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Assessing unconventional monetary policy in Japan using market operation-based monetary policy indices[*]

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Abstract

Open market operations (MOs) were not originally designed for making monetary policy changes during normal times. However, they became an integral part of the unconventional monetary policy (UMP) when the policy rates hit the effective lower bound during the 2008 global financial crisis in the major advanced countries. This study quantifies the effect of UMP carried out by MO on the macroeconomy in Japan, from 2002 to 2019, based on four market operation-based monetary policy indices (MO-MPIs), namely a broadly-defined quantitative easing index and three liquidity supply indices targeting different financial market segments. Our results indicate that there were three distinctive regimes with different policy impacts: (1) before mid-2008, (2) mid-2008 – mid-2016, and (3) after mid-2016. Moreover, UMP carried out using MO was the most effective in the second regime, with very strong effects of all MO-MPIs on almost all macroeconomic variables. Furthermore, MO-MPIs became substantially less effective in the third regime (after mid-2016) after the Bank of Japan introduced yield curve control.

Keywords: Unconventional Monetary Policy; Open Market Operations; Monetary Policy Indices; MSVAR
JEL classification: C32, E52, E58

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1 Introduction

During economic downturns such as the global financial crisis (GFC) of 2008–2009, central banks found that they were unable to lower the policy rate further to stimulate depressed aggregate demand because the policy rate was nearing the effective lower bound. Those central banks resorted to the "unconventional monetary policy" (UMP) (see, for example, Pattipeilohy et al. (2013) and Mouabbi and Sahuc (2019) for the European Central Bank (ECB), Kuttner (2018) and Bu et al. (2021) for the US Federal Reserve as well as Gambacorta et al. (2014) for their analysis of eight advanced economies) by substantially expanding the scope and quantity of open market operation (MO) measures, including large-scale government-bond purchases, and purchases of risky assets such as corporate bonds and stocks.

During normal times a vast majority of open MOs are not intended to make changes in monetary policy. Instead, they are conducted daily to prevent technical, temporary forces from pushing the policy rate too far from the target rate. Thus, these operations have not been the main subject of monetary policy analysis until UMP. However, when central banks are close to or hit the effective lower bound of the policy rate, MOs become an integral part of monetary policy tools by supplementing or replacing conventional monetary policy's rate control.

The Bank of Japan (BOJ) was the first central bank that introduced UMP (already in 1999) and still remains today as one of the most active central banks.[*1] The BOJ introduced various (regional and national) economy-supporting MOs coping with supply chain disruptions and slumping demand. These measures added BOJ's MOs as a part of UMP and increased its complexity substantially (see, Sudo and Tanaka (2021)).

Monetary policy in normal times is conducted by controlling the policy rate, therefore, most studies investigating the effectiveness of UMP use the policy rate adjusted for the effective lower bound. A monetary policy shock is defined as a shock that changes this

[*1] See Miyao and Okimoto (2020) and references therein for a detailed history and description of the BOJ's UMP.

adjusted policy rate. However, UMP makes this conventional policy analysis difficult.[*2] A strand of studies has typically used the shadow short rate (SSR) as a proxy for policy interest rates (see, for example, Kim and Singleton (2012), Bauer and Rudebusch (2016), Krippner (2013), Wu and Xia (2016), and Mouabbi and Sahuc (2019)), though the sensitivity of SSR estimates for monetary policy evaluation is also noted (Krippner (2020)). Moreover, because large-scale asset purchases and forward guidance of future policy paths are now an essential part of UMP, policy shocks are not likely to be presented by a single monetary policy indicator, but rather by multiple indicators. Some are inherently forward-looking, making their identification difficult. Recent examples of coping with these problems include Swanson (2021) and Boyarchenko et al. (2017). They argued that monetary policy cannot be reduced to one policy variable, but comprises multiple policy variables called monetary policy indicators.

The first contribution of this paper is to examine the effects of MOs in multiple perspectives, namely, liquidity provision effects of MO in addition to asset purchases, in assessing the effects of UMP on the macroeconomy in Japan. Liquidity effects are not considered in the traditional UMP analysis based on modified and expanded monetary policy indicator(s) described earlier. Thus, to properly account for the effects of liquidity provision, MO characteristics must be explicitly examined.[*3] Under UMP, people try to detect a change in the BOJ's monetary policy stance[*4] (including a subtle change of stance in liquidity provision) by looking at a change in the actual offer of the BOJ's MOs.

Based on a principal component analysis (PCA) of MOs by Heckel and Nishimura (2020, 2022),[*5] we identify four MO-based monetary policy indices (MO-MPIs) and

[*2] UMP can also be considered as switching from a traditional policy rate regime to a new regime of the monetary base or bank reserves. See for example, Kimura and Nakajima (2016), Hayashi and Koeda (2019) and Miyao and Okimoto (2020) for the case of Japan.

[*3] MOs are only a small part of short-term financial market transactions. However, they are indicative of the monetary policy stance of the BOJ.

[*4] Here we use the word "stance" instead of "policy," because a change in the BOJ's offer does not necessarily mean a change in policy. Rather, offers of MO may show the BOJ's view of the markets, and the assessment of their results may lead to an eventual change in monetary policy.

[*5] BOJ's MOs reported in https://www.boj.or.jp/en/statistics/boj/fm/ope/index.htm/ show 71 variables overall for the period 2002—2019. By eliminating duplicate variables and combining similar operations into one category, Heckel and Nishimura (2020) reduced 71 variables of operation measures to 21 variables listed in Table 1. Then, applying the PCA to these 21 variables, they found four PCs to explain the variance of MOs and their motives across the entire period. They also examined MOs for the subperiod of each governor's term in office to assess the possible influence of governorship. We used this supplemental information in the subsequent analysis.

their implicit motives for the entire period of 2003—2019, of which three are liquidity supply motives. They are: (1) an index of broadly defined quantitative easing (MO-MPI1), (2) an index of liquidity supply to medium to long-term lenders and investors (MO-MPI2), (3) an index of temporary liquidity supply to the specific segment of the short-term markets (MO-MPI3), and (4) an index of liquidity supply controlling policy rates and maintaining current accounts of financial institutions at the BOJ at a high level (MO-MPI4).[*6]

The differences and similarities between approaches in the existing literature and our new approach to MO-MPIs are explained below. In the conventional literature, the most important question is: How will a policy rate change (effective lower bound adjusted) impact macroeconomic variables in the future months? Under UMP, it is crucial to consider multiple monetary policy indicators, which encompass aspects like quantitative easing and forward guidance. By contrast, the question in our model is: How will an X % increase of broadly defined quantity easing (a particular linear combination of asset purchases) and Y % of the increase in liquidity supply (a particular linear combination of liquidity supply measures) in this month affect real GDP and the core consumer price index (CPI) in the future months? There is no one-to-one relationship between the former (conventional monetary policy change) and the latter (change in the principal component of MOs). Our new approach provides more detailed information about the impact of various parts of MOs, especially the impact of liquidity supply on the macroeconomic variables in the era of UMP. This information is unavailable and overlooked in the conventional approach.

To assess the effectiveness of UMP based on MO, we employ a structural Vector Autoregressive (VAR) model of a MO-MPI and four macroeconomic variables (GDP, core CPI, government bond prices, and stock prices), and estimate it by using monthly data for the period from March 2003 to December 2019. During this sample period, there

[*6] Three different components target different financial market segments. This shows that a preferred habitat theory applies to the Japanese market (see Sudo and Tanaka (2021)). Further, the quantitative significance of a relatively small amount of risky asset purchases (stocks and real estate investment trusts) in the broadly defined quantitative easing might mean that stock and related markets have inelastic demand and supply implying large price changes despite small monthly purchase quantities for these assets (see Gabaix and Koijen (2022)).

were three governors in office. Names and tenure of office are Toshihiko Fukui (2003/3–2008/3), Masaaki Shirakawa (2008/4–2013/3), and Haruhiko Kuroda (2013/3–2023/4). To account for possible changes in the impact of the MO-MPI, one approach is to divide the sample according to the tenure of each governor. However, monetary policy changes due to governor turnover do not necessarily imply that the effects are different for each governor.

The second contribution of this paper is to identify structural changes in the effects of each MO-MPI, possibly due to replacements of governors. This could be an important contribution since monetary policies were sometimes altered even within the same governor. For example, Fukui ceased the zero-interest policy in July 2006, Shirakawa introduced comprehensive monetary easing (CME) in October 2010, and Kuroda added the negative interest rate policy (NIRP) and yield-curve control (YCC) to quantitative and qualitative easing (QQE) in 2016. These policy changes could lead to a shift in monetary policy regimes without a change of governors. To explore this possibility and to assess the effects of monetary policy more precisely by identifying more reasonable monetary policy regimes, we extend our analysis using a three-regime Markov-Switching VAR (MSVAR) model with absorbing regimes, which incorporates permanent structural changes across the entire sample period (2003–2019). The results show that the first permanent structural change occurred between May and November 2008, when a series of global crises struck the Japanese economy shortly after Governor Shirakawa assumed office. The second permanent structural change took place in August 2016[*7] which is after Governor Kuroda initiated the NIRP in January 2016 and just before he adopted the YCC targeting not only the traditional overnight policy rate but also the 10-year government bond interest rates. This finding allows us to conduct a more precise evaluation of the effectiveness of the monetary policy in the latter half of the Kuroda era. This is a notable contribution to the literature, as few studies provide solid empirical evidence on the issue of NIRP and YCC, although there are several studies assessing the first half of the Kuroda era, such as Fukuda (2015), Hausman and Wieland (2015), De Michelis

[*7] The only exception is MO-MPI2, which underwent a second permanent structural change in May 2011. This point is discussed in Section 5.2.

and Iacoviello (2016), and Hanisch (2017).

The first regime of MO-based monetary policy overlapped with the Fukui period. MO-based monetary policy was not a sufficiently effective counter-deflationary measure in this regime. In contrast, the most striking and successful result was observed in the second regime. The second regime started when a series of global and domestic crises hit the Japanese economy. In response, the Shirakawa-led BOJ abolished old operation measures, introduced new operation measures in a short period, and expanded them gradually at first and later quickly as crises deepened. Furthermore, Governor Kuroda inherited these frameworks and expanded them to an unprecedented scale. This regime lasted until the end of August 2016. The scale and the effects of all MO-MPIs were substantially and extensively positive on the macroeconomy and financial markets.[*8] All MO-MPIs had very substantial and long-lasting effects on real GDP, CPI, bond prices, and stock prices.

Finally, the third regime started in August 2016, before the Kuroda-led BOJ introduced a YCC framework in September 2016 to make QQE less active (or precisely, more re-active) and the market became accustomed to the new regime. Hereon, monetary policy is not based on active asset purchases or active liquidity supply. Rather, asset purchases are offered only in case of weak asset demand, to drive up the long-term risk-free interest rate to exceed a prespecified range. Our results indicate that the responses of the macro variables to UMP had weakened considerably, suggesting that the effects of MO-related monetary easing measures in the latter years of Kuroda's term, including the NIRP and YCC, were ineffective.

This paper is organized as follows: Section 2 introduces MO-MPIs on the basis of PCA. Section 3 presents our benchmark structural VAR model and our extension toward an MSVAR model. Section 4 summarizes our data. Results are presented in Section 5, using impulse response functions (IRFs) of governor-specific VAR models and an MSVAR model. Section 6 presents concluding remarks including future research.

[*8] With respect to the second MO-oriented monetary policy MO-MPI2 - liquidity supply to long-term investors - Regime 3 (2011–2019) is the appropriate regime comparable to Regime 2 in the other three MO-MPIs.

2 Heckel-Nishimura's Monetary Policy Index

When analyzing the impact of monetary policy easing on the macroeconomy under UMP using VAR, previous studies have typically used either the monetary base or the SSR (see, for example, Kim and Singleton (2012), Bauer and Rudebusch (2016), Krippner (2013), and Wu and Xia (2016)). In this study, we take a different approach than the usual economic literature and use MPIs developed by Heckel and Nishimura (2022). By using PCA, Heckel and Nishimura (2022) constructed MPIs that represent policy objectives from 21 market operations data, temporarily aggregated at monthly frequency, using the entire sample period. The series is listed in Table 1.*9 We label the constructed policy indicators as MO-MPIs, and consider the change in the MO-MPIs as a change in the broadly defined monetary policy including market stabilizing policy, which is a prerequisite to effective conventional monetary policy. Then, by including Heckel-Nishimura's MO-MPIs in the standard monetary policy VAR model, we statistically analyze the effects of monetary policy for each policy objective.

*9 Heckel and Nishimura (2022) considered the period (interval) between regularly scheduled monetary policy meetings as the basic time unit for the baseline case because policies announced in the monetary policy meeting (MPM) introduce, continue, or abolish both conventional and unconventional policies through MOs. In this paper, however, we consider monthly data as the basic time unit because we examine the effects on monthly macroeconomic data. Further details of these MOs data are given in Appendix A.

	Open Market Operation	mnemonic	MO-MPI1	MO-MPI2	MO-MPI3	MO-MPI4
1	Corporate Bonds (Outright Purchases)	CB_op	0.272*	0.261	−0.137	0.033
2	Commercial Papers (Repo)	CP_repo	−0.232*	0.185	0.334*	0.245
3	Exchange Traded Funds	ETF	0.305*	−0.108	0.249	−0.108
4	ETFs to Support Investment in Physical and Human Capital	ETF2	0.267*	−0.130	0.350*	−0.238
5	Funds-Supplying Operations to Support Financial Institutions on Disaster Areas	FSO-Disaster	0.186	0.032	−0.134	−0.025
6	Funds-Supplying Operations to Support Financial Institutions on Disaster Areas of the 2016 Kumamoto Earthquake	FSO-Kumamoto	0.120	−0.051	0.180	−0.149
7	JGBs (Outright Purchases) 0-1 year	JGB-0-1_op	0.069	0.451*	−0.270	−0.190
8	JGBs (Outright Purchases) 1-10 years	JGB-1-10_op	0.328*	−0.075	0.063	0.218
9	JGBs (Outright Purchases) 10-30 years	JGB-10-30_op	0.360*	−0.026	0.014	0.183
10	JGBs (Outright Purchases) (Floating-Rate Bonds)	JGB-float_op	0.158	0.200	−0.196	0.071
11	JGBs (Outright Purchases) (Inflation-Indexed Bonds)	JGB-I_op	0.267*	0.020	0.279	−0.292*
12	JGBs (Outright Purchases) (under APP)	JGB_op	−0.313*	−0.251	0.062	−0.002
13	JGSs as Collateral for US Dollar Funds-Supplying Operations	JGS-C-USDFSOPC	0.130	−0.076	0.266	−0.158
14	Japan Real Estate Investment Trusts	J-REIT	0.267*	−0.003	−0.045	−0.006
15	Special Funds-Supplying Operations to Facilitate Corporate Financing	SFSOFCF	−0.063	0.453*	0.253	0.080
16	Bills (Outright Purchases) / Funds Supplying Operations against Pooled Collateral	Bills_op-FSOPC	−0.045	0.291	−0.231	−0.383*
17	Treasury Bills (Repo)	T-Bills_repo	0.031	0.044	−0.049	−0.185
18	Treasury Bills (Outright Purchases)	T-Bills_op2	0.128	−0.100	−0.112	0.576*
19	US Dollar Funds Supplying Operations against Pooled Collateral	USD-FSOPC2	−0.089	0.186	0.326*	0.128
20	Commercial Papers (Outright Purchases)	CP_op2	0.298*	0.194	−0.042	0.257
21	JGBs / JGSs (Repo)	JGB-JGS_repo	−0.120	0.415*	0.353*	0.119

Table 1 List of the 21 series of market operations, their mnemonics, and the eigenvectors of each element constituting MO-MPI

Note: The values in the four right-hand columns are the eigenvectors of each element constituting MO-MPI. Asterisks indicate the primary components of each MPI.

The characteristics of each MO-MPI are given by its eigenvector. Table 1 reports the estimated eigenvectors of MO-MPI1 to MO-MPI4. Specifically, the BOJ's UMP through open MOs is categorized as (1) broadly defined quantitative easing (asset purchasing) policies to reduce long-term risk-free rates, risk premiums of stocks and related markets, and risks in corporate finance (we denote this PC as MO-MPI1), (2) liquidity provision aiming at medium to long term lenders and investors, including emergency measures helping commercial banks meet the corporate funding needs during crises (MO-MPI2), (3) temporary liquidity provision aiming at specific financial market segments such as the US Dollar Funds Supplying Operations (MO-MPI3), and (4) policies to control overnight policy rates and maintain current accounts at high levels for financial institutions (MO-MPI4). This suggests that the BOJ's MOs cannot be reduced to a single dimension but is rather a complex policy mix of operations for realizing multiple goals. In this study, we perform a VAR analysis by using four series of monetary policy indices (MO-MPI1, MO-MPI2, MO-MPI3, and MO-MPI4) one at a time.

Nota bene, each of these MO-MPIs is estimated using the entire sample period, thus the index may not be directly related to the actual monetary policy conducted or even nonexistent within the governor's term. Thus, in order to obtain supplemental information, PCs are estimated by subsample periods. The correspondence between the MO-MPIs and subsample PCs is summarized in Table 2.

During Fukui's term, PC1 is primarily characterized by Commercial Papers (Repo) (mnemonic used in Table 2 is CP_repo) and JGBs/JGSs (Repo) (JGB_JGS_repo). This PC1 corresponds to MO-MPI3 in the whole period. This is because MO-MPI3 is primarily characterized by JGB-JGS_repo, [ETFs to Support Investment in Physical and Human Capital (ETF2)], CP_repo, [US Dollar Funds Supplying Operations against Pooled Collateral (USD-FSOPC2)], [JGBs (Outright Purchases) (Inflation-Indexed Bonds) (JGB-I_op)], [JGBs (Outright Purchases) 0-1 year (JGB-0-1_op)], [JGSs as Collateral for US Dollar Funds-Supplying Operations (JGS-C-USDFSOPC)], [Special Funds-Supplying Operations to Facilitate Corporate Financing (SFSOFCF)], and [Exchange Traded Funds (ETF)] in which [ ] shows an operation which does not exist in the Fukui period. Therefore, the remaining JGB-JGS_repo and CP_repo are the components characterizing MO-MPI3 in the Fukui subsample.

For Shirakawa's period, MO-MPI1 corresponds to PC1 (which is characterized by {JGB-0-1_op}, JGBs (Outright Purchases) 1-10 years (JGB-1-10_op), JGBs (Outright Purchases) 10-30 years (JGB-10-30_op), Corporate Bonds (Outright Purchases) (CB_op), JGBs (Outright Purchases) (under APP) (JGB_op), {USD-FSOPC2}, and ETF) and PC4 (which is characterized by {JGB-float_op}, ETF, Japan Real Estate Investment Trusts (J-REIT), {JGB-I_op}). Note that {} signifies a component that is not in the corresponding MO-MPI. MO-MPI2 is primarily characterized by SFSOFCF, JGB-JGS_repo, in addition to JGB-0-1_op. This corresponds to PC2 characterized by SFSOFCF, JGB-JGS_repo, in addition to CP_repo and CP_op. MO-MPI3 is characterized by JGB-JGS_repo, ETF2, CP_repo, and USD-FSOPC2. This MO-MPI3 does not have a clear relationship with PCs in the Shirakawa period. A possible candidate is PC2, but only JGB-JGS_repo is a common component. Lastly, MO-MPI4 is characterized by Treasury Bills (Outright Purchases) (T-Bills_op2), Bills (Outright Purchases)/Funds Supplying Operations against Pooled Collateral (Bills_op-FSOPC), in addition to JGB-I_op. This corresponds to PC3 primarily characterized by JGB-I_op, Bills_op-FSOPC, in addition to JGBs (Outright Purchases) (Floating-Rate Bonds) (JGB-float_op). During the Shirakawa period, monetary policy was very complex, and therefore five PCs were identified. As PC5 mainly consists of T-Bills_op2, Bills_op-FSOPC, JGB-float_op and JGB-I_op, it is part of MO-MPI4.

In the Kuroda period, PC1 is primarily characterized by ETF2, JGB-I_op, ETF, JGB-0-1_op, T-Bills_op2, and Commercial Papers (Outright Purchases) (CP_op2), and PC2 is characterized by JGB-1-10_op, JGB-10-30 op, J-REIT, USD-FSOPC2. These two PCs seem to correspond to MO-MPI1, which is characterized by JGB-1-10_op, JGB-10-30_op, JGB_op, ETF, CP_op2, CB_op, JGB-I_op, ETF2, J-REIT, and CP_repo. There is one more PC (PC3), a disaster relief measure, which is not included in the MO-MPIs.

Table 2 indicates that neither the number nor the order of importance of PCs was identical across the overall sample period and the subsample periods of the governors' terms in office.

While there were differences in PCs between the entire sample and the subsample of

Full sample	Fukui	Shirakawa	Kuroda
MO-MPI1(Quantitative Easing)	n.a.	PC1 & PC4	PC1&PC2
MO-MPI2(Liquidity Provision 1)	n.a.	PC2	n.a.
MO-MPI3(Liquidity Provision 2)	PC1	n.a.	n.a.
MO-MPI4(Liquidity Provision 3)	n.a.	PC3 & PC5	n.a.

Table 2 Approximate correspondence between MO-MPIs for the entire sample period and PCs for each governor's term in office (monthly data)

Note: Author's classification based on Heckel and Nishimura (2022).

each governor's term, some subsample PCs could be categorized as MO-MPIs for the entire sample period. In the VAR analysis section, we will supplement the information summarized in Table 2 for interpreting the impulse response analysis.

However, there is an important caveat. Monetary policy is often considered to have long and variable lags in its effects. Thus, the subsample period of the governor's term may be too short to account for the full effects of monetary policy. We will discuss this subsequently.

3 Methodology

To examine the effects of UMPs on the macroeconomy between 2003 and 2019, we employ a VAR model consisting of a MO-MPI and four macroeconomic variables (GDP, core CPI, government bond prices, and stock prices). Then, we extend the model by including regime-switching to analyze changes in the impact of each MPI irrespective of the timing of changes. This section introduces our benchmark model, followed by the MSVAR model and its estimation.

3.1 Benchmark Model

Our benchmark model is a VAR model given by the following equation:

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

where $\mathbf{Y}_t$ is a vector of endogenous variables, $\boldsymbol{\alpha}$ is a vector of constants, and $\mathbf{A}_k$ 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 GDP, the logarithm of the (seasonally adjusted) core CPI, a MO-MPI extracted by the PCA, the logarithm of the government bond price index, and the logarithm of the stock price index. This has been a standard VAR model to assess the MP effects since Christiano et al. (1999) proposed a block-recursive structural VAR. A similar model was used to analyze the UMP effects of major countries, including the US, UK, and Japan, by Weale and Wieladek (2016), Hesse et al. (2018), Hara et al. (2020), and Miyao and Okimoto (2020), among others. For our empirical analysis, L was set to two, consistent with the above studies.[*10]

A critical issue for the VAR analysis is the identification of monetary policy shocks. Christiano et al. (1999) proposed a block-recursive identification by assuming that outputs and prices do not respond contemporaneously to any shocks (including monetary policy shocks) other than aggregate demand and supply shocks. Moreover, the block-recursive identification assumes that the MP authority does not see financial variables while deciding the MP, but a MP shock can contemporaneously affect financial variables. In the early literature, this was a natural assumption. However, when the MP makers shifted focus to the real economy and price stability, it became unreasonable especially in recent times, as financial markets have become an essential factor affecting MP decisions, particularly for Japan. Therefore, we replace this assumption with the sign restrictions on the MP instrument and financial variables. Specifically, we assume that an expansionary MP shock increases the MO-MPI, bond prices, and stock prices. Our identification assumptions were essentially the same as those of Hesse et al. (2018) and Hara et al. (2020), and similar to one of the identification schemes of Weale and Wieladek (2016). All sign restrictions were imposed upon impact and one month thereafter.

3.2 MSVAR Model

We estimate the benchmark model using three subsamples corresponding to each governor's term to compare the effects of UMP instruments within each term and across the three terms. This is because the purposes and procedures of UMPs could heavily depend on the distinctive governors. However, UMPs have noticeably changed within

[*10] We also checked the optimal lag based on the SIC and AIC. The choice of SIC was one for most cases, while that of AIC was one to five depending on the subsamples. Given these results and sample size, the choice of two also appeared reasonable.

the same term as well. For example, Fukui ceased the zero-interest policy in July 2006, Shirakawa introduced the CME with the asset purchase program in October 2010, and Kuroda added the NIRP and YCC to QQE in 2016. These policy changes could affect the effectiveness of UMP. To examine this possibility and check the robustness of our subsample analysis, we extend the model by accommodating a Markov regime-switching model to analyze changes in the effects of each MPI without restrictions on the timing of changes. In this subsection, we introduce the MSVAR model and its estimation.

MSVAR models have been used to analyze MP regimes by Sims and Zha (2006), Fujiwara (2006), Inoue and Okimoto (2008), and Hara et al. (2020) among others. Similarly, our baseline VAR model (1) is extended as:

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

where s_t is a latent variable that takes a value from $1, 2, \ldots, K$, with K being the number of regimes. Thus, this model allows us to specify different VAR models for different regimes.

Hamilton (1989) introduced the Markov-switching autoregressive model to capture the US business cycle. He proposed modeling the stochastic process of s_t using a Markov chain, which is a simple but flexible 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 $Pr[s_t = i|s_{t-1} = j]$. Without imposing any restrictions on the transition probability, the MS model can capture recursive regimes. However, it is more reasonable to assume that regimes are not recursive to investigate the changes in MP effects, given the evolution of MPs in Japan over the sample period 2003–2019. Therefore, we impose zero restrictions on the elements of matrix $\mathbf{P}$ to capture permanent structural changes. More specifically, we consider the three-regime MSVAR model with absorbing regimes characterized by the following transition probability matrix:

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

In this transition probability matrix, the regime dynamics are assumed to start from

Regime 1. In Regime 1, the regime stays in Regime 1 with probability p_{11} and shifts to Regime 2 with $1 - p_{11}$. Thus, 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 stays in it with the probability p_{22} and shifts to Regime 3 with $1 - p_{22}$. This means that the regime 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, because the zero restrictions on p_{13} and p_{23} prevent a change from Regime 3 to Regime 1 or Regime 2. Therefore, we can consider that this three-regime MSVAR model with transition probability matrix (3) has two permanent structural changes within the sample period.

MSVAR models are estimated mainly by the Bayesian Markov chain Monte Carlo (MCMC) approach, or more specifically a Gibbs sampler,[*11] because it is difficult to estimate many parameters using the popular maximum likelihood estimation method. The MCMC method provides feasible algorithms for sampling based on the posterior distribution computed from the prior distribution and the observed data. This is achieved by constructing a Markov chain with the desired posterior distribution as its stationary distribution. We assume conjugate diffuse priors for the prior distributions of the unknown parameters. Specifically, we use uniform distribution between 0 and 1 for the prior of the transition probability, p_{11} and p_{22}, and Normal-Wishart diffuse priors for the VAR model parameters of each regime. Finally, we assume that each regime has more than 24 months, or two years, of observations to avoid detecting a very short regime and guarantee the estimation precision of the parameters of each regime. The details of the estimation procedure are given in Appendix B.

4 Data

Our empirical analysis is based on monthly data of MO-MPIs, real GDP, the CPI, nominal government bond price index, and nominal stock price index, with the sample period, March 2003–December 2019. MO-MPIs were constructed using PCA, as described in

[*11] For details of the Gibbs sampler to estimate the two-regime MSVAR model, see Krolzig (1997). Please also see Chib (1998) for an extension to the three-regime model.

Heckel and Nishimura (2022), from the 21 series of MOs data. Monthly GDP data were obtained from NLI Research Institute. The CPI values were obtained from the BOJ. This index was seasonally adjusted and excluded the effect of the consumption tax rate increase from 2019. The sovereign bond price index was obtained from the S&P Dow Jones Fixed Income Index.

For the nominal stock price index, we use the TOPIX index, obtained from Monthly Monetary and Financial Statistics, OECD Statistics. This index measures changes in the share prices of all companies listed in the First Section of the Tokyo Stock Exchange (TSE).

The tenure of the three governors was: Toshihiko Fukui (2003/3–2008/3), Masaaki Shirakawa (2008/4–2013/3), and Haruhiko Kuroda (2013/3–2023/4) respectively. Although Governor Kuroda's actual term of office was until April 2023, the analysis period is limited to the end of 2019 to exclude the disruption caused by the novel Covid-19 pandemic.

5 Results

We use four MO-MPIs, representing different monetary policy objectives,[*12] constructed by Heckel and Nishimura (2022), and investigate the responses of four macroeconomic variables (GDP, CPI, government bond prices, and stock prices) to the monetary policy shocks, using IRFs. The estimated IRF results for each governor's term are presented in Section 5.1. However, as mentioned in the previous section, the effect of monetary policy on macroeconomic variables may get substantially altered by permanent structural changes. Therefore, we discuss the possibility of monetary policy changes using the results from the MSVAR model Eq.(2) in Section 5.2.

5.1 Impulse response analysis on subsamples by governor tenure

The entire sample period is divided into three subsamples for each governorship period, and the VAR model Eq.(1) is estimated for each subsample. As there are four MO-

[*12] Here monetary policy objectives are broadly defined, including financial stability objectives that are prerequisites to effective monetary policy.

MPIs, there are also four estimation models, respectively. For each of these, we apply one standard deviation (1SD) shock to a MO-MPI and examine the response of the endogenous variables. As these four MO-MPIs were constructed using PCA, they are mutually orthogonal, and thus each can be interpreted as an independent policy shock. Figure 1 reports the responses for all four MO-MPIs for the whole sample period.

Figure 1 shows, from the left panel to the right panel, the IRFs for Fukui's term, Shirakawa's term, and Kuroda's term. In the panel for each governor, the IRFs of the four MO-MPIs are shown. Broadly defined quantitative easing (MO-MPI1) is the most important monetary policy index and the other three (MO-MPI2, MO-MPI3, and MO-MPI4) are liquidity supply indices to enhance the effectiveness of the monetary policy.

We start with the interpretation of the IRF results for Fukui's term. The monthly GDP (1^{st} row) shows short-lived but positive and significant responses to MO-MPI1, MO-MPI2, and MO-MPI4, and a positive but marginally significant response only appears after 10 months to MO-MPI3. By contrast, the CPI (2^{nd} row) shows insignificant responses to quantitative easing MO-MPI1, whereas there are significant negative responses to three liquidity supply MO-MPIs, indicating that no MO-MPI is an effective counter-deflationary measure. The third row, which displays the response of government bond prices, shows a positive but very short response to MO-MPI1, and even negative for MO-MPI3 and MO-MPI4 before settling at virtually no effect. The IRFs of stock prices illustrated in the fourth row show a significant increase in prices, though the duration of the effects varies across MO-MPIs. Our results suggest some minor positive effects, but overall monetary policy in the Fukui era was not overly effective.

It should be noted that not all MO-MPIs are always meaningful but one or some of MO-MPIs represents the policies that the governor in question has deemed important. According to Heckel and Nishimura (2022), they extract only one PC from the monthly data of Fukui's term, which corresponds to liquidity supply to short-term markets (MO-MPI3) as reported in Table 2.[*13] Therefore, in Figure 1, the third column of Fukui's panel

[*13] When estimated from MPM data, there are two PCs corresponding to MO-MPI1 and MO-MPI3 for the entire period. However, for a monthly-based time unit, the PC corresponding to MO-MPI1 for the entire period disappeared because the monthly amount of purchased JGBs did not change much during Fukui's term.

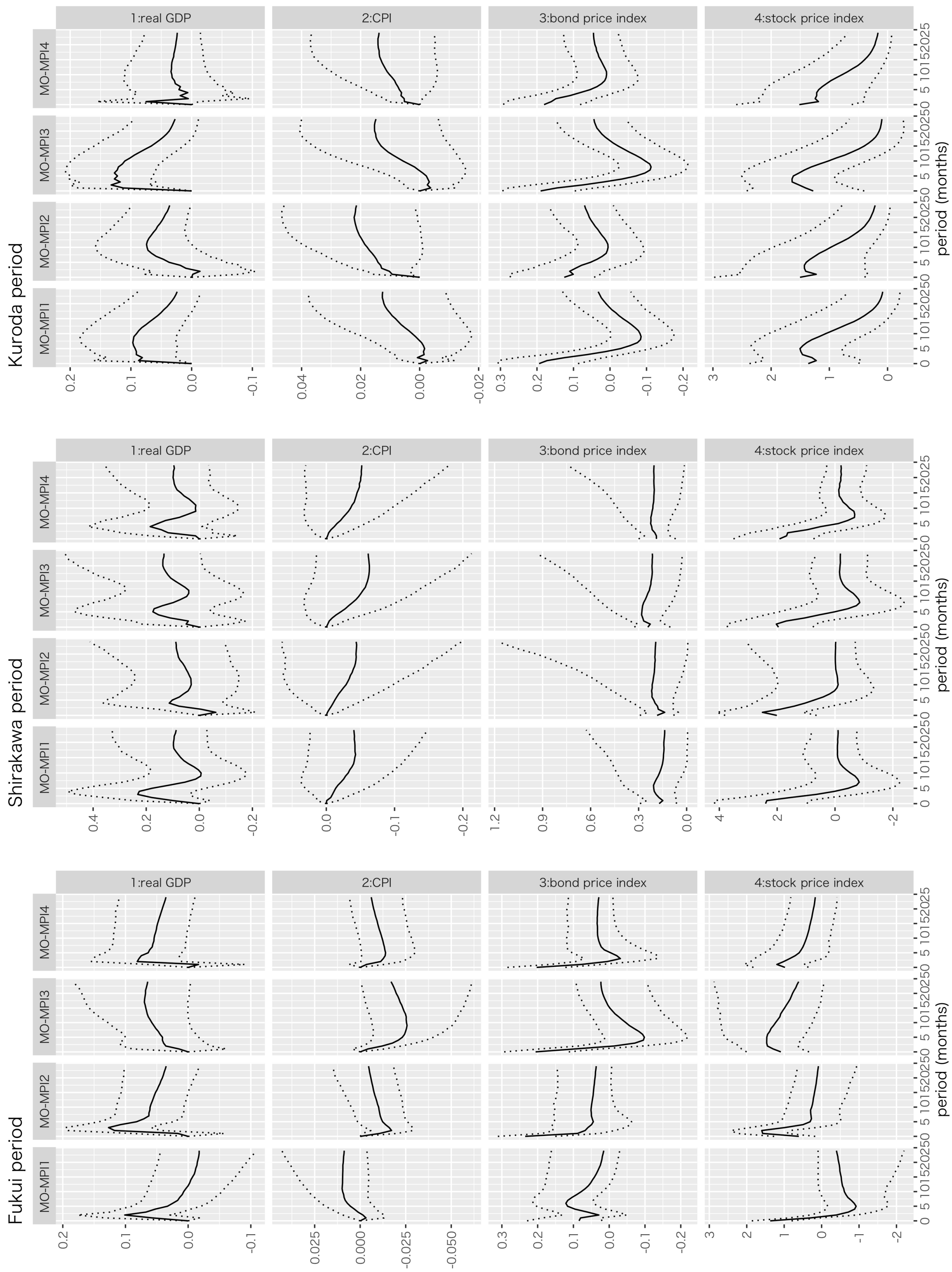

Fig. 1 IRF to 1SD increase of MO-MPIs

Note: The solid lines correspond to the median value; the dotted lines correspond to the upper/lower 16% of the distribution. The horizontal axis represents time in months. From left to right, the figure corresponds to Governor Fukui, Governor Shirakawa, and Governor Kuroda. Additionally, for each governor, the columns are, from left to right, the response of the endogenous variables to 1SD shocks to the first, second, third, and fourth MO-MPIs, respectively.

is more relevant for the evaluation of the monetary policy effect. The figure shows that the expansionary monetary policy of the Fukui era had a long-term and significant increase in stock prices, but only a weak increase in GDP. Still, its impact on government bond prices was temporary and it had a deflationary impact on consumer prices. These results indicate that, during the Fukui era, MO-based monetary policy was not a sufficiently effective anti-deflationary measure.

Next, the IRFs for the Shirakawa period are shown in the center panel of Figure 1. Its shape is quite similar across the MO-MPIs, despite differences in their characteristics. According to Heckel and Nishimura (2022), there are five PCs based on monthly data for the Shirakawa period, and they are related to MO-MPI1, MO-MPI2, and MO-MPI4, except for MO-MPI3. However, their relationship with the relevant MO-MPIs is complex and does not necessarily have a one-to-one correspondence. This complexity may be due to the frequent introduction of new measures during the Shirakawa period. Moreover, the similarity of responses when comparing MO-MPI1, MO-MPI2, and MO-MPI4 made it challenging to interpret the impact of each component in isolation. Overall, while GDP may have responded positively only in the short term, no significant response was observed for CPI, and government bond prices tended to rise constantly, while the impact on stock prices could only be kept in the short term. In sum, the monetary easing policy increased government bond prices only.

Similar to the Fukui period, except for the response of government bond prices, the MO-MPIs in the Shirakawa era had only insignificant and temporary effects on the macroeconomy in general. The result of enhanced complexity and inconclusiveness could be due to consecutive changes in monetary policy and its transmission mechanism when the BOJ faced various global as well as domestic crises during this period. This might also imply that it could take a much longer than the usual term of five years to determine the effectiveness of the monetary policy more precisely countering these problems. We will address this issue in Section 5.2.

Finally, the Kuroda era show the most intriguing results which cannot be easily explained by the assumption that there were no structural changes during this period. Although the importance of MO-MPI1 (which corresponded to 1^{st} PC and 2^{nd} PC in the monthly subsample of the Kuroda era) was noted, a shock to MO-MPIs mainly led to a year-long increase in stock prices and GDP growth, but the impact on the government bond prices was short-lived. Moreover, there was a positive but insignificant impact on CPI. Thus, overall, we observed only a limited effect on the economy and inflation.

Our results seem to diverge from the general monetary policy assessment under Governor Kuroda. While it was consistent with the historical rise in the TOPIX stock index when Abenomics was being implemented, it was debatable that the results showed little contribution to long-term economic expansion. Of course, because long-term economic growth was achieved under the most radical and continuous monetary easing in history, it could be interpreted that the cumulative effect of the marginal easing was significant even if the impact was short-lived. However, the results indicate that prices had not responded to the monetary easing policy, even though Kuroda declared immediately after taking office that he would achieve a 2% price inflation rate in about two years by introducing QQE.

One possible reason for this is that although QQE seemed to have had a sizable impact on inflation initially, the effects disappeared with time. In other words, MO-based monetary policy effects could have changed significantly during Kuroda's term. Therefore, in the next section, we will deepen our analysis by using the MSVAR model Eq.(2) that can accommodate structural changes at any time during the sample period.

5.2 Regime-by-regime policy evaluation based on the MSVAR model

5.2.1 Estimated regimes for each MO-MPI

The MO-MPIs are added to the MSVAR model of Eq.(2) one at a time, so the estimated regime transitions (smoothed probabilities) may be different depending on MO-MPI. Assuming three non-recurrent regimes, we investigate the relationship between the estimated months of change with the governor's tenure. Table 3 organizes the transition months for the second and third regimes. Interestingly, among the four MO-MPIs, the regime turning points for MO-MPI1, MO-MPI3, and MO-MPI4 are nearly identical. The second regime of the four MO-MPIs started within eight months after Governor Shirakawa' s inauguration. There are a couple of possible reasons for this. First, there

	MO-MPI1	MO-MPI2	MO-MPI3	MO-MPI4
Starting year-month of regime 2	2008/06	2008/05	2008/08	2008/11
Starting year-month of regime 3	2016/08	2011/05	2016/08	2016/08

Table 3 Estimated turning points per MO-MPI

Note: Smoothed probabilities are estimated from the three-regime MSVAR model Eq.(2). The point of change is identified if the estimated smoothed probability exceeds 0.5.

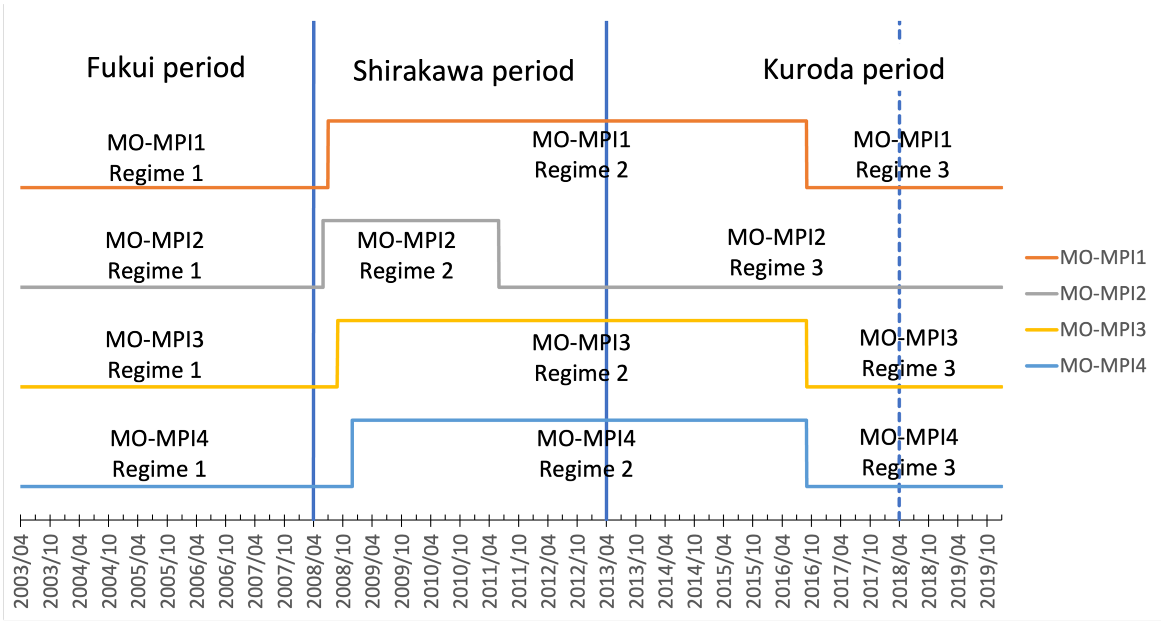

Fig. 2 Regime for each governor term and MO-MPI

Note: The tenure of the governors is Toshihiko Fukui (2003/3–2008/3), Masaaki Shirakawa (2008/4–2013/3), and Haruhiko Kuroda (2013/3–2023/4, with a second term starting from 2018/4), respectively. The three vertical blue lines indicate the timing of the change of governors. The four horizontal colored lines divide the term into three regimes for each MO-MPI.

is the possibility that the change in monetary policy direction by Governor Shirakawa occurred with a lag. Second, it is also possible that the GFC triggered by the bankruptcy of Lehman Brothers in September 2008 had a strong impact because MO-MPI4 is a policy tool to keep current accounts of financial institutions at a high level. The regime's turning point may capture this complex situation.

Further, MO-MPI1, MO-MPI3, and MO-MPI4 share the exact turning point for the third regime, suggesting that the third regime started in August 2016, after the initiation of the NIRP in January 2016 and just before the introduction of the YCC in October 2016. Hence, it is evident that these two policy measures played a pivotal role in triggering a shift in monetary policy regimes. In contrast, MO-MPI2 indicated the regime change in May 2011. As the Great East Japan Earthquake happened in March 2011, and MO-

MPI2 was characterized as supplying liquidity to long-term lenders and investors, this turning point could be considered to capture monetary policy changes in response to the economic crisis in Japan. For example, the BOJ increased the amount of the Asset Purchase Program from 35 to 40 trillion yen. It may capture such changes in monetary policy and its effects, reflecting the economic crisis due to the earthquake in March 2011. Interestingly, Miyao and Okimoto (2020) also identified a regime change around the same time, using a smooth-transition VAR model with data between March 2001 and December 2015. However, our findings, based on more recent data, highlight a major monetary policy regime change in the fall of 2016 when the BOJ implemented two revolutionary policies, namely NIRP and YCC.

5.2.2 Impulse response analysis for each regime

The left panel of Figure 3 shows the IRFs for all MO-MPIs in Regime 1. According to Figure 2, this period roughly overlapped with the Fukui era. However, the end of Regime 1 occurred after the inauguration of Governor Shirakawa, as shown in Table 3. This delay could be attributed to the policy lag, even if the monetary policy had different objectives than before. In any case, this delay generated little difference in IRFs between the first regime (left panel of Figure 3) and the Fukui era (left panel of Figure 1). MO-MPIs affected the GDP significantly and positively, in the short run generally, regardless of the policy measures. On the other hand, the CPI showed insignificant but negative responses to all MO-MPIs, implying that none of MO-MPI was an effective counter-deflationary measure. MO-MPIs appeared to have a very short-lived impact, if any, on government bond prices and stock prices regardless of the policy measures. In sum, our results suggest some minor positive effects, but overall monetary policy in Regime 1 was not very effective, like the Fukui era.

Next, we examine the results for Regime 2 (the central panel in Figure 3). Regime 2 consisted of Shirakawa and early Kuroda eras for all MO-MPIs except for MO-MPI2, for which Regime 2 corresponded to the early Shirakawa era. Except for MO-MPI2, all expansionary monetary policies positively affected GDP, CPI, government bond prices, and stock prices in this period. However, only MO-MPI2, the supply of credit to long-

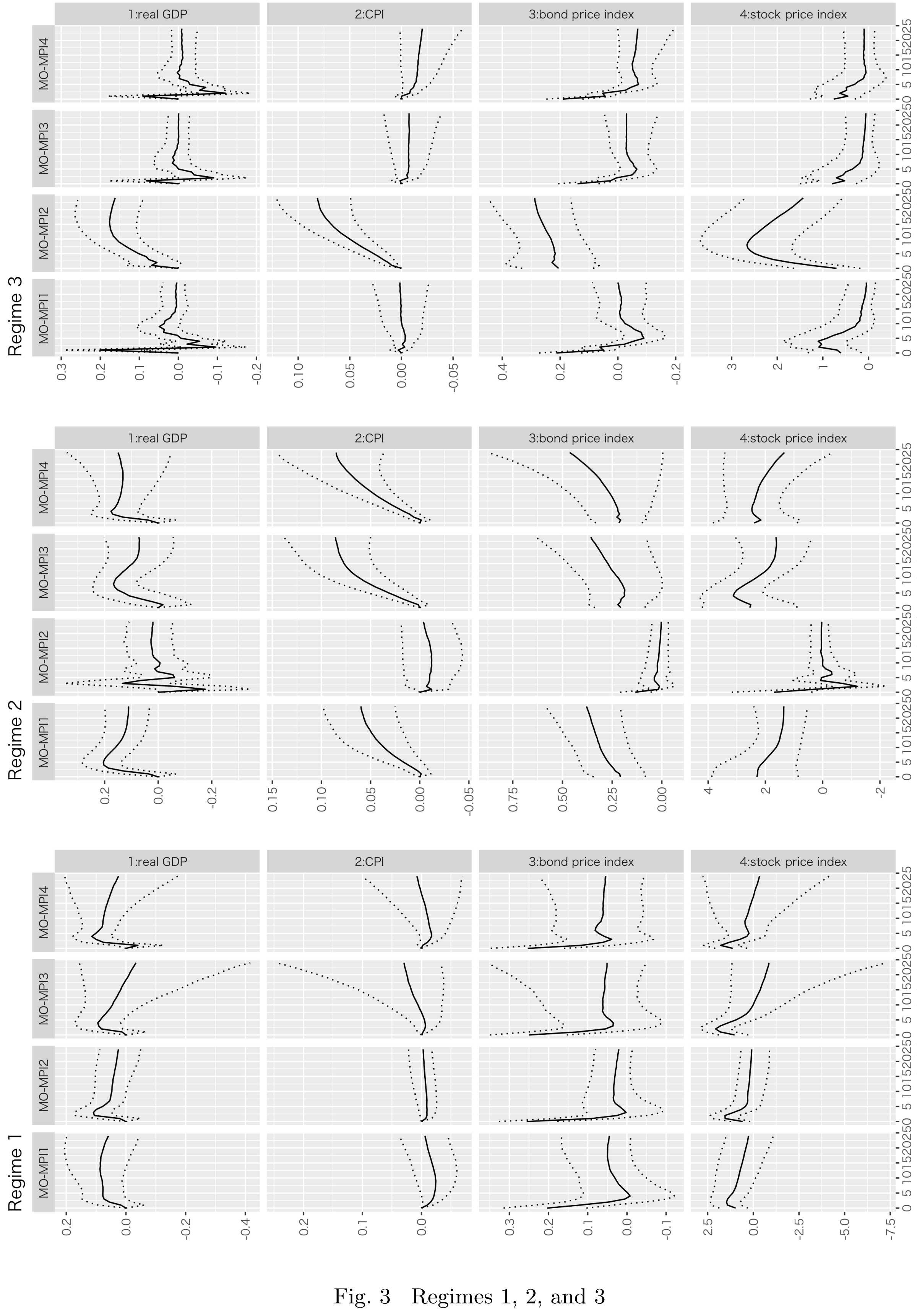

Fig. 3 Regimes 1, 2, and 3

Note: The solid lines correspond to the median value; the dotted lines correspond to the upper/lower 16% of the distribution. The horizontal axis represents time in months. From left to right, the figure corresponds to Regime 1, Regime 2, and Regime 3. Additionally, for each regime, the columns are, from left to right, the response of the endogenous variables to 1SD shocks to the first, second, third, and fourth MO-MPIs, respectively.

term lenders and investors, had no significant effect on all four macro variables. In Regime 2, Governor Shirakawa introduced the CME in October 2010, expanding its balance sheet by purchasing various financial assets such as long-term Japanese government bonds and exchange-traded funds (ETFs). Governor Kuroda took monetary easing one step further by introducing the QQE in April 2013, accelerating the purchase of unconventional assets, particularly long-term Japanese government bonds and ETFs. Our results indicate that the CME and early stage of QQE were effective and provided meaningful macroeconomic support to the Japanese economy. Our results are fairly consistent with Miyao and Okimoto (2020) who found that the CME and early stage of QQE lead to a significant rise in real output and inflation. Our findings are also in line with those by Michaelis and Watzka (2017) who documented that the early stage of QQE had pronounced effects on the real economy, particularly for inflation.

According to Heckel and Nishimura (2022), the Shirakawa era's main policy objectives were MO-MPI1, MO-MPI2, and MO-MPI4. Among them, MO-MPI1 was the most important indicator. Though it was debatable which MO-MPIs should be selected as essential policy instruments, a deeper look at the responses of macroeconomic series to shocks to this indicator showed that all series responded significantly in the expected direction to an expansionary monetary policy shock. This result was very different from the results estimated exclusively from the Shirakawa era subsample.

During the term of Governor Shirakawa, the CME was introduced in October 2010. In addition, the GFC and the Great East Japan Earthquake occurred as foreign and domestic factors, respectively, suggesting that monetary policy management might have been difficult and complicated. Furthermore, Governor Kuroda extended the CME to the QQE by accelerating several measures including the purchase of long-term government bonds and ETFs to achieve 2% inflation target within two years. This can be considered as a drastic change in the monetary policy, but it can be also seen as a continuation of aggressive monetary easing, followed by the CME. Analyzing monetary policy under these circumstances based only on a subsample of each governor term made it difficult to derive correct policy evaluations because it incorrectly formulated that those structural changes might have occurred immediately after Shirakawa retired, although the regime lasted much longer in reality. Using a model that endogenously incorporates the more flexible structural change through the MSVAR, we were able to examine whether the QQE had distinguishably different impacts on the macroeconomy, as it is often believed. Contrary to popular belief, the MSVAR model did not detect the monetary-policy regime shift in 2013 and Regime 2 continued until mid-2016. This implies that the UMP was developed and evolved steadily throughout Fukui's term, and this trend might have been accelerated and become successful throughout Shirakawa's term to early Kuroda's term.

The situation changed drastically in Regime 3. As shown in Figure 3, except for MO-MPI2, the responses of the macro variables had weakened considerably. The results indicate that the effects of monetary easing measures in the latter years of Kuroda's term, including the NIRP and YCC, were ineffective. As seen in the right panel of Figure 3, except MO-MPI2, the responses of the macro variables have weakened considerably. However, according to Heckel and Nishimura (2022), both 1^{st} PC and 2^{nd} PC of the Kuroda era corresponded to MO-MPI1. Unfortunately, the IRFs of MO-MPI1 indicate that its policy effects in boosting the economy were just temporal, and the impact on inflation was almost nonexistent. As for effects on financial markets, although stock prices did rise, their influence seemed limited compared to the early Kuroda period. Whereas Honda and Inoue (2019) presented a more positive assessment of the NIRP in encouraging private residential investment and boosting overall growth, Ito (2021) confirmed our findings that the positive effects were only short-lived. Our findings align with the theory of secular stagnation in that NIRP is inefficient in boosting output (Di Bucchianico (2021)). Similarly, our findings are consistent with those of Harada and Okimoto (2021), who demonstrated that the BOJ's ETF purchases had a much weaker impact on stock prices after the YCC.

6 Conclusion

In normal times MOs are conducted daily to prevent technical, temporary forces from pushing the policy rate too far from the target rate. However, in the past decade, when many central banks hit the effective lower bound of the policy rate, especially during a financial crisis, MOs became an essential part of UMP. Although the effects of large-scale asset purchases and forward guidance have been one focus of UMP, effective liquidity supply to maintain financial stability is another important part of UMP (or in more detail, a prerequisite of successful UMP) which is heavily underrepresented in the economic literature.

This study focused on the effect of UMP carried out by MOs on the macroeconomy in Japan from 2003 to 2019. Four MO-MPIs were constructed and interpreted: an index of broadly defined quantitative easing and three liquidity supply indices targeted to different segments of financial markets. Thus, liquidity supplies constitute another key part of UMP carried out by MOs. We investigated how a shock in each MO-MPI affected macroeconomic variables such as real GDP, inflation, bond prices, and stock prices.

The results indicated differences in the effect of MOs on the macroeconomy, among three periods: (1) before mid-2008, (2) from mid-2008 to mid-2016, and (3) after mid-2016. Contrary to popular belief, a drastic policy change in April 2013 was not a regime changer. MOs were the most effective in the second regime spanning the Shirakawa and early Kuroda periods (mid-2008 – mid-2016), showing very strong effects of all MO-MPIs on all macroeconomic variables. The aggressive UMP carried out by MOs was shown to be very effective. By contrast, MOs became substantially less effective in the third regime (after mid-2016), when the policy of YCC was adopted.

Although our approach based on the PCA of MOs is simple and intuitive, there are some issues to be addressed through further research. Two issues that deserve immediate attention are: First, the relationship between our MO-MPIs, in which various liquidity supplies play an important role, and more conventional monetary policy indicators, such as an SSR taking account of the effective lower bound and balance sheet variables such as monetary base and bond holdings, is not clear. One may argue that SSRs and balance-sheet variables are the gauges of quantitative easing while liquidity supplies relate to financial stability policy. However, they are interlinked in the real economy under UMP.

Second, we obtained a striking result of the substantially reduced effectiveness of MO-MPIs after the introduction of the YCC. This was the case even for broadly defined quantitative easing. It had negligible effects on real GDP and CPI, revealing a sharp contrast with very significant positive effects on real GDP and CPI between mid-2008 and the fall of 2016. This has nothing to do with liquidity supply effects.

We believe that the introduction of the NIRP in January 2016 fundamentally changed the behavior of commercial banks as financial intermediaries by substantially lowering lending rates and their financial viability. In that case, our finding of substantially weakened impacts on the real economic effect of broadly defined MPs has a profoundly negative implication for monetary policy in the future.

References

Bauer, M. D. and Rudebusch, G. D. (2016). Monetary policy expectations at the zero lower bound. *Journal of Money, Credit and Banking*, 48(7):1439–1465.

Boyarchenko, N., Haddad, V., and Plosser, M. C. (2017). The Federal Reserve and market confidence. Staff Report No. 773, Federal Reserve Bank of New York.

Bu, C., Rogers, J., and Wu, W. (2021). A unified measure of Fed monetary policy shocks. *Journal of Monetary Economics*, 118:331–349.

Chib, S. (1996). Calculating posterior distributions and model estimates in Markov mixture models. *Journal of Econometrics*, 75(1):79–97.

Chib, S. (1998). Estimation and comparison of multiple change-point models. *Journal of Econometrics*, 86(2):221–241.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. (1999). Monetary policy shocks: What have we learned and to what end? In Taylor, J. B. and Woodford, M., editors, *Handbook of Macroeconomics*, pages 65–148. Elsevier Science.

De Michelis, A. and Iacoviello, M. (2016). Raising an inflation target: The japanese experience with abenomics. *European Economic Review*, 88:67–87.

Di Bucchianico, S. (2021). Negative interest rate policy to fight secular stagnation: Unfeasible, ineffective, irrelevant, or inadequate? *Review of Political Economy*, 33(4):687–710.

Fujiwara, I. (2006). Evaluating monetary policy when nominal interest rates are almost zero. *Journal of the Japanese and International Economies*, 20(3):433–453.

Fukuda, S.-i. (2015). Abenomics: Why was it so successful in changing market expectations? *Journal of the Japanese and International Economies*, 37:1–20.

Gabaix, X. and Koijen, R. S. J. (2022). In search of the origins of financial fluctuations: The inelastic markets hypothesis. Swiss Finance Institute Research Paper No. 20-91.

Gambacorta, L., Hofmann, B., and Peersman, G. (2014). The effectiveness of unconventional monetary policy at the zero lower bound: A cross-country analysis. *Journal of Money, Credit and Banking*, 46(4):615–642.

Hamilton, J. D. (1989). A new approach to the economic analysis of nonstationary time series and the business cycle. *Econometrica*, 57(2):357–384.

Hanisch, M. (2017). The effectiveness of conventional and unconventional monetary policy: Evidence from a structural dynamic factor model for japan. *Journal of International Money and Finance*, 70:110–134.

Hara, N., Miyao, R., and Okimoto, T. (2020). The effects of asset purchases and normalization of US monetary policy. *Economic Inquiry*, 58(3):1279–1296.

Harada, K. and Okimoto, T. (2021). The boj's etf purchases and its effects on nikkei 225 stocks. *International Review of Financial Analysis*, 77:101826.

Hausman, J. K. and Wieland, J. F. (2015). Overcoming the lost decades?: Abenomics after three years. *Brookings Papers on Economic Activity*, 2015(2):385–431.

Hayashi, F. and Koeda, J. (2019). Exiting from quantitative easing. *Quantitative Economics*, 10:1069–1107.

Heckel, M. and Nishimura, K. G. (2020). Unconventional monetary policy through open market operations: A principal component analysis. CARF Working Paper CARF-F-501.

Heckel, M. and Nishimura, K. G. (2022). Unconventional monetary policy through open market operations: A principal component analysis. *Asian Economic Papers*, 21(1):1–28.

Hesse, H., Hofmann, B., and Weber, J. M. (2018). The macroeconomic effects of asset purchases revisited. *Journal of Macroeconomics*, 58:115–138.

Honda, Y. and Inoue, H. (2019). The effectiveness of the negative interest rate policy in japan: An early assessment. *Journal of the Japanese and International Economies*, 52:142–153.

Inoue, T. and Okimoto, T. (2008). Were there structural breaks in the effect of Japanese monetary policy? Re-evaluating the policy effects in the lost decade. *Journal of the Japanese and International Economies*, 22(3):320–342.

Ito, T. (2021). An assessment of abenomics: Evolution and achievements. *Asian Economic Policy Review*, 16(2):190–219.

Kim, D. H. and Singleton, K. J. (2012). Term structure models and the zero bound: An empirical investigation of Japanese yields. *Journal of Econometrics*, 170(1):32–49.

Kimura, T. and Nakajima, J. (2016). Identifying conventional and unconventional monetary policy shocks: a latent threshold approach. *B.E. Journal of Macroeconomics*, 16(1):277–300.

Krippner, L. (2013). Measuring the stance of monetary policy in zero lower bound environments. *Economics Letters*, 118(1):135–138.

Krippner, L. (2020). A note of caution on shadow rate estimates. *Journal of Money, Credit and Banking*, 52(4):951–962.

Krolzig, H.-M. (1997). *Markov-Switching Vector Autoregressions: Modelling, Statistical Inference, and Application to Business Cycle Analysis*. Springer.

Kuttner, K. N. (2018). Outside the box: Unconventional monetary policy in the great recession and beyond. *Journal of Economic Perspectives*, 32(4):121–146.

Michaelis, H. and Watzka, S. (2017). Are there differences in the effectiveness of quantitative easing at the zero-lower-bound in japan over time? *Journal of International Money and Finance*, 70:204–233.

Miyao, R. and Okimoto, T. (2020). Regime shifts in the effects of Japan's unconventional monetary policies. *Manchester School*, 88:749–770.

Mouabbi, S. and Sahuc, J.-G. (2019). Evaluating the macroeconomic effects of the ecb's unconventional monetary policies. *Journal of Money, Credit and Banking*, 51(4):831–858.

Pattipeilohy, C., van den End, J. W., Tabbae, M., Frost, J., and de Haan, J. (2013). Unconventional monetary policy of the ECB during the financial crisis: An assessment and new evidence. DNB Working Papers 381.

Sims, C. A. and Zha, T. (2006). Were there regime switches in U.S. monetary policy? *American Economic Review*, 96(1):54–81.

Sudo, N. and Tanaka, M. (2021). Quantifying stock and flow effects of qe. *Journal of Money, Credit and Banking*, 53(7):1719–1755.

Swanson, E. T. (2021). Measuring the effects of Federal Reserve forward guidance and asset purchases on financial markets. *Journal of Monetary Economics*, 118:32–53.

Weale, M. and Wieladek, T. (2016). What are the macroeconomic effects of asset purchases? *Journal of Monetary Economics*, 79:81–93.

Wu, J. C. and Xia, F. D. (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit and Banking*, 48(2-3):253–291.

Appendix

A Monetary policy index - Original series

MO reported in https://www.boj.or.jp/en/statistics/boj/fm/ope/index.htm/ show 71 variables overall for the period 2002–2019. These variables are narrowed down to 21 by eliminating duplicate variables and combining similar operations into one category across different analytical steps of variable reduction. See Heckel and Nishimura (2020) for details. By using the 21 series of market operations in Table 1, Heckel and Nishimura (2022) constructed the MO-MPIs by PCA. In the following, we denote Heckel-Nishimura's PC1, PC2, PC3, and PC4 as MO-MPI1, MO-MPI2, MO-MPI3, and MO-MPI4, respectively. All variables are net figures, that is, fund supply minus fund absorption.[*14]

Heckel and Nishimura (2022) used the offer date (instead of the exercise date) and the amounts offered as data points. For cases such as ETF purchases, where amounts offered were unavailable, the amounts of the successful bid were used instead. In their baseline case, they aggregated all offers of each variable for each period between regularly scheduled monetary policy meetings. They considered the period (interval) between regularly scheduled monetary policy meetings as the basic time unit for the baseline case because policies announced in the monetary policy meeting (MPM) introduce, continue, or abolish both conventional and unconventional policies through MO. In this paper, however, we considered the month as the basic time unit because we examined monthly macroeconomic data. The number of observations did not change much. Compared to the 232 MPMs between 2002 and 2019, we observed 214 cases for the monthly data. Details are available in Heckel and Nishimura (2020).

Table A.1 reports the descriptive statistics of the 21 series. The sample period (2002/3/1 to 2019/12/31) is turbulent, comprising various crises: accordingly, old measures were terminated and new ones introduced making market operations complex and changing. This is reflected in Table A.1. First, only a small fraction of the 21 series of MO was offered at any time. Thus, there are many series of which the minimum

[*14] Finally, despite differences in methods of organizing market operations and time units, the results of our analysis are robust.

	mnemonic	Mean	SD	Min	Max
1	CB_op	686.45	682.39	0.00	2,500.00
2	CP_repo	7,345.79	11,242.61	0.00	49,000.00
3	ETF	1,271.24	1,995.23	0.00	8,436.00
4	ETF2	51.36	99.96	0.00	276.00
5	FSO-Disaster	167.48	342.71	0.00	1,293.00
6	FSO-Kumamoto	28.94	147.24	0.00	1,763.00
7	JGB-0-1_op	2,021.03	2,413.61	0.00	6,200.00
8	JGB-1-10_op	26,852.80	29,054.89	0.00	90,000.00
9	JGB-10-30_op	5,214.25	6,886.78	0.00	22,000.00
10	JGB-float_op	366.36	557.31	0.00	1,400.00
11	JGB-I_op	164.02	214.64	0.00	600.00
12	JGB_op	4,955.61	5,788.86	0.00	15,000.00
13	JGS-C-USDFSOPC	303.74	1,291.46	0.00	10,000.00
14	J-REIT	26.07	39.62	0.00	165.00
15	SFSOFCF	1,755.02	6,832.48	0.00	40,383.00
16	Bills_op-FSOPC	100,079.44	124,549.13	-344,000.00	1,020,000.00
17	T-Bills_repo	-56.07	820.30	-12,000.00	0.00
18	T-Bills_op2	33,016.36	28,079.00	0.00	140,000.00
19	USD-FSOPC2	2,059.69	9,854.28	0.00	76,990.00
20	CP_op2	5,764.02	5,297.64	0.00	16,500.00
21	JGB-JGS_repo	56,364.49	155,059.33	-17,000.00	906,000.00

Table A.1 Descriptive statistics for 21 series (in 100 million yen)

Note: The number of sample months is 214.

is zero. By contrast, the two most prominent operations were Bills_op-FSOPC and T-Bills_op2. CP_op2 was also a relatively traded asset, although it was not traded in some periods. Second, the timing of the offer was also skewed for other operations. For example, CP_repo, JGB_op, and JGB-JGS_rep were actively offered in the first half of the sample period (during the Fukui period to Shirakawa period), while ETFs, FSO-Disaster, JGB-0-1_op, JGB-10-30_op, JGB-1-10_op, JGB-float_op, JGB-I_op, JGB-REIT were offered more in the second half (Shirakawa period and Kuroda period). Third, some operations were offered intensively only at certain times of the year. Examples include FSO-Kumamoto, JGS-C-USDFSOPC, SFSOFCF, and USD-FSOPC2. They were short-term and temporary.

B Estimation of two-regime MSVAR model with an absorbing regime

In this appendix, 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), Chib (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 $\boldsymbol{\theta}_1' = [s_{25}, s_{26}, \ldots, s_{T-24}]'$, $\boldsymbol{\theta}_2' = p_{11}$,[*15] $\boldsymbol{\theta}_3' = [\mathrm{vech}(\boldsymbol{\Sigma}(1))', \mathrm{vech}(\boldsymbol{\Sigma}(2))']'$, and $\boldsymbol{\theta}_4' = [\boldsymbol{\beta}(1)', \boldsymbol{\beta}(2)']'$, where $\boldsymbol{\beta}(j)$ is a column vector of the form $\boldsymbol{\beta}(j) = [\boldsymbol{\alpha}, \mathrm{vec}(\boldsymbol{A}_1(j))', \mathrm{vec}(\boldsymbol{A}_L(j))']'$. Further, let $\tilde{\boldsymbol{Y}}_t = \{\boldsymbol{Y}_{-L+1}, \boldsymbol{Y}_{-L+2}, \ldots, \boldsymbol{Y}_t\}$ and $p(\boldsymbol{\theta}|\tilde{\boldsymbol{Y}}_T)$ be the desired posterior distribution. Then the Gibbs sampler allows us to generate random samples from $p(\boldsymbol{\theta}|\tilde{\boldsymbol{Y}}_T)$ as follows:

1. Set initial values $\boldsymbol{\theta}^{(0)}$ and set $j = 0$.
2. Draw $\boldsymbol{\theta}_1^{(j+1)}$ from $p(\boldsymbol{\theta}_1|\boldsymbol{\theta}_2^{(j)}, \boldsymbol{\theta}_3^{(j)}, \boldsymbol{\theta}_4^{(j)}\tilde{\boldsymbol{Y}}_T)$
3. Draw $\boldsymbol{\theta}_2^{(j+1)}$ from $p(\boldsymbol{\theta}_2|\boldsymbol{\theta}_1^{(j+1)}, \boldsymbol{\theta}_3^{(j)}, \boldsymbol{\theta}_4^{(j)}\tilde{\boldsymbol{Y}}_T)$
4. Draw $\boldsymbol{\theta}_3^{(j+1)}$ from $p(\boldsymbol{\theta}_3|\boldsymbol{\theta}_1^{(j+1)}, \boldsymbol{\theta}_2^{(j+1)}, \boldsymbol{\theta}_4^{(j)}\tilde{\boldsymbol{Y}}_T)$
5. Lastly draw $\boldsymbol{\theta}_4^{(j+1)}$ from $p(\theta_4|\boldsymbol{\theta}_1^{(j+1)}, \boldsymbol{\theta}_2^{(j+1)}, \boldsymbol{\theta}_3^{(j+1)}\tilde{\boldsymbol{Y}}_T)$
6. Set $\boldsymbol{\theta}^{(j+1)} = [(\boldsymbol{\theta}_1^{(j+1)})', (\boldsymbol{\theta}_2^{(j+1)})', (\boldsymbol{\theta}_3^{(j+1)})', (\boldsymbol{\theta}_4^{(j+1)})']'$.
7. If $j + 1 = N$, then stop the algorithm. Otherwise, repeat it from Step 2.

Here N is the number of iterations, and we discard the first N_0 samples. Thus, $\{\boldsymbol{\theta}^{(j)}\}_{j=N_0+1}^{N}$ are the samples that can be considered to follow $p(\boldsymbol{\theta}|\tilde{\boldsymbol{Y}}_T)$ approximately. We set $N = 30,000$ and $N_0 = 20,000$. We assume diffuse conjugate priors for the prior distributions of unknown parameters. 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.

[*15] We assume that each regime has more than 24 months or two years of observations to avoid detecting a very short regime and to guarantee the estimation precision of each regime's parameters. Therefore, $s_1 = s_2 = \cdots = s_{24} = 1$ and $s_{T-23} = s_{T-22} = \cdots = s_T = 2$ for the two-regime model. $\{s_t\}_{t=25}^{T-24}$ are the latent variables, and not the parameters. However, they are usually treated as unknown parameters in the Bayesian framework because they are estimated from the data.