A Regime Switch in the Effects of Japan's Unconventional Monetary Policies*

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Abstract

Japan is the country with the longest history of implementing unconventional monetary policies, which were first introduced more than fifteen years ago and have since been expanded several times. This study attempts to assess the overall macroeconomic effects of Japan's unconventional monetary policies based on a stylized block-recursive vector autoregression with a smooth-transition. The results suggest that expansionary unconventional monetary policy shocks have clear macroeconomic effects, leading to a persistent rise in real output and inflation. In addition, we show that these macroeconomic effects became more persistent in recent years including the recent quantitative and qualitative monetary easing period.

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1. INTRODUCTION

The use of unconventional monetary policies – that is, policies by central banks to pursue further monetary easing by using unconventional instruments such as large-scale asset purchases once conventional policy rates had been lowered to virtually zero percent – has become common practice among major central banks since the outbreak of the global financial crisis triggered by the collapse of Lehman Brothers in 2008. These unconventional measures continued even after the acute phase of the financial crisis had largely passed. In Japan, the use of unconventional monetary policies dates back even further – more than fifteen years – to the severe banking crisis in Japan during the late 1990s/early 2000s.

Even though unconventional policies have been widely employed, whether they have in fact significant effects on economic activity or inflation remains a matter of debate. Critics tend to argue that such policies have meaningful effects only when financial markets are under severe stress. Put differently, the effects or "returns" of these measures, they contend, diminish as the economy and financial markets return to more or less normal conditions.[3] As we will see below, in the extant literature, a number of studies have sought to quantify the financial market effects of unconventional policies such as the effects on long-term bond yields or other asset prices. However, evidence on the overall macroeconomic effects is relatively limited and more comprehensive analyses are necessary.

Against this background, the aim of the present study is to measure the possible macroeconomic effects of unconventional monetary policies in Japan, focusing in particular on the aggressive monetary easing initiatives introduced in recent years. After a number of years of unconventional policies such as the first quantitative easing policy introduced in 2001 and subsequent rounds of asset purchases as part of its "comprehensive monetary easing" policies in 2010-2013, the Bank of Japan (BOJ) in April 2013 took monetary easing one step further by introducing quantitative and qualitative monetary easing (QQE). QQE aimed at expanding the monetary base and government bonds purchases more aggressively (i.e., doubling the monetary base and government bond purchases in two years). More precisely, the BOJ started to expand the monetary base at an annual pace of 60-70 trillion yen and government bonds purchases at an annual pace of 50 trillion yen. The average remaining maturity of government bond purchases was also extended to 7 years. Prior to the introduction of QQE, the BOJ in January 2013 had set a 2% price stability target, and it subsequently stated that it would continue with the program as long as necessary to achieve the 2% inflation target. The QQE program was further expanded in October 2014, raising the annual pace of increases in the monetary base and government bond purchases to 80 trillion yen and extending the average remaining maturity of government bond purchases to 7-10 years.[4] Note that Japan's non-performing loans problem was already resolved well before these recent developments, and the severe phase of the global financial crisis --- and the Eurozone crisis in particular --- was also largely over by 2013. This means that economic and financial conditions in Japan were relatively normal when these additional expansionary measures were introduced, providing a good backdrop to examine the impact of unconventional policy measures on the real economy and inflation.

To examine the dynamic effects of unconventional policy measures in Japan, this study employs a stylized-block recursive vector autoregression (VAR) model developed by Christiano,

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[3] See e.g. Goodhart and Ashworth (2012), Roubini (2013), and Blanchard (2016) for these criticisms. On this issue, Friedman (2014) provides a positive judgement arguing that use of large-scale asset purchases is not merely a temporary, emergency measure, but is likely to persist as part of the standard toolkit of monetary policy in normal times.

[4] Since February 2016, the QQE program also includes a negative interest rate on part of banks' excess reserves with the BOJ.

Eichenbaum, and Evans (1999). The model includes key macroeconomic variables such as real output, inflation, the monetary base, and indicators of financial conditions such as long-term interest rates and asset prices. It is argued that, in the proposed framework, an exogenous increase in the monetary base in the period after the first quantitative easing policy was introduced in March 2001 can be effectively identified as an expansionary unconventional monetary policy shock. To highlight the effects of the recent QQE regime, two observation periods are examined: a subperiod that ends before the introduction of QQE in April 2013 and the full observation period including the QQE period after April 2013. The full observation period covers the period from March 2001 to December 2015.

In addition, to see the difference in the effects of quantitative easing policy between an aggressive easing regime such as QQE and a non-aggressive easing regime more formally, we also estimate a smooth-transition vector autoregressive (STVAR) model. By doing so, we can examine the possible regime changes in the effects of quantitative easing monetary policy as the changes in the aggressiveness of monetary easing.

The main findings of the benchmark analysis can be summarized as follows. An exogenous shock to the monetary base has clear macroeconomic effects, leading to a persistent rise in real output and inflation. These macroeconomic effects become more pronounced after the introduction of the QQE regime. In terms of transmission channels, the traditional interest rate and asset price channels (the latter via stock prices and exchanges rates) both appear to operate as expected and have contributed to the macroeconomic effects. The results of the STVAR analysis generally support these benchmark findings. The empirical evidence broadly indicates that unconventional monetary policies have indeed been effective in stimulating the real economy and inflation in Japan over the last fifteen years.

The rest of this study is organized as follows. The next section provides an overview of unconventional monetary policies in Japan. Next, Section 3 outlines the existing literature on the macroeconomic effects of unconventional policy measures and presents the econometric framework employed in this study. Section 4 then provides the main empirical results, additional results using alternative specifications, and a discussion of possible interpretations. Section 5 concludes.

2. UNCONVENTIONAL MONETARY POLICIES IN JAPAN

This section offers a brief overview of the use of unconventional monetary policies in Japan. Unconventional monetary policies can be broadly defined as central bank measures employing unconventional policy instruments and pursuing further monetary accommodation once the policy rates (such as the overnight money market rates) had been lowered to virtually zero percent.[5] The Bank of Japan has pioneered and enhanced unconventional measures for more than fifteen years since it introduced the zero interest rate policy (ZIRP) in 1999.

In general terms, unconventional policy instruments by major central banks can be classified into the following three categories:

(i) "Forward guidance," which consists of promising to continue with virtually zero (or very low) interest rates into the future.

(ii) "Quantitative easing" or "balance sheet policies," consisting of purchases of government bonds and other unconventional assets with longer maturities.

(iii) What may be called "forward guidance with regard to asset purchases," that is,

[5] There is a large theoretical literature on monetary policy at the zero lower bound: See e.g. Krugman (1998) and Eggertsson and Woodford (2003) among others.

promises to continue asset purchases under quantitative easing into the future, typically in an open-ended manner with a clear link to the policy goal.

In fact, unconventional monetary policy in Japan gradually expanded from (i) to (ii) to (iii) with the implementation of the ZIRP from 1999 to 2001, quantitative easing from 2001 to 2006, comprehensive monetary easing from 2010 to 2013, and QQE since 2013.[6]

The anticipated transmission channels of these unconventional measures in more or less normal times (rather than during an acute crisis) are similar to those of conventional policy, at least qualitatively. That is, the aim is to strengthen downward pressure on long-term interest rates or the entire yield curve by expanding purchases of long-term government bonds and other securities and promising to continue with a virtually zero policy rate and/or asset purchases for a prolonged period of time. The decline in interest rates leads to an improvement in credit conditions and availability, higher asset prices, a weakening of the currency, and higher inflation expectations, all of which ease overall financial conditions. This in turn helps to stimulate spending by firms and households, and boosts real output and inflation accordingly. Of course, the extent to which spending responds to more accommodative financial conditions may differ depending on the economy's fundamentals, such as growth expectations and the underlying productivity or profitability of the corporate sector. Nonetheless, the channels described above are qualitatively equivalent to those of conventional monetary policy. The only difference is that unconventional policies directly exert downward pressure on long-term interest rates, while conventional policy does so only indirectly by controlling the short-term policy rate.

However, it should be also stressed that forward guidance operates through a transmission channel that is truly novel in that it seeks to affect expectations. It does so by clearly spelling out conditions that need to be met before any tightening would be considered. For instance, in implementing the ZIRP, the Bank of Japan announced that it would continue with the zero interest rate until consumer prices inflation rose above zero percent in a stable manner. Similarly, the Federal Reserve in late 2012 introduced an open-ended commitment to continue with its third round of large-scale asset purchases (LSAP3) until labor market conditions had sufficiently improved. Under its current QQE policy, the BOJ makes it clear that it will continue with the program as long as necessary to achieve the 2% price stability target in a stable manner. And the European Central Bank started purchases of government bonds (sometimes called "sovereign quantitative easing") in early 2015, stating that it would continue with the program until it sees a sustained adjustment in the path of inflation towards its 2% inflation goal. What these measures have in common is that they aim to shape market expectations with regard to current and future financial conditions through a commitment to monetary easing until clearly stated conditions have been met.

Given weak global economic growth and inflation, central banks and their unconventional policies have come to occupy center stage in the debate on how to steer the economy in major countries around the world. At the same time, the effectiveness of such policies and the transmission channels through which they operate is coming under increasing scrutiny. Because Japan's experience with unconventional policies goes back a decade and a half, it provides an ideal case study to examine the macroeconomic effects in a comprehensive manner.

3. ECONOMETRIC ANALYSIS

[6] A fourth category of a negative interest rate should be also added here. Some European central banks started to impose a negative interest rate on excess reserves in 2014 and 2015. The BOJ joined this camp in February 2016.

3.1 Previous literature

Most studies to date examining the impact of unconventional policy measures have focused on the effects of large-scale asset purchases on financial markets, typically by looking at the risk or term premium component of bond yields and other prices (see, e.g., Gagnon et al. (2011) and Hamilton and Wu (2011) for the United States; Kimura and Small (2006) and Ueda (2012) for Japan; and Rogers, Scotti, and Wright (2014) for several major economies). However, there are also a small number of studies assessing the overall macroeconomic effects, such as the study by Chen, Curda, and Ferrero (2014) employing a fully-specified dynamic stochastic general equilibrium framework as well as those by Chung et al. (2012) and Engen, Laubach, and Reifschneider (2015) using traditional large-scale econometric models. An important shortcoming of these approaches, though, is that they have to rely on economic models estimated for periods that include conventional monetary policy.

An alternative approach to evaluate the macroeconomic effects is to employ time-series models based on a more parsimonious system. The time-series approach makes it possible to examine dynamic interactions among the main macroeconomic variables using fewer identifying assumptions. It also makes it possible to take regime shifts or time-varying parameters as a result of unconventional policies into account. Studies employing this approach include those by Baumeister and Benati (2013) on the United States and Britain, and Kimura and Nakajima (2016), Hayashi and Koeda (2013), and Michaelis and Watzka (2017) on Japan.

When data covering a relatively large sample of countries or a relatively long observation period is available, it is possible to employ time-series analysis exclusively for the period in which the central bank balance sheet is the primary policy instrument. Studies employing such an approach include those by Gambacorta, Hofmann, and Peersman (2014), who investigate the acute phase of the global financial crisis in eight advanced economies, and Honda, Kuroki, and Tachibana (2007) and Shibamoto and Tachibana (2013), who focus on the six-year period of the first quantitative easing policy in Japan.

Turning to the QQE program, a small number of studies on the effects are available. These include the studies by Ueda (2013) and Fukuda (2015) exploring the impact on financial markets and the studies by Hausman and Wieland (2014) and Michelis and Iacoviello (2016) providing a preliminary analysis of the package of policy measures generally referred to as "Abenomics," of which aggressive monetary easing forms a part. Yet, to the best of the author's knowledge, there are few studies providing a comprehensive examination of the overall macroeconomic effects of QQE.[7]

The present study falls into the strand of studies employing the time-series approach and attempts to quantify the effectiveness of unconventional monetary policies in Japan. As elaborated below, the analysis regards the BOJ's balance sheet (or, equivalently, the monetary base) as effectively the main policy instrument throughout the period since the introduction of quantitative easing in early 2001. The analysis then examines the effects of QQE by

[7] A recent study by Michaelis and Watzka (2017) examines the changing effectiveness of Japan's quantitative easing for 1996-2015 using a time-varying parameters VAR framework. For identification, they use a set of sign restrictions proposed by Schenkelberg and Watzka (2013). The results indicate positive responses of consumer prices and output at the third quarter of 2014 in the QQE period, although the output responses are estimated insignificantly. Another recent article by Hanisch (2017) uses a structural dynamic factor model with a set of sign restrictions for 1985-2014. In the analysis for 2001-2014, a monetary policy shock has a weak positive effect on output and a strong effect on prices with allowing no shift in the economic structure. The present study makes an important contribution to the literature by explicitly examining a regime shift and provides clear macroeconomic effects, leading to a persistent rise in real output and inflation in the aggressive easing period including the QQE policy.

comparing the period from 2001 up to the introduction of QQE in early 2013 and the period from 2001 up to the end of 2015, which includes the QQE period. In addition, the analysis more formally investigates the difference in the effects of quantitative easing policy between an aggressive easing regime such as QQE and a non-aggressive easing regime, based on a STVAR model.

3.2 Benchmark Econometric framework

To examine the effects of unconventional monetary policies in Japan, a simple VAR framework is employed as a benchmark model. Following the stylized approach in the literature, the block-recursive identification framework developed by Christiano, Eichenbaum, and Evans (1999) is used. In this approach, a policy instrument variable is placed between the real economy and the financial sector and shocks to the monetary base are regarded as an indicator of exogenous monetary policy. The base model employed for the analysis here consists of the following five key macroeconomic variables: real output (real GDP, denoted by *y*), inflation (consumer prices inflation, denoted by π), the monetary base (*MB*), long-term government bond yields (R_B), and stock prices (P_K). The stylized structural VAR model is then given by $B(L)X_t = \varepsilon_t$, where $X_t = (y_t, \pi_t, MB_t, R_{Bt}, P_{kt})$, $B(L) = B_0 - B_1 L - \cdots - B_p L^p$ is the pth-order lag polynomial of a five-by-five matrix of coefficients, and ε_t is a five-by-one vector of serially uncorrelated, orthogonalized structural disturbances. A corresponding reduced-form VAR model is estimated to recover the structural model using a block-recursive identification procedure. In addition, to examine to what extent the exchange rate acts as a transmission mechanism of unconventional monetary policy, we also estimate the model using the nominal effective exchange rate (*FX*) instead of stock prices. Figure 1 exhibits the time series data of those variables used in the main analysis. Detailed definitions and sources for the series used in the analysis are provided in the Data Appendix. All variables are expressed in logarithm except for the inflation and interest rate variables. Monthly observations are used for the entire observation period from March 2001 to December 2015. Based on information criteria, the lag length in the reduced-form estimation is set to three.[8]

The setup just described is employed to examine disturbances to the monetary base, which are regarded as exogenous unconventional monetary policy shocks in Japan over the past fifteen years. The BOJ has pursued unconventional balance sheet policies more or less continuously since March 2001, that is, since quantitative easing policies were first introduced. The operating instrument used during the initial program of quantitative easing was current account balances held at the BOJ, which effectively corresponds to the monetary base.[9] There was also a brief period from June 2006 to the end of 2008 when the policy rate, the overnight call rate, was raised above zero percent, although one could argue that the policy rate still remained in the range of virtually zero percent. During that period, the call rate was raised to the range of 0.25-0.5 percent. In the analysis, a dummy variable for this period is included in order to account for possible effects due to the shift in the operating target. Since the onset of the global financial crisis, the BOJ has introduced a number of new measures involving funds-supplying operations and unconventional asset purchases, most notably the Asset Purchase Program as part of the comprehensive monetary easing scheme in

[8] The Schwarz information criterion suggests that the lag length should be set to two, with a lag length of three yielding the second smallest criterion value. Akaike's information criterion indicates that the lag length should be set to three. In addition, employing the conventional maximum likelihood procedure, the null hypothesis of two lags is rejected against the alternative of three lags. Judging from these results, the lag length is set to three.

[9] The monetary base is the sum of current account balances and currency in circulation. Historically, currency in circulation shows very stable movements, and earlier studies on Japan's unconventional policies often used the monetary base as the policy indicator.

October 2010.[10] The asset purchase scheme continued to expand and was followed by the present QQE program in April 2013. Judging from these developments, the monetary base can be regarded as the BOJ's primary policy instrument over the last fifteen years.

Based on the benchmark analysis, the macroeconomic effects of QQE are assessed by comparing two observation periods: the subperiod ending before the launch of QQE regime and the full observation period including the QQE period. Three threshold dates are considered. The first is April 2013, the month that the QQE program was introduced. The second possible threshold date is January 2013, when the Bank of Japan set the new policy goal of a 2% price stability target in the joint statement with the newly elected government. Because the new inflation target was more ambitious than the previous 1% inflation goal, further aggressive easing was widely anticipated. The third possible threshold date is November 2012, when the lower house of the Diet was dissolved. It was widely expected that the Liberal Democratic Party --- then the opposition party --- would win a majority in the general election in December, and that the new government would promote a more aggressive monetary regime by setting a higher inflation target and appointing a dovish BOJ governor and deputy governors in the following spring. Financial markets clearly priced in these highly probable outcomes concerning the regime shift in advance. Given these developments, November 2012 is regarded as the preferred threshold date.[11,12]

3.3 Smooth-transition Vector Autoregression Analysis

In addition to the benchmark analysis, we also estimate the smooth-transition VAR (STVAR) model to formally examine the possible regime changes in the effects of quantitative easing monetary policy as the aggressiveness of monetary easing increases. This is relevant because the BOJ has expanded its balance sheet along with changes in the contents as the BOJ conducted more aggressive monetary easing. As we illustrated above, the BOJ started the comprehensive monetary easing with the Asset Purchase Program in October 2010, expanding its balance sheet by purchasing various financial assets such as the long-term Japanese government bonds, ETFs and J-REITs. The BOJ has launched the QQE in April, 2013, accelerating the purchase of unconventional assets, particularly the long-term Japanese government bonds. Therefore, it is instructive to investigate how these changes affect the effects of quantitative easing policy more formally than the comparison of two observation periods in the benchmark analysis.

The smooth-transition autoregressive (STAR) model was developed by, among others, Chan and Tong (1986), and Granger and Teräsvirta (1993), and its statistical inference was established by Teräsvirta (1994). Since then, many types of the smooth-transition model have been considered. In particular, the STVAR is an extension of STAR model to a multivariate system of equations to analyze the dynamic relations among several variables with taking a possible regime change or asymmetry into account (e.g., Weise (1999), Gefang and Strachan

[10] Other measures include the "Special Funds-Supplying Operations to Facilitate Corporate Financing" in December 2008, outright purchases of corporate bonds in February 2009, the increase of outright purchases of Japanese government bonds in March 2009, and the "Fixed-Rate Funds-Supplying Operations against Pooled Collateral" in December 2009 as well as the expansion of such operations in March and August 2010. After implementing these initiatives, the BOJ established the Asset Purchase Program in October 2010 and expanded its balance sheet (and thereby the monetary base) by purchasing various financial assets such as Japanese government bonds, treasury discount bills, commercial paper, corporate bonds, exchange-traded funds (ETFs) and Japan real estate investment trusts (J-REITs) as well as increasing the fixed-rate funds-supplying operations until the launch of the QQE program.

[11] The analysis was repeated using the other two threshold dates to check the robustness of the results. The empirical results were qualitatively very similar.

[12] Furthermore, the various alternative series and model specifications are estimated. See footnote 17 for details.

(2010), Auerbach and Gorodnichenko (2012), and Caggiano et al. (2015)).[13] Following these studies, we adopt a STVAR model to examine the effects of quantitative monetary easing policy measured by the monetary base with a possible regime change depending on the aggressiveness of monetary easing.

Our STVAR model extends the benchmark VAR model by using the smooth-transition framework and can be written as

$$(1 - F(z_{t-1}))B^{(1)}(L)X_t + F(z_{t-1})B^{(2)}(L)X_t = \varepsilon_t,$$

where $B^{(i)}(L) = B_0 - B_1^{(i)}L - \cdots - B_p^{(i)}L^p$ is the pth-order lag polynomial of a five-by-five matrix of coefficients for regime i, and $F(z_t)$ is a logistic transition function given by

$$F(z_t) = \frac{1}{1 + \exp(-\gamma(z_t - c))}, \qquad \gamma > 0.$$

Following Weise (1999) and Gefang and Strachan (2010), we assume B_0 and variances of structural disturbances do not depend on the regime.[14]

As discussed, the purpose of introducing the STVAR model is to examine a possible regime change in the effects of quantitative easing monetary policy as the aggressiveness of monetary easing increases. To this end, we employ the level of unconventional assets held by the BOJ, which include the long-term Japanese government bonds, commercial paper, corporate bonds, stocks, ETFs and J-REITs, as a transition variable z_t.[15] This is a natural measure for the aggressiveness of monetary easing, since the BOJ has increased the purchase of unconventional assets considerably as they conduct more aggressive monetary easing. Adopting the convention, we date the index z by $t-1$ to avoid contemporaneous feedbacks from policy actions into their effects on other economic variables.

With this choice of transition variable and the assumption of $\gamma > 0$, we can interpret $B^{(1)}(L)$ as describing the dynamics of the system in the "non-aggressive monetary easing regime" (regime 1) with $F(z_{t-1}) \approx 0$ and $B^{(2)}(L)$ as describing the dynamics of the system in the "aggressive monetary easing regime" (regime 2) with $F(z_{t-1}) \approx 1$. The parameter γ determines the speed of the transition from regime 1 to regime 2 as the aggressiveness of monetary easing increases. More specifically, when γ takes a large value, the transition is abrupt, whereas the transition is gradual for small values of γ. Additionally, the location parameter c can adjust the location of the reflection point of the regime transition. In this sense, we can consider c as the threshold of the aggressiveness of monetary easing. It is critical to estimate it as there is no practical guidance for the threshold.

In principle, we can estimate all the parameters of a STVAR model simultaneously by the

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[13] Weise (1999) examine the asymmetric effects of monetary policy based on a STVAR model and find that shocks to the money supply have stronger effects on outputs and weaker effects on inflation when output growth is initially low. Similarly, Gefang and Strachan (2010) use a STVAR model to investigate the impact of international business cycles on the UK economy. They find that the UK's business cycles are asymmetrically influenced by the business cycles of the US, France and Germany. In addition, Auerbach and Gorodnichenko (2012) employ a STVAR model to measure the output responses to fiscal policy shock in US. Their results indicate that there are large differences in the size of spending multipliers in recessions and expansions with fiscal policy being considerably more effective in recessions than in expansions. Caggiano et al. (2015) also find differences in the size of fiscal spending multiplier in the U.S. economy over the business cycle based on a STVAR model.

[14] In other words, we assume that differences in the propagation of structural shocks across regimes are solely captured by the changes in the coefficients in the reduced form of VAR. Theoretically, we can further extend the model by allowing B_0 to be regime dependent as Auerbach and Gorodnichenko (2012), but we decide not to do so, given the relatively small sample size after the introduction of QQE. On the other hand, in contrast to Auerbach and Gorodnichenko (2012), we do not assume $c = 0$, since it is important to estimate the threshold for the aggressiveness of monetary easing as discussed below.

[15] More precisely, we normalized z_t so that it has mean of 0 and standard deviation of 1.

maximum likelihood (ML) estimation, assuming ε_t follows the multivariate normal distribution. However, it is formidable, if not impossible, to maximize the likelihood function with respect to all parameters due to large number of parameters and a highly non-linear structure of the STVAR model. Indeed, Weise (1999) fixes c at a predetermined value and estimates γ by the grid search, while Auerbach and Gorodnichenko (2012) assume $c = 0$ and calibrate γ without any estimation. In contrast to these studies, we estimate both c and γ by the grid search.[16] Given fixed values of c and γ, the STVAR model becomes a seemingly unrelated regression (SUR) model with the same set of regressors. In this case, we can maximize the likelihood by the equation-by-equation ordinary least squares (OLS). Therefore, using the grid search we can find the ML estimates of c and γ relatively easily.

4. EMPIRICAL RESULTS

This section presents the empirical results based on the simple VAR analysis, followed by the results of the STVAR model. Specifically, four sets of results are presented: (a) the estimated macroeconomic effects of a monetary base shock based on the entire observation period; (b) a comparison of output and inflation responses when the QQE period is excluded and when it is included in the observation period; (c) the estimated macroeconomic effects of a monetary base shock based on the STVAR model; and (d) a comparison of output and inflation responses when the BOJ's government bond holdings or risky asset holdings are used instead of monetary base. This is followed by a discussion of the findings.

4.1 Macroeconomic effects of an expansionary monetary base shock

Figure 2 shows the estimated impulse responses for the full observation period employing the five-variable benchmark model. The solid line in each graph represents the estimated response in levels over the following 24 months to an exogenous one-standard-deviation monetary base shock. The thick and thin dotted lines represent 68% and 90% confidence bands using the Monte Carlo integration procedure.

Looking at the figure, the overall estimated responses seem plausible. An exogenous rise in the monetary base is followed by a persistent rise in real output and inflation within a reasonably tight standard error band.[17] Moreover, it has a negative impact on government bond yields and a positive impact on stock prices, both of which are as expected. These results suggest that the traditional interest rate and stock price channels appear to function effectively.

Figure 3 presents the impulse responses when the exchange rate (i.e., the nominal effective exchange rate) is used instead of stock prices. This model specification allows us to assess the role of the exchange rate channel in the transmission of monetary policy. Using the exchange rate variable yields very similar persistent output and inflation responses: an exogenous increase in the monetary base again leads to a persistent decline in government bond yields as well as a decrease in the exchange rate (i.e., a depreciation of the yen). A caveat is that the standard error band for the exchange rate response appears to be relatively wide. Nevertheless, judging at least from the point estimates, the exchange rate channel seems to have operated during the period examined.

The results in Figures 2 and 3 for the observation period as a whole indicate that exogenous

[16] One cost to estimate the c and γ by the grid search is that standard errors are not computed for c and γ. Therefore, the standard errors for the impulse responses calculated below do not consider the effects of estimation of c and γ.

[17] The results indicate that a one-percent monetary base shock raises output by 0.12 percent point and inflation by 0.02 percent point over 24 months.

monetary policy shocks in the form of monetary base disturbances had a clear impact on real output and inflation.

4.2 Comparing the pre-QQE period and the entire observation period including QQE

Next, to examine the effects of QQE, the pre-QQE period and the entire observation period including QQE are compared. As discussed above, November 2012 is selected as the preferred threshold date.

Figure 4 shows the estimated impulse responses for the pre-QQE period employing the five-variable benchmark model. Comparing with the point estimates of the impulse responses based on the entire observation period (shown in Figure 2), all graphs in this figure indicate that there is a noticeable shift in the estimated response between the two periods. The positive responses of real output and inflation become more persistent when the QQE period is included in the analysis (graphs A and B). Moreover, as seen in graph C, monetary base shocks have a larger and longer-lasting impact on the monetary base, which is likely due to the size and continuous nature of the large-scale, open-ended government bond purchases under QQE. There are also clear differences in the responses of government bond yields and stock prices. Graph D indicates that the downward pressure on long-term yields was much larger, while graph E shows that the increase in stock prices was more persistent than in the pre-QQE period.

Figure 5 presents the results based on the exchange rate model. The results with respect to the estimated impulse responses of output, inflation, the monetary base, and government bond yields are very similar to those based on the stock prices model. Moreover, as seen in graph E, expansionary monetary base shocks generate a more persistent depreciation of the yen when the QQE period is included. This indicates that the exchange rate channel contributed to making financial conditions more accommodative.

These comparisons provide clear indication that due to the launch of the QQE program unconventional monetary base shocks have more persistent macroeconomic effects on the Japanese economy. The findings are generally robust to the use of alternative variables and model specifications.[18]

4.3 Smooth-transition VAR model analysis

The results in the benchmark analysis above suggest that there is a significant change in the effects of monetary base shocks on the Japanese economy as well as inflation in the QQE regime. To examine this point more formally, this subsection provides the evidence based on the STVAR model.

To further motivate the use of the STVAR model, we first conduct tests of linear VAR models against STVAR models proposed by Weise (1999) and Teräsvirta and Yang (2014).[19] A test of linear VAR models against STVAR models is a test of the null hypothesis $H_0: \gamma = 0$ against the alternative $H_0: \gamma > 0$. However, this test is not standard due to the identification problem of the pth-order lag polynomial $B^{(i)}(L), i = 1, 2$ under the null hypothesis. To deal with this identification problem for a smooth-transition AR (STAR) model, Luukkonen, Saikkonen, and

[18] Specifically, to examine the role of bank loans as an alternative transmission channel, bank loans instead of stock prices or the exchange rate are used as the transmission variable; alternative indicators of real output and inflation (monthly GDP series by Japan Center for Economic Research and GDP deflator inflation); and to control for other external factors such as oil prices, uncertainty and US interest rates, a six-variable system is also used adding WTI oil prices, VIX index, or US 10 year Treasury bond yield on the top of the benchmark five-variable model with stock prices. The benchmark results are generally robust to the use of these alternative specifications.

[19] For a nice summary of these tests, see Hubrich and Teräsvirta (2013).}

Teräsvirta (1988) suggest approximating the logistic transition function with a first-order Taylor approximation around $\gamma = 0$ to derive the auxiliary regressions.[20] They confirm that testing AR models against STAR models is equivalent to testing 0 restrictions on the coefficients related to the transition variable in the auxiliary regressions and proposed several tests. Weise (1999) extends their tests to a STVAR framework based on the log-likelihood ratio type test statistic, while Teräsvirta and Yang (2014) consider a generalization using the Lagrange Multiplier type test statistic. We applied both tests to our VAR model. *P*-values of these two tests are 0.000 and 0.029, respectively, suggesting a rejection of linear VAR models against STVAR models. Therefore, we proceed to estimate the STVAR model.

Figure 6 plots the dynamics of transition function, $F(z_{t-1})$, based on the estimates for c and γ.[21] As can be seen, $F(z_{t-1})$ takes the values close to 1 during the period between August 2003 and March 2006 and after May 2011, suggesting that monetary easing during these periods are classified as the aggressive monetary easing. In March 2003 Mr. Toshihiko Fukui was inaugurated as the governor of the BOJ and expanded the balance sheet aggressively during his first year or so, maintaining a very accommodative policy stance until the end of the quantitative easing policy in March 2006. In March 2011 the Japanese economy was hit by the Great East Japan Earthquake, and the BOJ further strengthened the stance of comprehensive monetary easing afterwards, which in the end led to the introduction of QQE. Thus, our results indicate that not only QQE but also a later period of quantitative easing and comprehensive monetary easing can be considered as the aggressive monetary easing regime, and the rest as the non-aggressive monetary easing regime.

To see the difference in the effects of expansionary monetary policy across regimes, Figures 7 and 8 plot the impulse responses to an exogenous monetary base shock for each regime based on the benchmark stock prices model. As can be seen from Figure 7, an exogenous rise in the monetary base boosts the real output and inflation significantly and persistently in the aggressive easing regime. Moreover, it has a significant negative impact on government bond yields and a marginally significant positive impact on stock prices, suggesting that the traditional interest rate and stock price channels appear to function effectively, but the former seems to play more significant role in the aggressive easing regime. In addition, comparing Figures 7 and 8 demonstrates that there is a clear difference in the estimated response between the two regimes. The positive responses of real output and inflation are more persistent and significant in the aggressive monetary easing regime than those of the non-aggressive easing regime (graphs A and B). Monetary base shocks have a larger and longer-lasting impact on the monetary base in the aggressive regime (graph C). There are also noticeable differences in the responses of government bond yields and stock prices (graphs D and E).

Figures 9 and 10 present the impulse responses to an exogenous monetary base shock for each regime when the exchange rate is used instead of stock prices. The results indicate that the estimated impulse responses of output, inflation, the monetary base, and government bond yields are quite similar to those based on the stock prices model. Particularly, there are notable difference in the responses of inflation and government bond yields between two

[20] Luukkonen, Saikkonen, and Teräsvirta (1988) also suggest using a higher-order Taylor approximation to increase the power of the test. Nonetheless, we use the first-order, since a number of parameters become too large if we use a higher-order for our problem. In addition, the employed tests seem to be powerful enough to reject linear VAR models against STVAR models.

[21] They are given by $\hat{c} = -0.2892$, which corresponds to about 62.7 trillion yen, and $\hat{\gamma} = 300$. If γ takes a very large value, the transition function looks like a step function and the likelihood becomes insensitive with γ. Therefore, we set the upper bound of γ as 300.

regimes. In contrast, the exchange rate channel seems not to be working in either regime.

These comparisons provide another indication that unconventional monetary base shocks have more persistent and significant macroeconomic effects on the Japanese economy in the aggressive monetary easing period, which is generally in support of the main findings.

4.4 Additional analysis distinguishing between quantitative and qualitative aspects of monetary easing

The policy actions here are assumed to be captured by exogenous shocks to the monetary base. In aggressive easing periods, the BOJ expanded the monetary base primarily by increasing government bonds purchases. The increase in the monetary base via government bond purchases is commonly viewed as "quantitative easing." A variety of other actions --- such as purchases of commercial papers, corporate bonds, ETFs and J-REITs --- also expanded the monetary base and are often called "qualitative easing." They likely influenced the risk and maturity composition differently and thereby might have had different effects on the economy.

A simple way to distinguish between quantitative and qualitative aspects of monetary easing is to replace the monetary base with the BOJ's government bonds holdings or risky assets holdings and examine the dynamic effects of each shock separately. To this end, we estimate two systems based on the smooth transition framework: (y, π, GB, R_B, P_K) and (y, π, RA, R_B, P_K). GB is the log of the BOJ's government bonds holdings. RA is the log of the BOJ's risky assets holdings, which include commercial papers, corporate bonds, ETFs, J-REITs and stocks.[22] Monthly data for these series are available at the BOJ's homepage. As shown in Figure 11, both government bonds and risky assets expanded rapidly in recent years of aggressive monetary easing.

Estimation results for the STVAR models based on (y, π, GB, R_B, P_K) and (y, π, RA, R_B, P_K) are summarized in Figures 12 and 13. Figure 12 exhibits the dynamic effects of a one-standard deviation shock to BOJ's government bonds holdings on real output and inflation. The estimated impulse responses are quite similar to the results using the monetary base (see Figures 7 and 8). A government bond holding shock generates a more persistent and significant rise in output and inflation in the aggressive easing regime compared to the non-aggressive easing regime. As shown in Figure 13, an exogenous rise in the BOJ's risky assets holdings is followed by a persistent rise in real output especially in the aggressive easing regime. Inflation responses are estimated to be generally less significant. This additional exercise suggests that persistent output and inflation responses to a monetary base shock are largely driven by quantitative aspects of monetary easing, while the qualitative aspects also strengthened the macroeconomic effects especially on real output.[23]

4.5 Discussion

The analysis has shown that expansionary shocks to the monetary base have had clear macroeconomic effects, leading to a persistent rise in real output and inflation. Moreover, the macroeconomic and financial market effects were larger and more persistent following the introduction of the QQE program. It is useful to "zoom out" and consider these findings in the broader context of Japan's economy.

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[22] The BOJ's risky asset holdings were 0 until November 2002. To take log we replace these 0 with 1 and include a dummy variable taking 1 until November 2002 and 0 after that for the STVAR analysis.

[23] These findings are generally confirmed when we use benchmark VAR models rather than the smooth transition VAR models.

There are probably at least two factors that help to explain the findings regarding the macroeconomic effects of the BOJ's policy programs. First, a general background factor is the fact that private sector fundamentals in Japan improved on a broad basis during the observation period. The balance sheet adjustments in Japan's corporate and banking sectors had largely been completed by the mid-2000s, that is, soon after the unconventional balance sheet policies were launched in 2001. Specifically, following the severe banking crisis in Japan between 1998 and 2001, the government launched the "Program for Financial Revival" in October 2002 to fully resolve the non-performing loans problem that had been lingering since the collapse of the bubble economy, accelerating the disposal of bad loans and the exit of zombie firms. As a result, the decline in bank loans eventually bottomed out in 2005, while improvements in the efficiency of resource allocation helped to sustain overall productivity and profitability in the corporate sector. It is likely that the improvement in economic fundamentals made monetary easing and the loosening of financial conditions more effective in terms of promoting productive risk-taking, raising investment, and providing a persistent boost to real economic activity.[24]

Second, the reason that the macroeconomic effects of an expansionary monetary base shock were more persistent and significant for the QQE regime likely is that the program contains powerful open-ended forward guidance with regard to such large-scale government bond purchases and the fact that the average remaining maturity of government bonds purchases was substantially extended. Further, the clear statement by the BOJ that it would continue with the program as long as necessary to achieve the 2% inflation target likely shaped market expectations in a way that contributed to a more long-lasting decline in government bond yields, higher stock prices, and a greater depreciation of the yen, leading to more pronounced effects on output and inflation after the introduction of the QQE program.

While these two factors above arguably contributed to the clear macroeconomic effects of unconventional measures in Japan, some additional issues are worth discussing to understand the empirical results. One such issue concerns a possible shift in inflation dynamics after the launch of QQE. As was illustrated in graphs A and B of Figures 7 and 8, the upward shift of the inflation response appears more pronounced than that of the output response after the launch of the QQE regime. This suggests that some structural shift in the Phillips curve relationship --- such as an increase in the slope and/or intercept --- took place in recent years around the time when QQE was introduced. It is likely that the comprehensive policy package initiated by the new government raised expectations of higher and more sustained demand growth and that, in response, firms have become more aggressive in their price-setting behavior, charging higher markups and passing on increases in production costs to sales prices to a greater extent.[25] It is also likely that the introduction of the higher 2%

[24] The long-lasting impact on real output may also be attributable to the potential hysteresis effects highlighted by Larry Summers (see, e.g., Summers (2015)). One way through which such hysteresis effects may come about is that an increase in real investment raises potential output by raising the capital stock and possibly total factor productivity due to new technology embodied in the investment. Such improvement in the aggregate supply would bring about a long-lasting increase in output. Although not shown in the figure, our analysis indicates that an expansionary monetary base shock is followed by a persistent increase in real business investment. Similarly, a persistent positive investment response was also found when focusing on the pre-QQE observation period. These results support the argument that hysteresis effects may have played a role.

[25] While to date much of the evidence showing that firms have become more aggressive in their price-setting behavior is anecdotal, more robust empirical evidence can be found in the literature on exchange rate pass-through. Conducting a time-varying parameter estimation, Hara, Hiraki and Ichise (2015) for example show that the rates of exchange rate pass-through into consumer prices have been increasing since the late 2000s and that a large part of the increase in the exchange rate pass-through is explained by increases in the response of inflation to marginal costs reflecting changes in firms' pricing behavior.

price stability target and subsequent aggressive unconventional policies raised the public's inflation expectations.[26] Thus, it appears that some form of structural shift in the Phillips curve relationship is another potential mechanism underlying the greater inflation response of a monetary base shock in the period including the QQE policy.

5. CONCLUDING REMARKS

This study attempted to provide a comprehensive VAR analysis measuring the macroeconomic effects of unconventional monetary policies in Japan. Using a stylized block-recursive framework and monthly observations for the period 2001-2015, the analysis showed that expansionary monetary base shocks led to a persistent rise in real output and inflation. The evidence suggests that traditional transmission channels such as the interest rate channel, the stock price channel, and the exchange rate channel all played a role in generating such macroeconomic effects. Further, comparing the period up to the introduction of QQE and the entire observation period including the period after the introduction of QQE showed that the macroeconomic effects of expansionary monetary base shocks became more persistent and significant following the launch of the QQE program. A formal analysis that allowed for a regime shift based on a smooth-transition VAR model also generally supported these findings.

These results suggest that the unconventional monetary policies adopted by the Bank of Japan provided meaningful macroeconomic support to the Japanese economy over the last fifteen years. Of course, this does not necessarily imply that expansionary balance sheet policies will continue to have such effects in the future. The effectiveness of these policies depends on the fundamentals of the economy and a variety of additional factors, all of which are subject to change. However, the fact that, so far, they have had their intended effects in Japan – the country with the longest experience of unconventional monetary policies – should prove instructive for other major industrial economies confronting similar challenges.

[26] Some surveys of inflation expectations such as consensus forecasts indicate that inflation expectations have increased since the QQE regime was launched in 2013. In recent empirical studies on the Phillips curve, Kaihatsu and Nakajima (2015) and Okimoto (2016) find that Japan's expected inflation, after staying at around zero percent for about fifteen years, shifted away from zero percent following the introduction of the 2% price stability target and QQE.

DATA APPENDIX

Real output (y): seasonally adjusted real GDP series, retrieved from the Cabinet Office SNA statistics. Quarterly data is interpolated to obtain monthly observations.

Inflation (π): consumer price index year-on-year inflation excluding food and energy, taken from Ministry of Internal Affairs and Communications statistics. The effects of consumption tax increase for April 2014 – March 2015 are excluded.

Monetary base (MB): monthly average, seasonally adjusted series available from the Bank of Japan statistics.

Government bond yields (R_B): 10-year Japanese government bond yields, monthly average, taken from Bloomberg.

Stock prices (P_K): Nikkei Stock Average index, monthly average, taken from Bloomberg.

Exchange rate (FX): nominal effective exchange rates, monthly, available from the Bank of Japan statistics.

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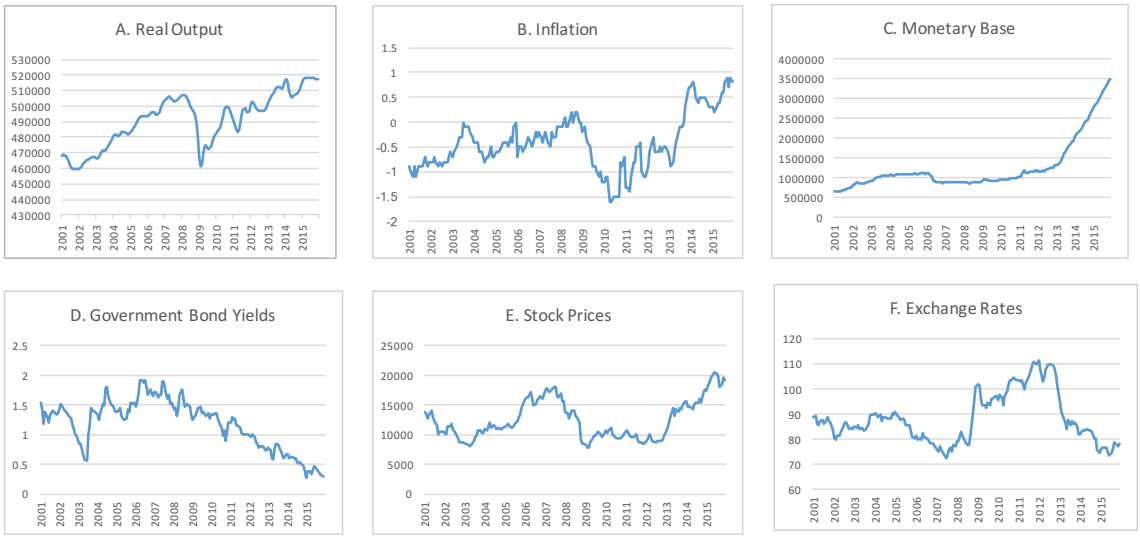
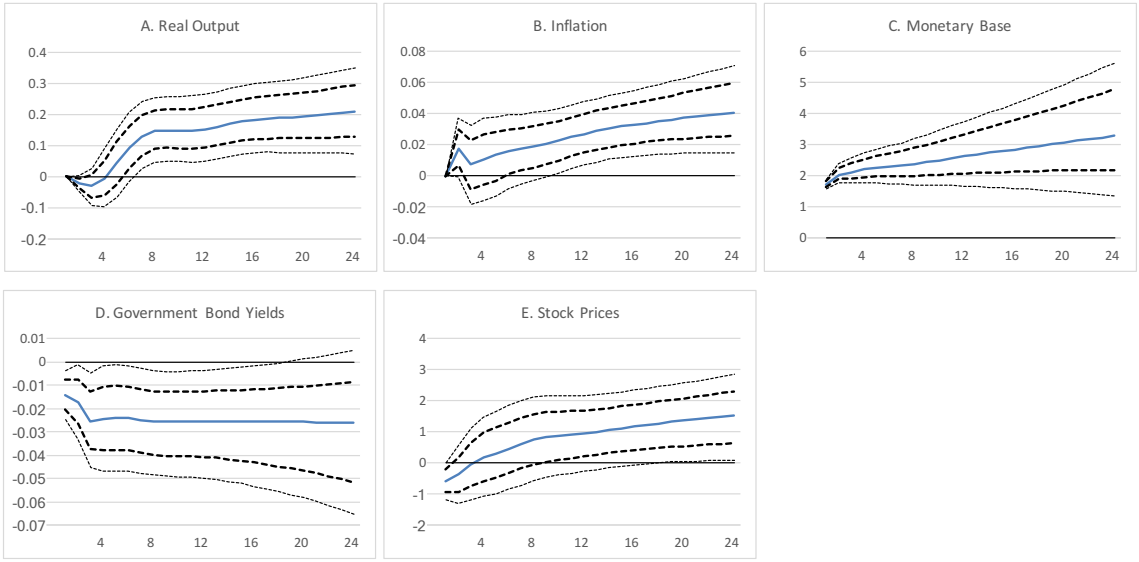
Figure 1. Time series data



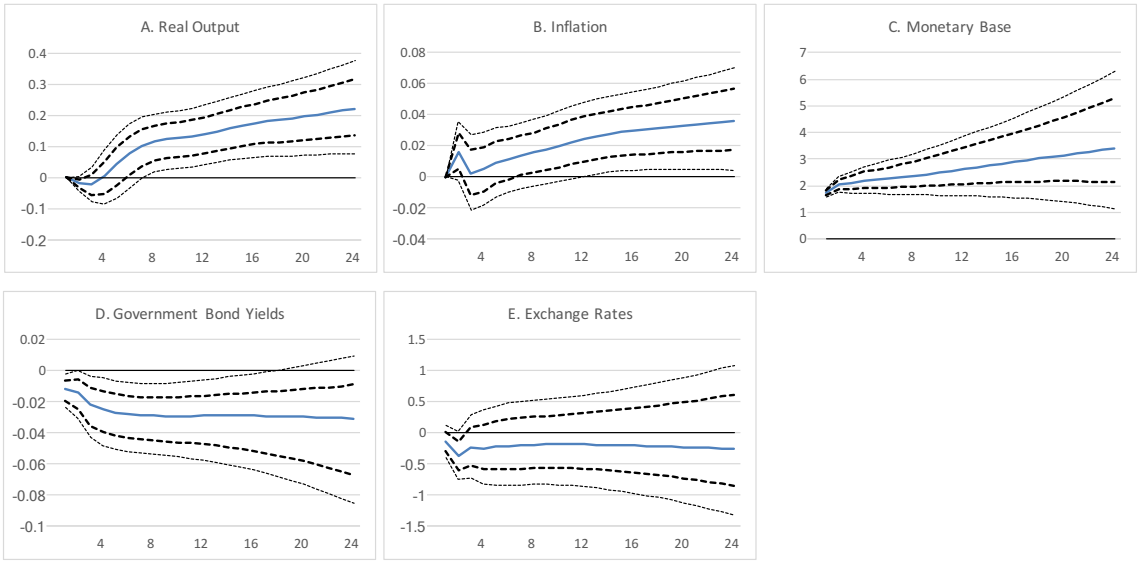
Note : The figure plots the time series of each data used in the main analysis from January 2001 to December 2015. See the Data Appendix for details.

Figure 2. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, P_k) model, entire observation period —



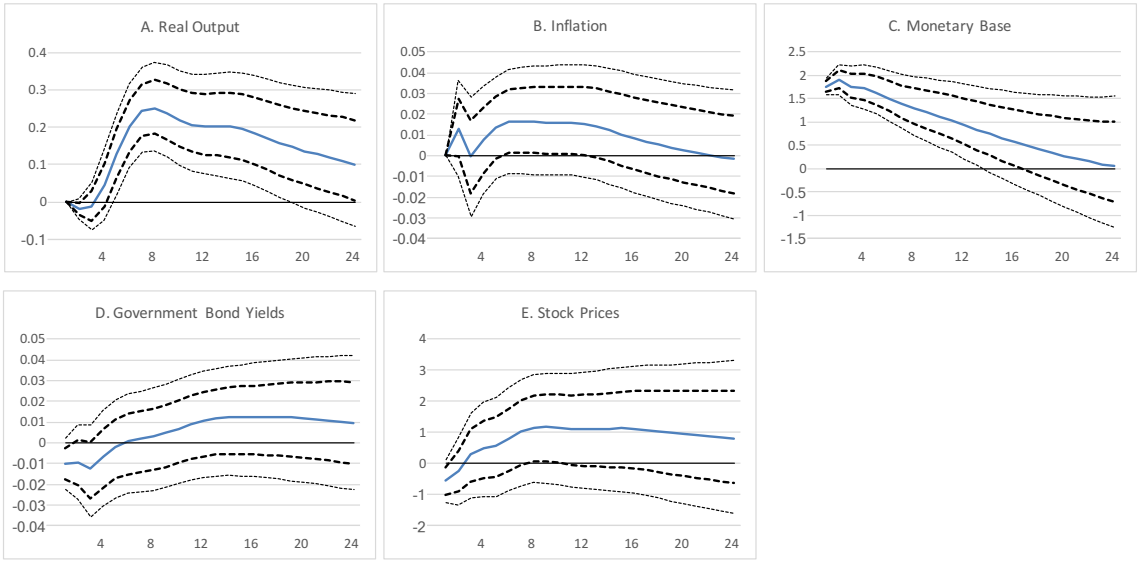
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 3. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, FX) model, entire observation period —



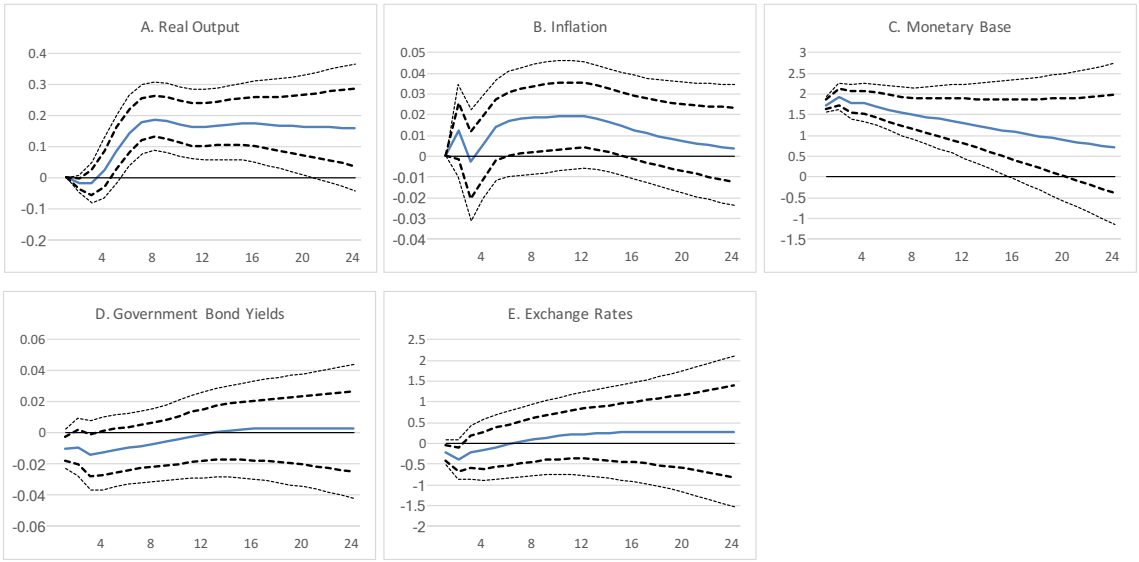
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 4. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, P_k) model, pre-QQE period —



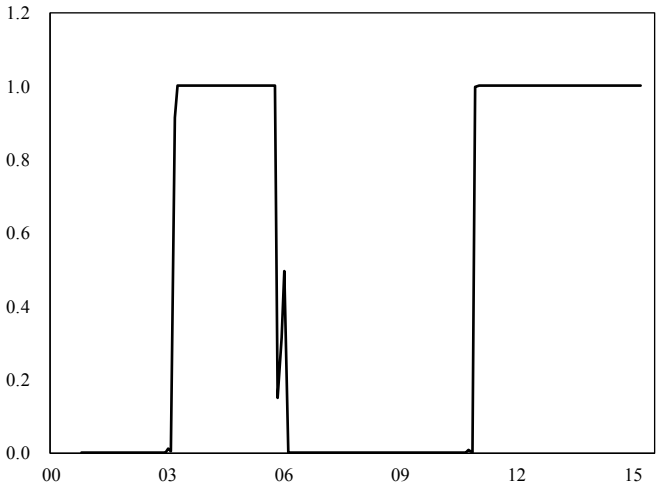
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 5. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, FX) model, pre-QQE period —



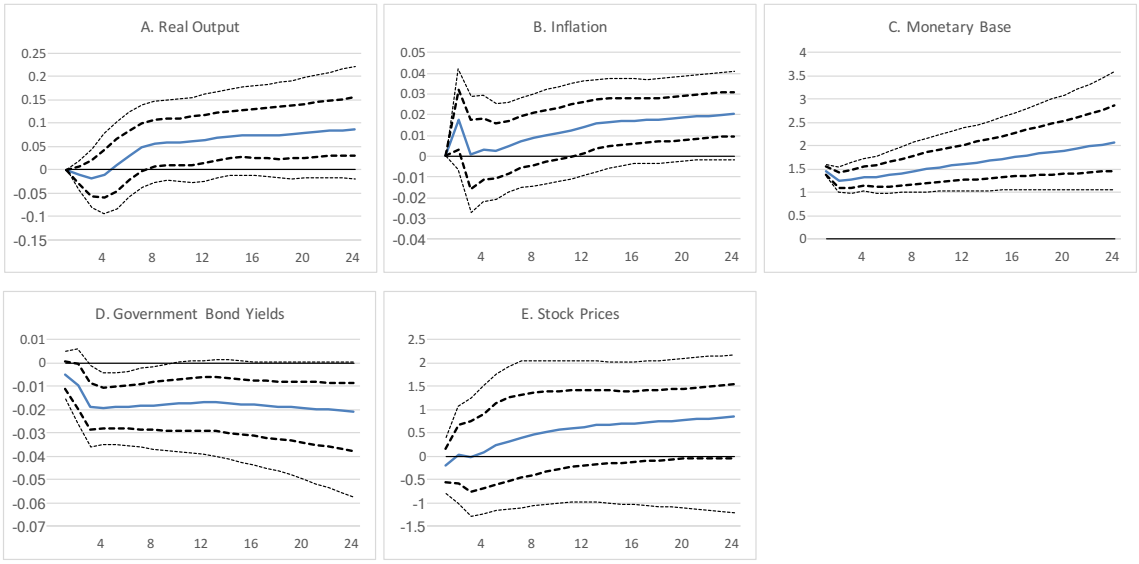
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 6. Estimated transition function



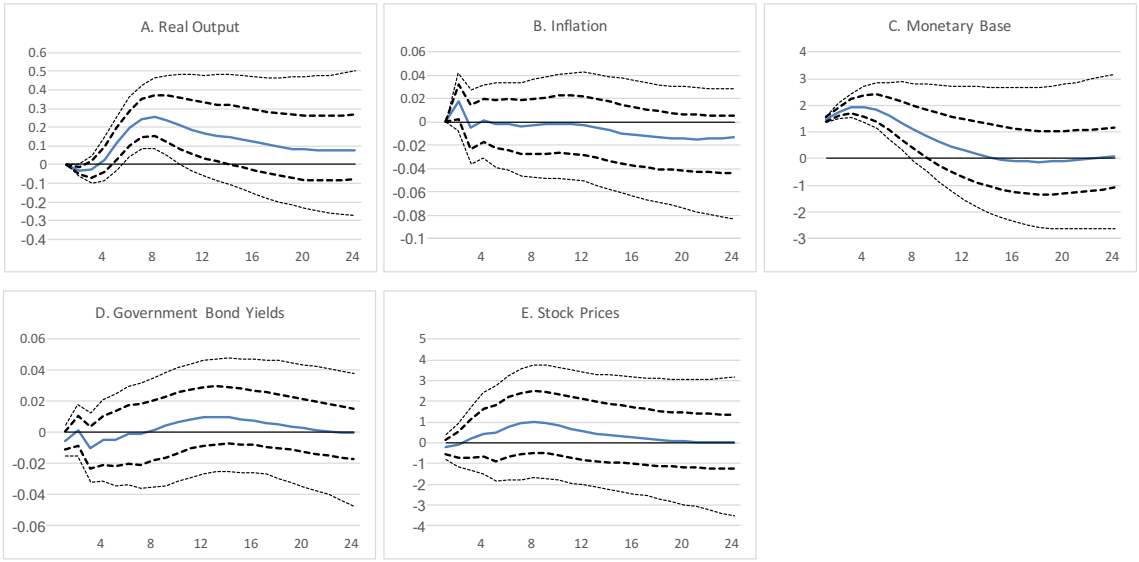
Note: The figure plots the estimated transition function for the smooth-transition VAR based on (y, π, MB, R_B, P_k) model. The function takes values close to 0 for the non-aggressive regime and takes values near 1 for the aggressive regime.

Figure 7. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, P_k) STVAR model, aggressive easing regime —



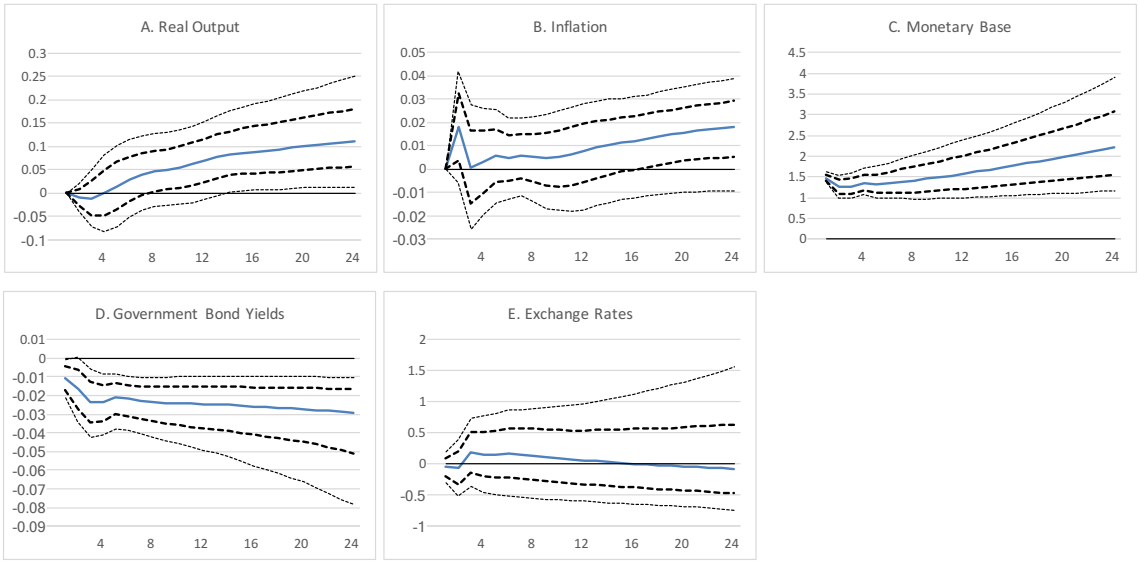
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 8. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, P_k) STVAR model, non-aggressive easing regime —



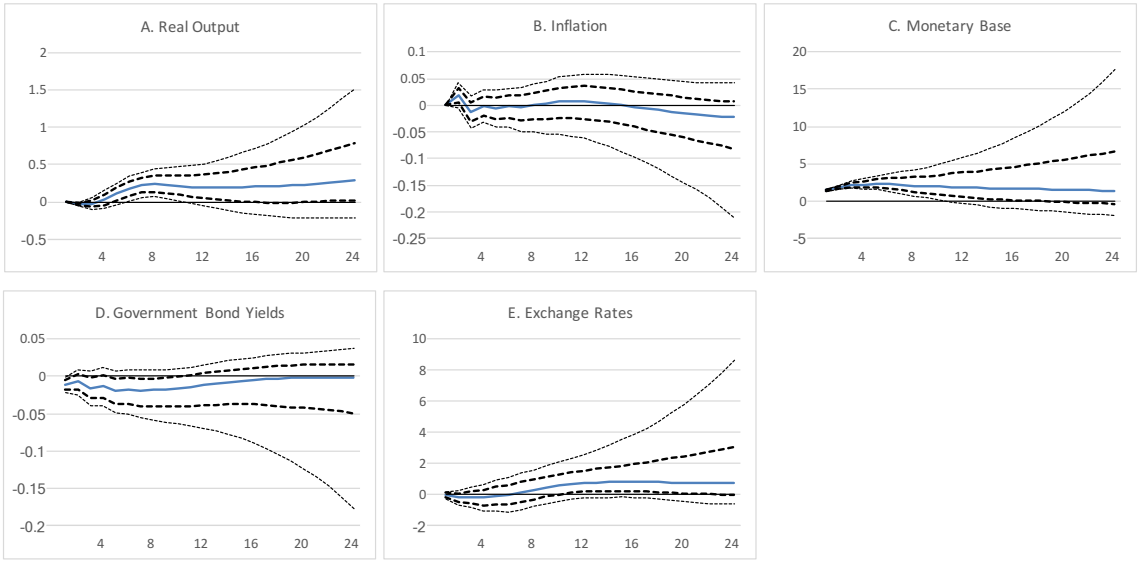
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 9. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, FX) STVAR model, aggressive easing regime —



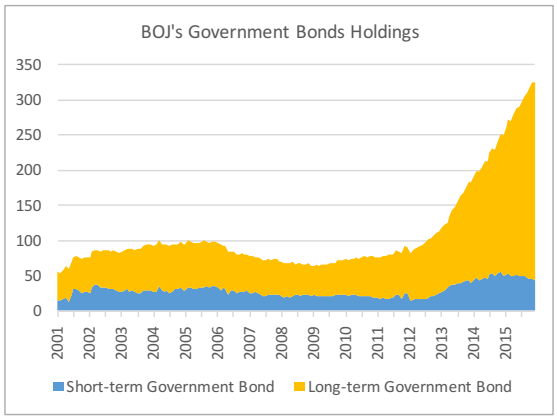
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

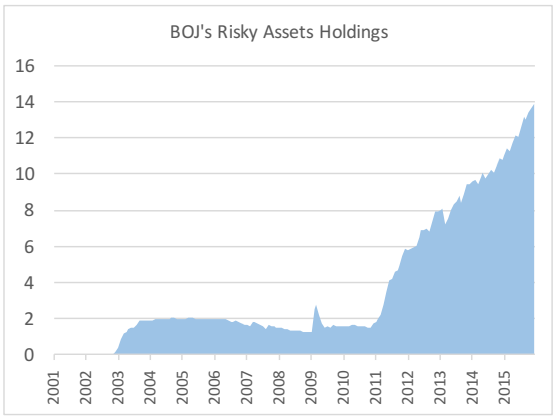
Figure 10. Dynamic effects of an expansionary monetary base shock
— (y, π, MB, R_B, FX) STVAR model, non-aggressive easing regime —



Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the monetary base. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 11. BOJ's Government Bonds and Risky Assets Holdings
— 2001:1-2015:12, trillion yen —

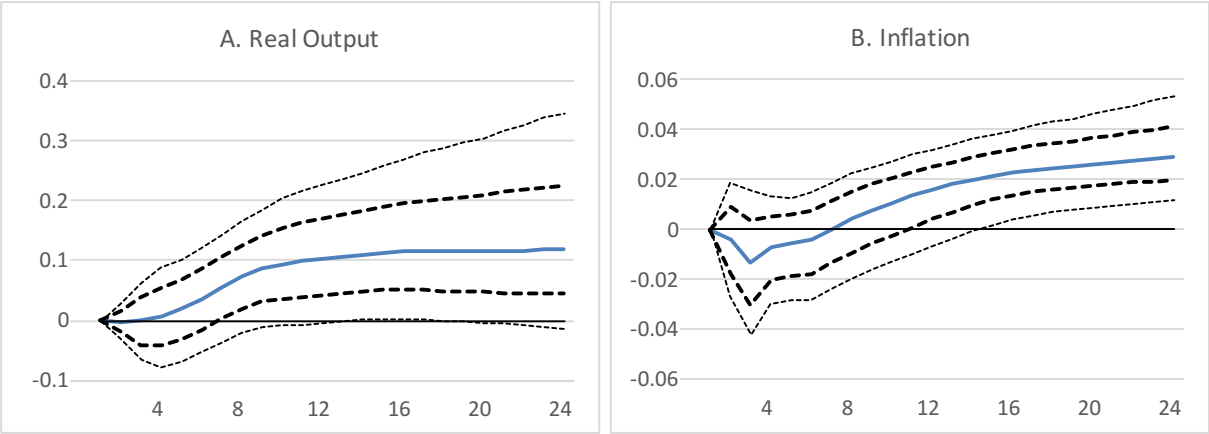




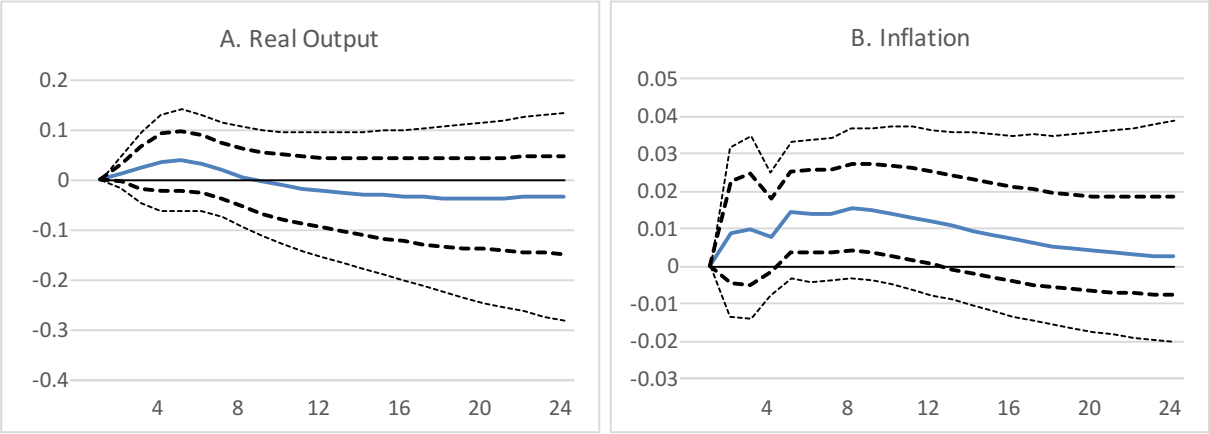
Notes: The figure plots the monthly data for BOJ's government bond and risky asset holdings taken from the BOJ's home page. Risky assets include commercial papers, corporate bonds, ETFs, J-REITs, and stocks.

Figure 12. Dynamic effects of BOJ's government bond holding shock
$-(y, \pi, GB, R_B, P_K)$ model

(1) Aggressive easing regime



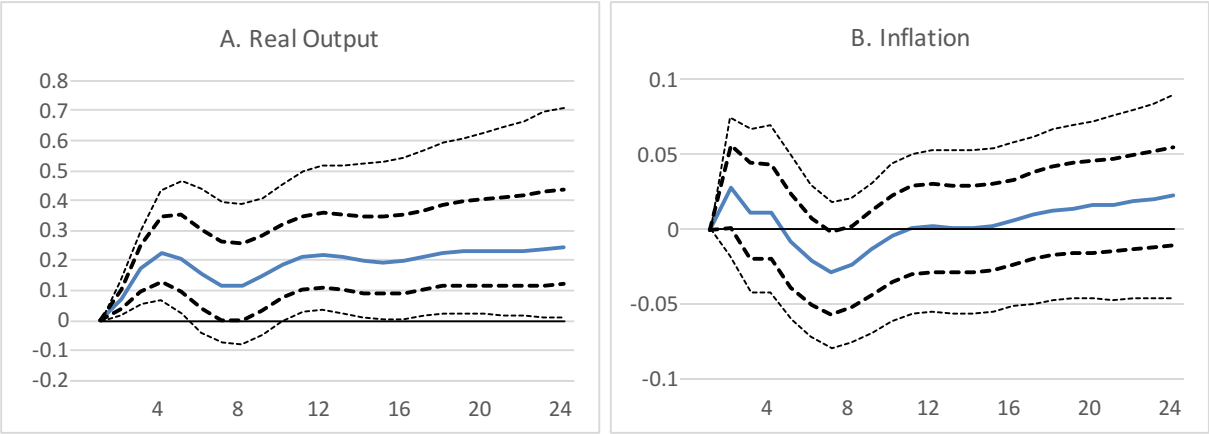
(2) Non-aggressive easing regime



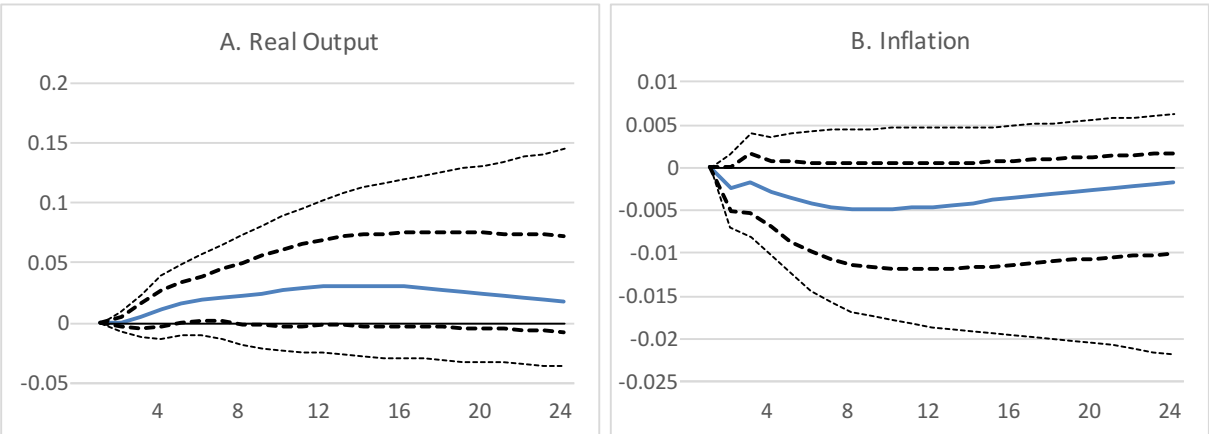
Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the BOJ's government bond holdings. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.

Figure 13. Dynamic effects of BOJ's risky asset holding shock
$-(y, \pi, RA, R_B, P_K)$ model

(1) Aggressive easing regime



(2) Non-aggressive easing regime



Note: The figure plots percent responses over a 24-month horizon to a one-standard-deviation shock to the BOJ's risky asset holdings. The thick and thin dotted lines show 68% and 90% confidence bands, respectively.