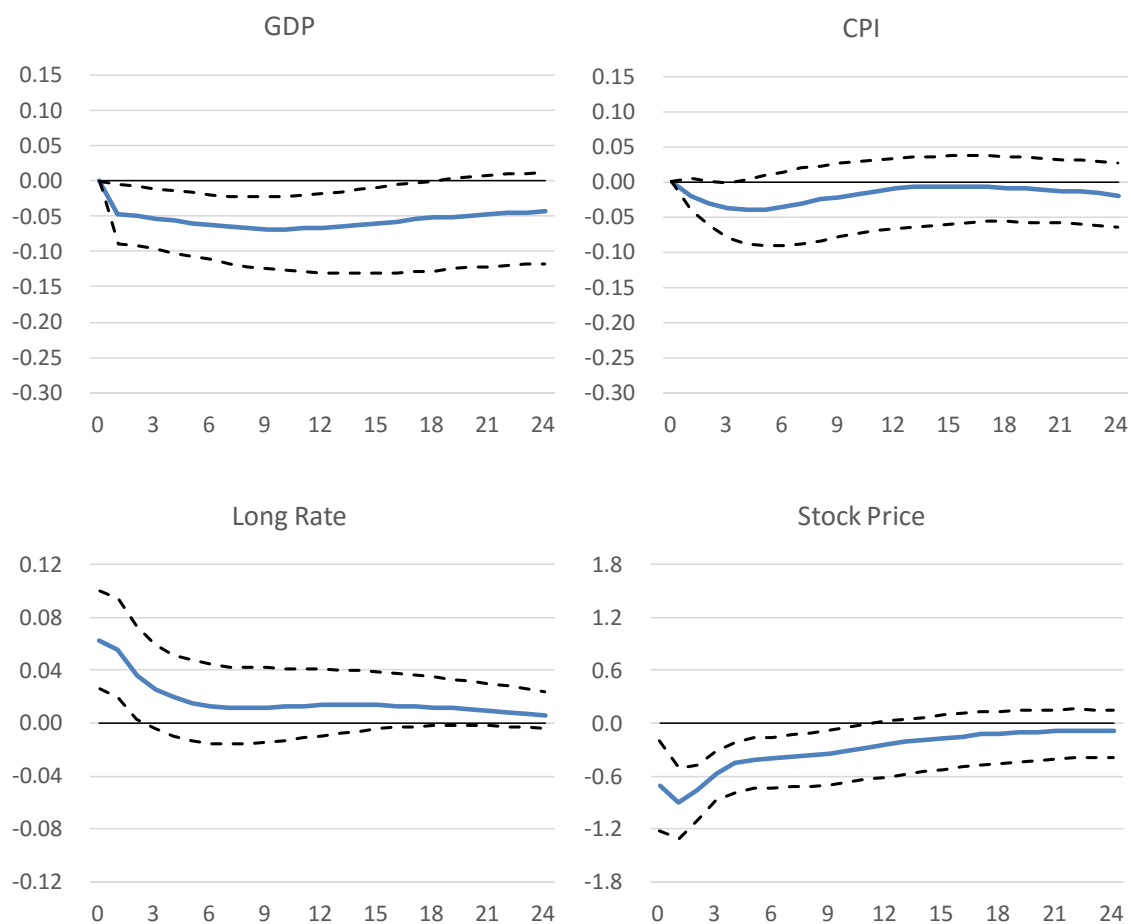


Figure 3 (b). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to a contractionary monetary policy shock under Regime 2. The results are obtained from estimating Equation (2) with $K = 2$. The sample period is January 2009 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

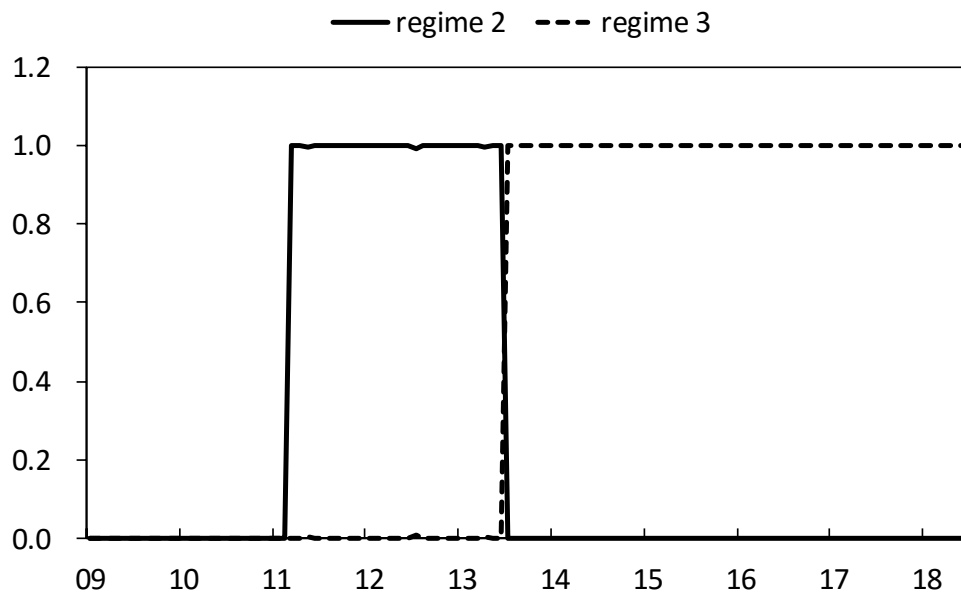


Figure 4. Smoothed probabilities of Regimes 2 and 3 from Equation (2) with $K = 3$. The sample period is January 2009 to September 2018.

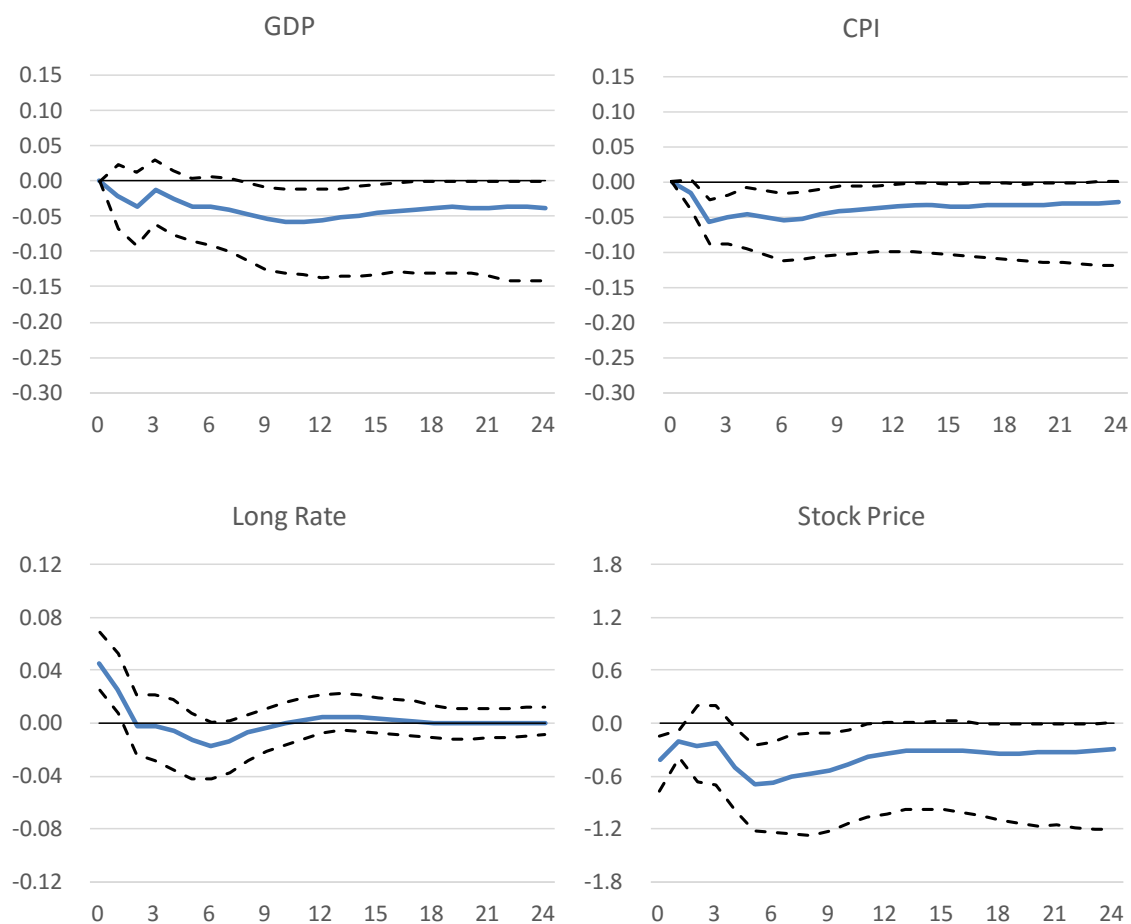


Figure 5 (a). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to a contractionary monetary policy shock under Regime 1. The results are obtained from estimating Equation (2) with $K = 3$. The sample period is January 2009 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

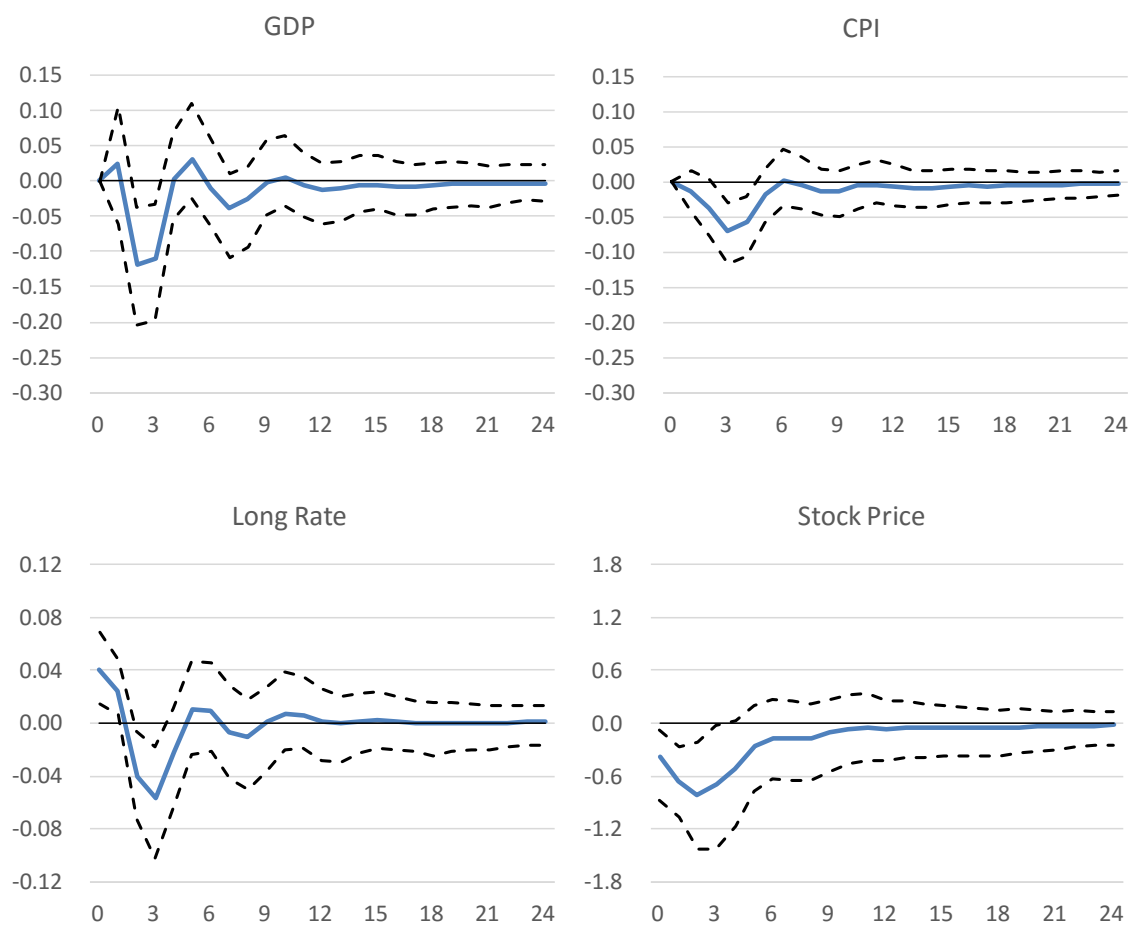


Figure 5 (b). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to a contractionary monetary policy shock under Regime 2. The results are obtained from estimating Equation (2) with $K = 3$. The sample period is January 2009 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

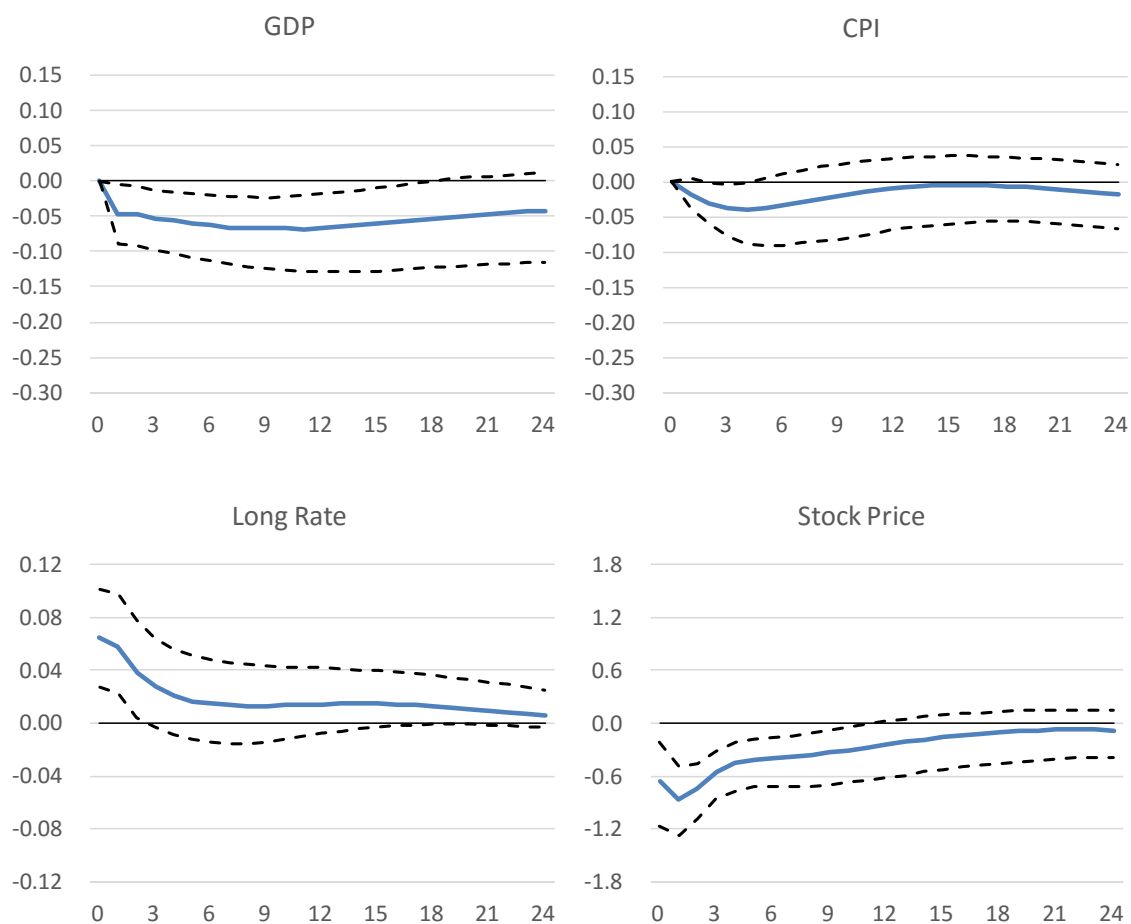


Figure 5 (c). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to a contractionary monetary policy shock under Regime 3. The results are obtained from estimating Equation (2) with $K = 3$. The sample period is January 2009 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

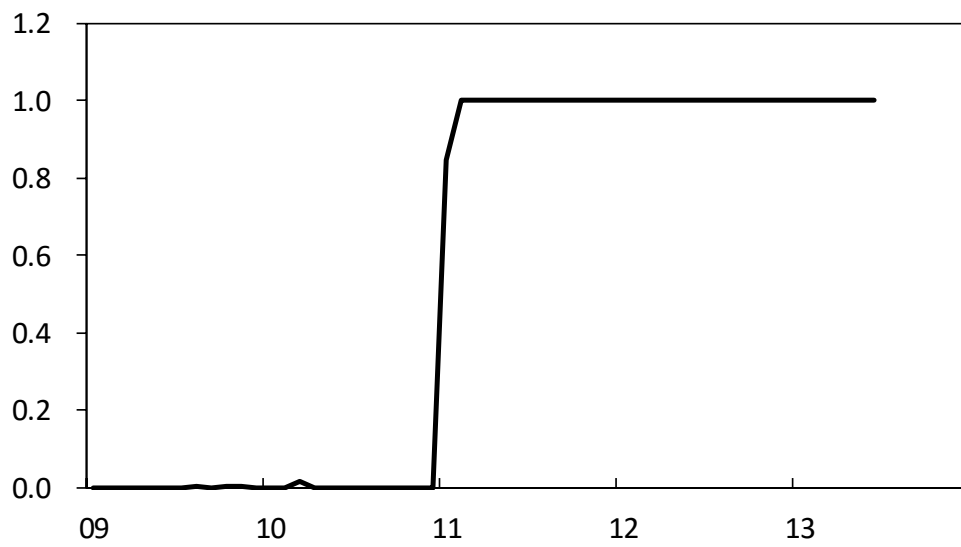


Figure 6. Smoothed probabilities of Regime 2 from Equation (2) with $K = 2$. The sample period is January 2009 to June 2013.

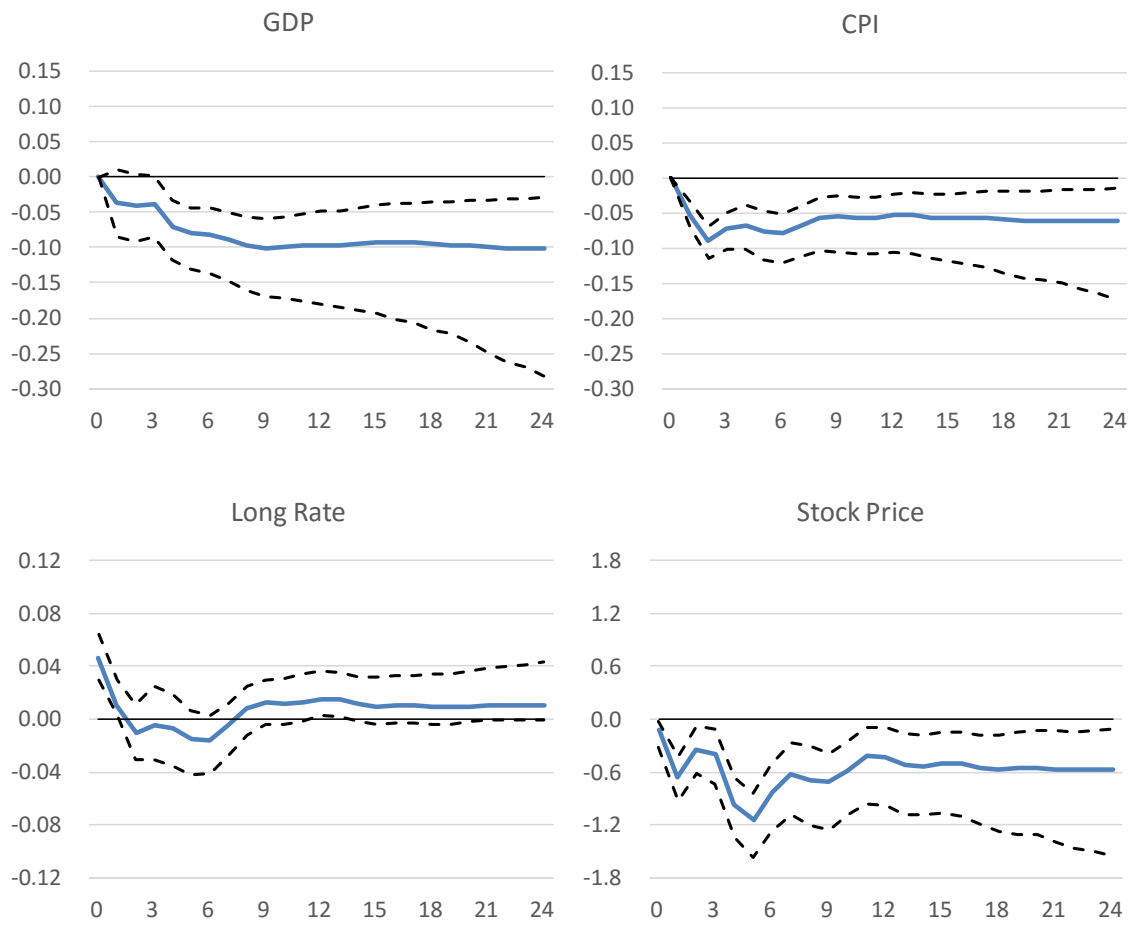


Figure 7 (a). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to a contractionary monetary policy shock under Regime 1. The results are obtained from estimating Equation (2) with $K = 2$. The sample period is January 2009 to June 2013. Dashed lines represent the 68% credible intervals of the impulse responses.

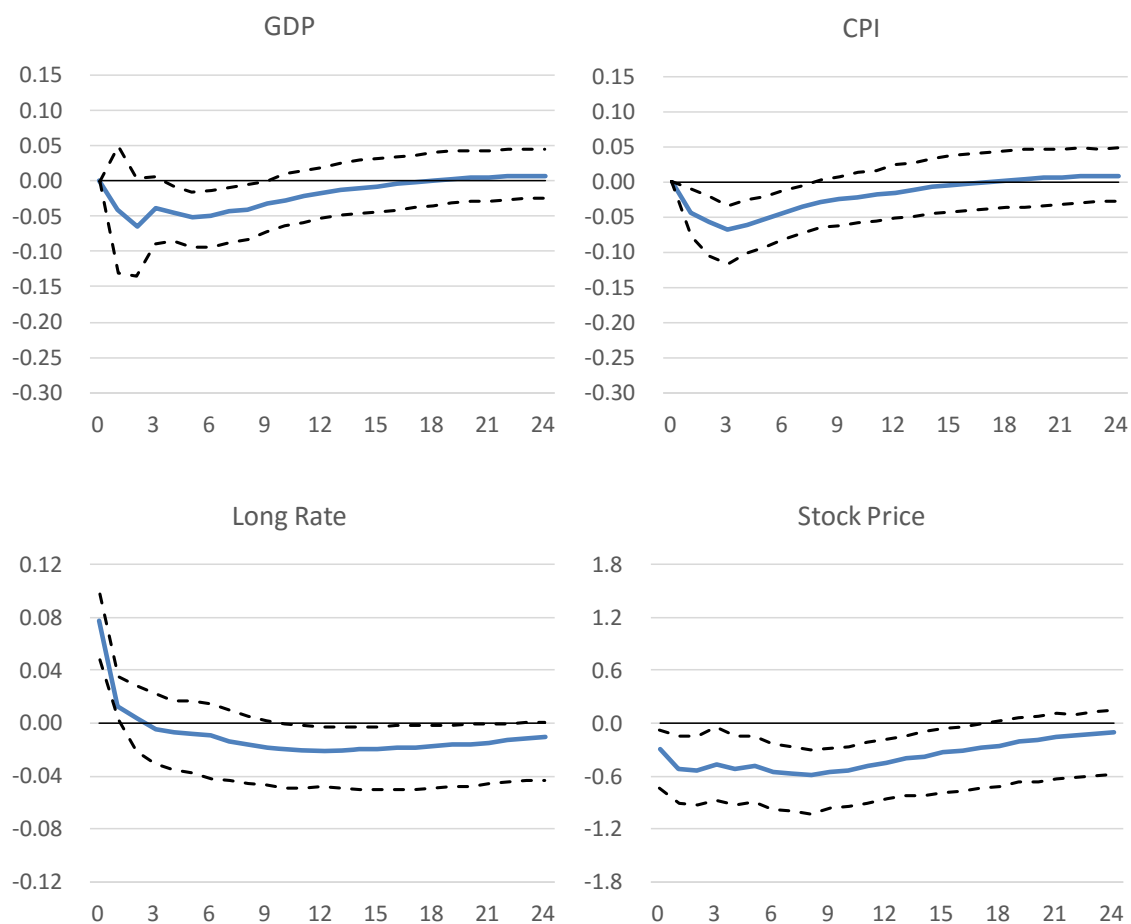


Figure 7 (b). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to a contractionary monetary policy shock under Regime 2. The results are obtained from estimating Equation (2) with $K = 2$. The sample period is January 2009 to June 2013. Dashed lines represent the 68% credible intervals of the impulse responses.

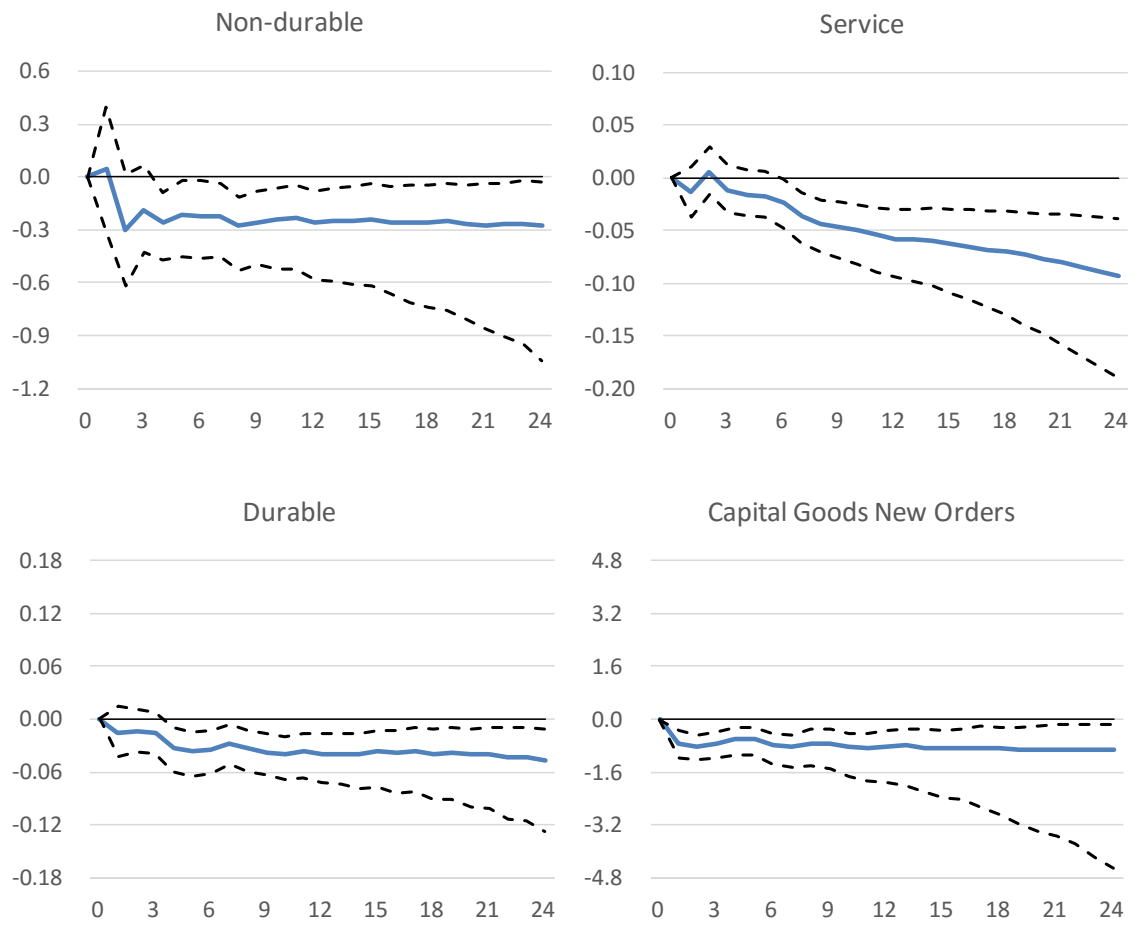


Figure 8 (a). Impulse responses of non-durable consumption, service consumption, durable consumption and capital goods new orders to a contractionary monetary policy shock under Regime 1. The results are obtained from estimating Equation (2) with $K = 2$. The sample period is January 2009 to June 2013. Dashed lines represent the 68% credible intervals of the impulse responses.

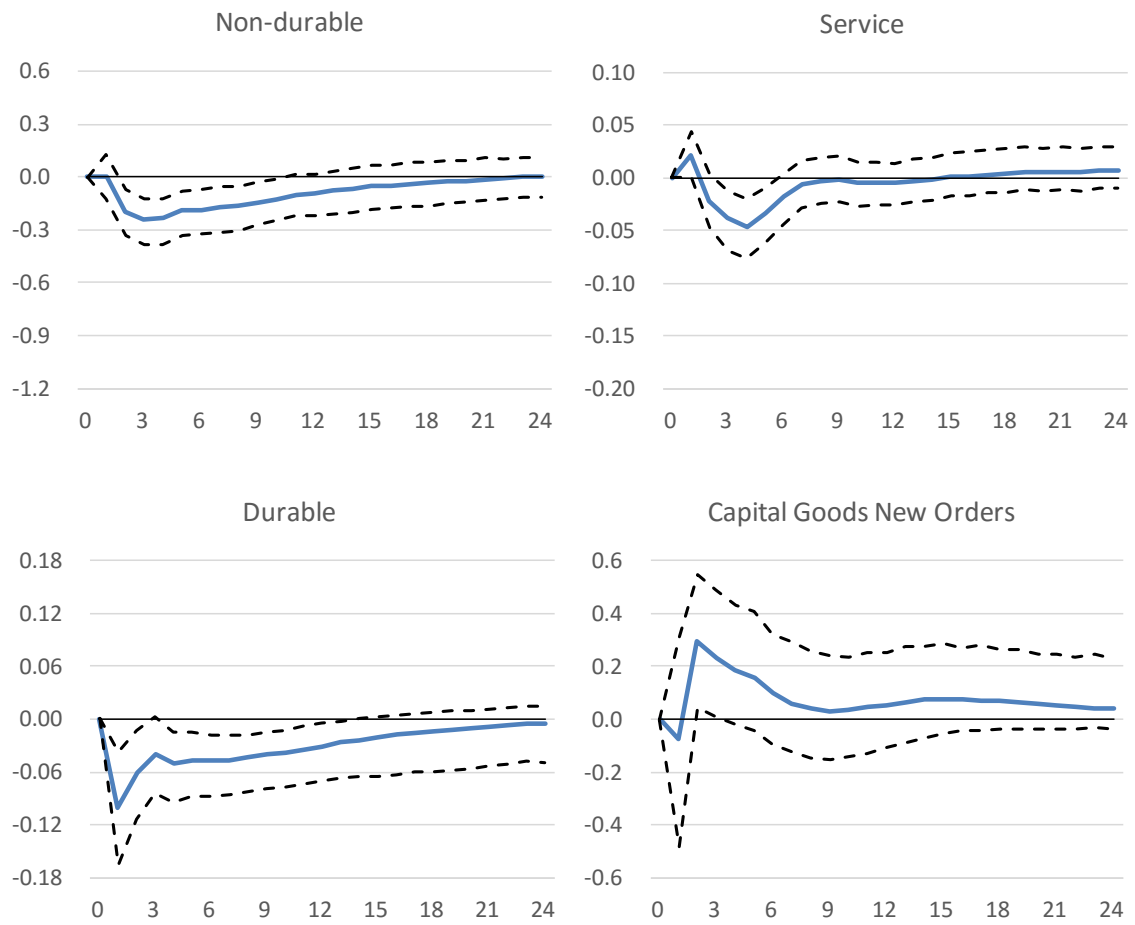


Figure 8 (b). Impulse responses of non-durable consumption, service consumption, durable consumption and capital goods new orders to a contractionary monetary policy shock under Regime 2. The results are obtained from estimating Equation (2) with $K = 2$. The sample period is January 2009 to June 2013. Dashed lines represent the 68% credible intervals of the impulse responses.

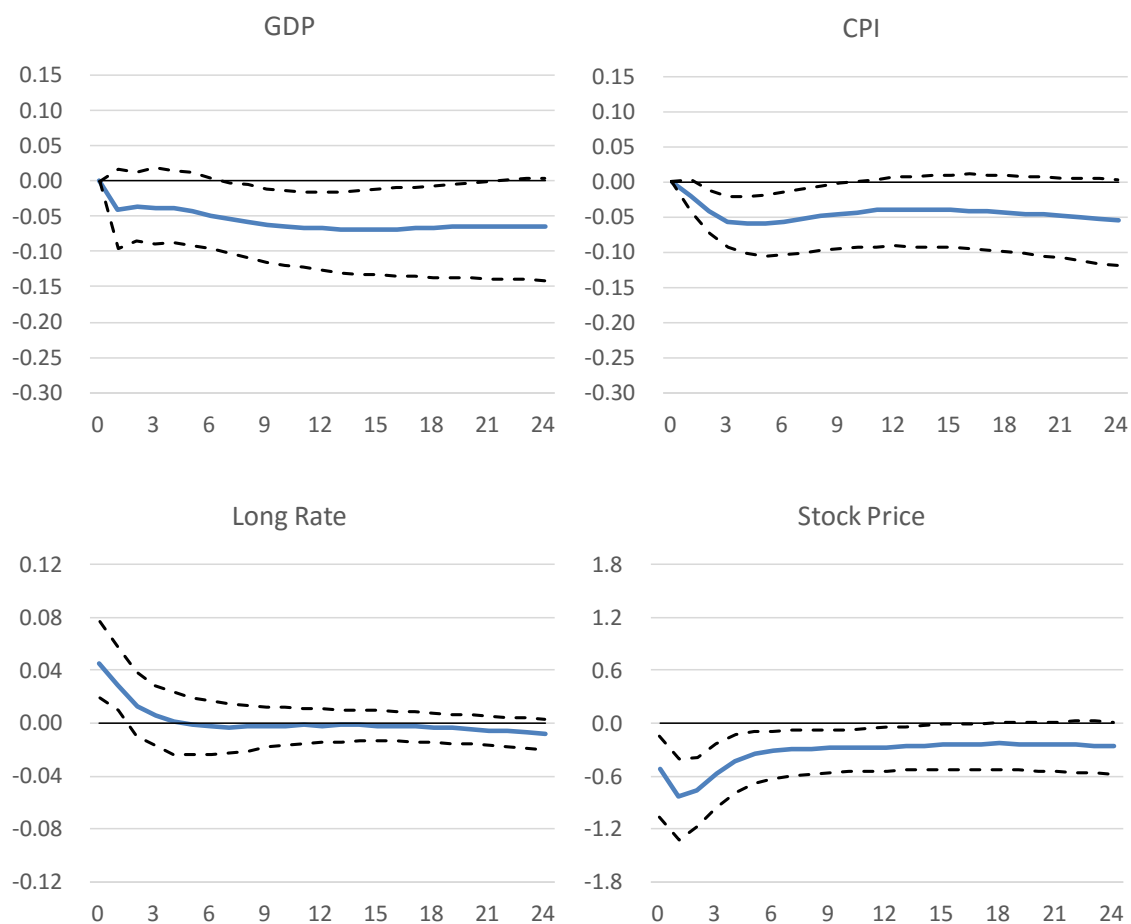


Figure 9 (a). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to an unexpected decrease in the Fed's total assets. The results are obtained from estimating Equation (2) with $K = 1$. The sample period is September 2013 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

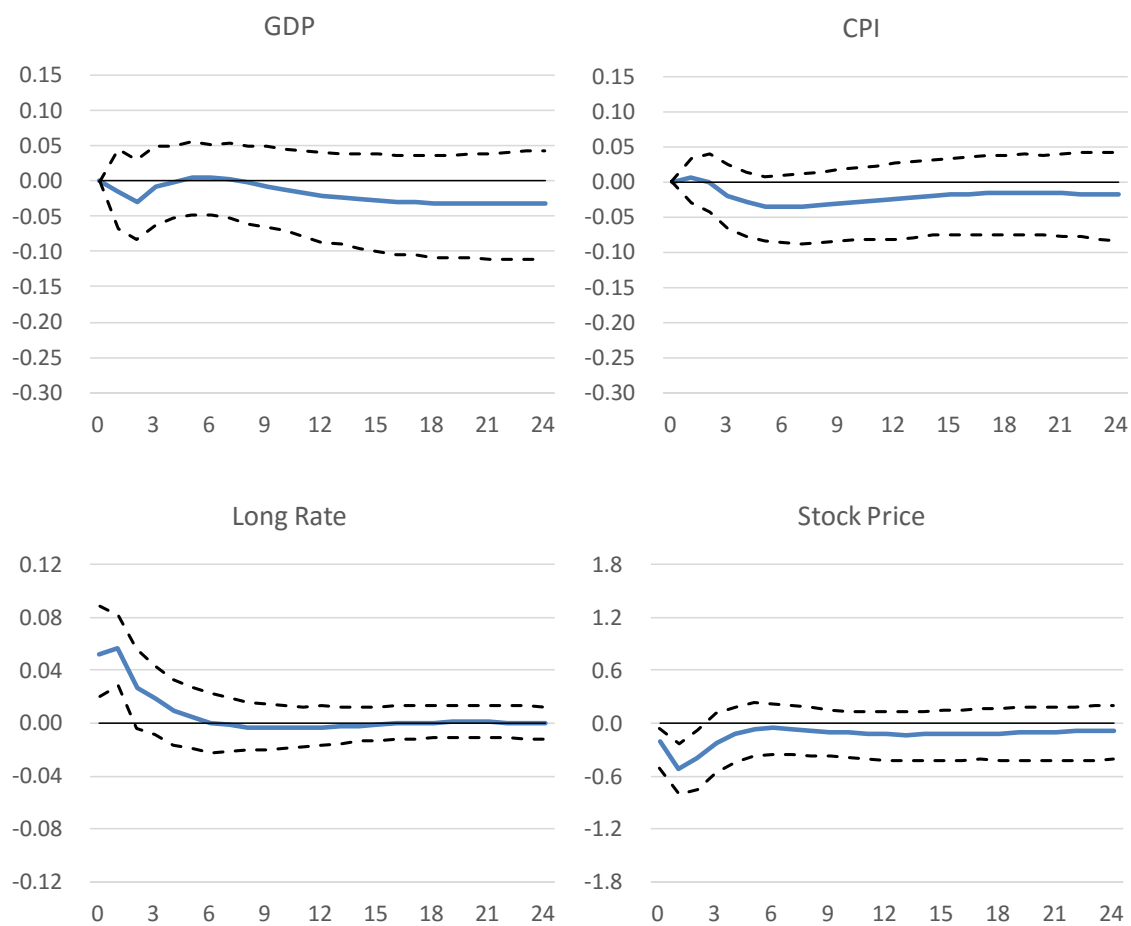


Figure 9 (b). Impulse responses of GDP, the CPI, the long-term interest rate and stock prices to an unexpected increase in the FF rate. The results are obtained from estimating Equation (2) with $K = 1$. The sample period is September 2013 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

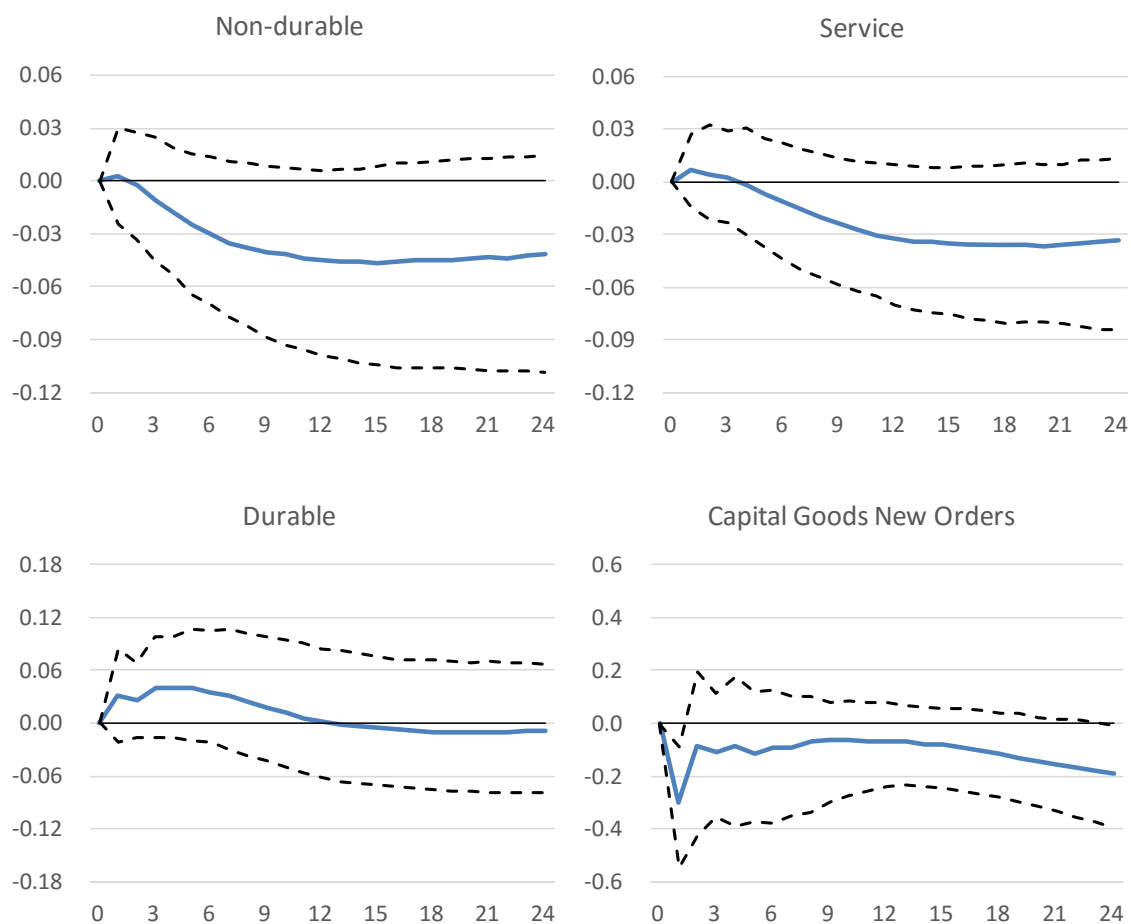


Figure 10 (a). Impulse responses of non-durable consumption, service consumption, durable consumption and capital goods new orders to an unexpected decrease in the Fed's total assets. The results are obtained from estimating Equation (2) with $K = 1$. The sample period is September 2013 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.

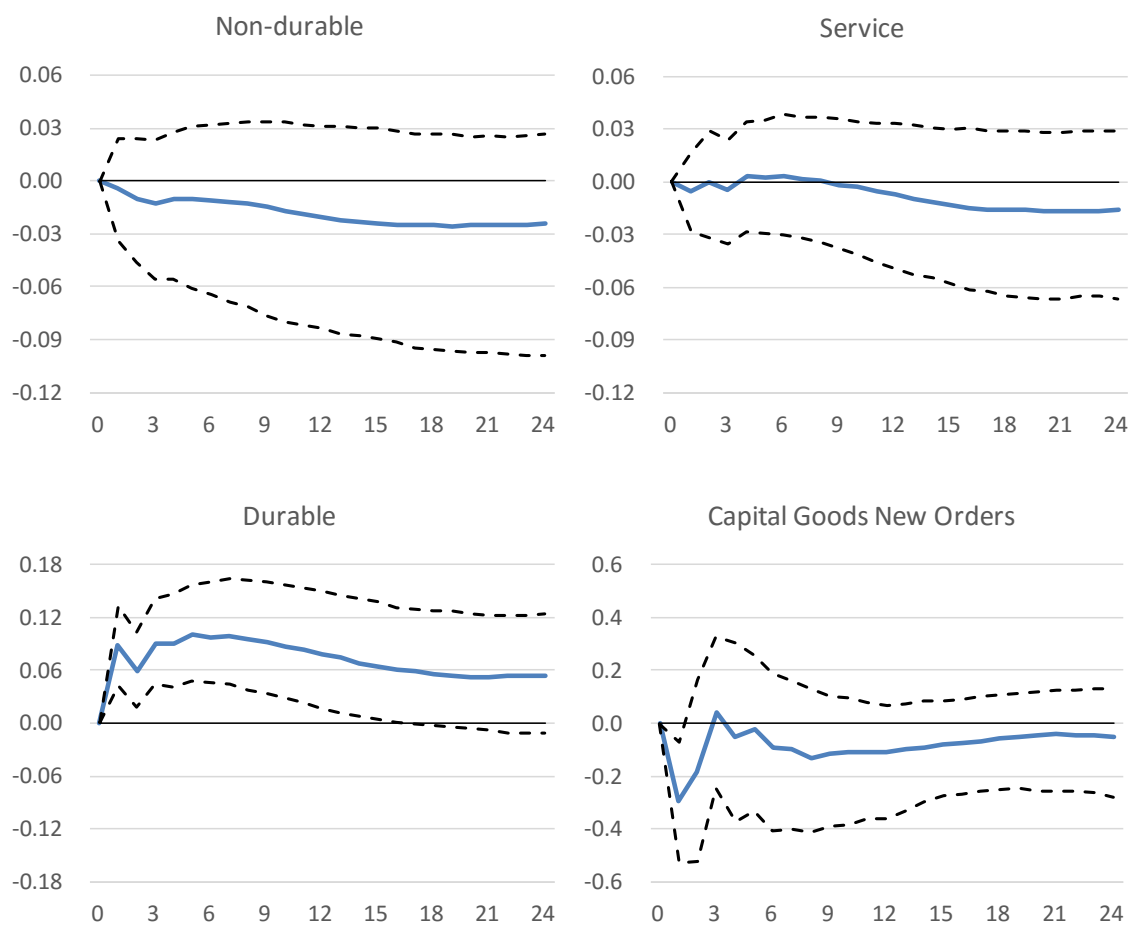


Figure 10 (b). Impulse responses of non-durable consumption, service consumption, durable consumption and capital goods new orders to an unexpected increase in the FF rate. The results are obtained from estimating Equation (2) with $K = 1$. The sample period is September 2013 to September 2018. Dashed lines represent the 68% credible intervals of the impulse responses.