The Effectiveness of Unconventional Monetary Policy at the Zero Lower Bound: A Cross-Country Analysis*

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Abstract

This paper assesses the macroeconomic effects of unconventional monetary policies by estimating a panel VAR with monthly data from eight advanced economies over a sample spanning the period since the onset of the global financial crisis. It finds that an exogenous increase in central bank balance sheets at the zero lower bound leads to a temporary rise in economic activity and consumer prices. The estimated output effects turn out to be qualitatively similar to the ones found in the literature on the effects of conventional monetary policy, while the impact on the price level is weaker and less persistent. Individual country results suggest that there are no major differences in the macroeconomic effects of unconventional monetary policies across countries, despite the heterogeneity of the measures that were taken.

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1 Introduction

In the wake of the global financial crisis, many central banks in advanced economies embarked on unconventional monetary policy measures in order to counter the risks to economic and financial stability. As policy rates approached and ultimately got stuck at their effective lower bounds, central bank balance sheets basically replaced interest rates as the main policy instrument.[1] As a consequence, the models that were estimated over the pre-crisis period with a short-term interest rate as the monetary policy instrument are not suitable for studying the effectiveness of monetary policy in the aftermath of the crisis. The challenge is to figure out a suitable econometric approach for analyzing the macroeconomic impact of central banks' balance sheet policies in a crisis period when interest rates reach the zero lower bound.[2]

The evidence available so far has mainly focused on the financial market impact of unconventional monetary policy measures using high-frequency financial data.[3] A few papers go one step further and try to assess the macroeconomic effects of such policies (e.g. Chung *et al.* 2011, Lenza *et al.* 2011, Peersman 2011, Joyce, Tong and Woods 2011). A potential caveat concerning these studies is that they rely on models estimated over sample periods covering also the pre-crisis period, which may not be adequate for assessing macroeconomic dynamics and monetary transmission in a liquidity trap. In addition, central bank balance sheet policies before the crisis were usually not aimed at influencing macroeconomic conditions. On the other hand, there are a number of papers exploring the effectiveness of the Bank of Japan's quantitative easing at the zero lower bound between 2001 and 2006 (e.g. Ugai 2007, Schenkelberg and Watzka 2011), but

[1] For an overview and taxonomy of the various unconventional monetary policy measures taken by central banks during the crisis, see e.g. Borio and Disyatat (2010) and Stone *et al.* (2011).

[2] Throughout the paper, we will refer to central bank balance sheet policy and unconventional monetary policy interchangeably.

[3] Specifically, there are numerous studies on the effects of central banks' liquidity measures on money markets and FX and cross-currency swap markets in the first stage of the crisis (e.g. Hördahl and King 2008, Baba *et al.* 2008, Christensen *et al.* 2009, Taylor and Williams 2009, Thornton 2010) and on the effects of subsequent large-scale asset purchases on long-term interest rates and other asset prices (e.g. D'Amico and King 2010, Hamilton and Wu 2010, Neely 2010, Gagnon *et al.* 2011, Joyce, Lasaosa, Stevens and Tong 2011). For a survey and comparison of the estimated effects of recent large-scale asset purchases on ten-year yields, see Williams (2011). Cecioni *et al.* (2011) provide a survey of the evidence on the effectiveness of the various unconventional monetary policy measures adopted by the Federal Reserve and the Eurosystem. Overall, these studies find that such policies were effective in reducing financial market risk spreads or yields.

it is not clear whether the experience of the Bank of Japan during that period can be generalized to a worldwide financial crisis.

In this paper, we propose an alternative way to assess the effects of unconventional monetary policies on the macroeconomy during the global financial crisis. We focus exclusively on the period since the onset of the crisis, but enhance the efficiency and power of the empirical analysis by also exploiting its cross-country dimension. In particular, the crisis has been an important common factor in the business cycles, financial market dynamics and monetary policy conduct of several advanced economies. This high degree of commonality allows for the adoption of panel estimation techniques in order to improve the accuracy of the analysis.[4]

More precisely, we estimate a panel structural vector autoregressive (SVAR) model with monthly data over a sample period where central bank balance sheets effectively became the main policy instrument in many advanced economies. The economies included in the panel analysis are Canada, the euro area, Japan, Norway, Sweden, Switzerland, the United Kingdom and the United States. The time series sample is January 2008 until June 2011. We use a mean group estimator in the spirit of Pesaran and Smith (1995) to accommodate potential cross-country heterogeneity in macroeconomic dynamics, the monetary transmission mechanism and the adopted unconventional monetary policy measures. In order to keep the analysis tractable, the model set-up is parsimonious but aims to incorporate the main common features of the crisis: (i) the macroeconomic dimension of the crisis captured by the dynamics of aggregate output and prices, (ii) the aggressive use of balance sheet policies by central banks while policy rates got stuck at the zero lower bound and (iii) the recurrent bouts of uncertainty and risk aversion in financial markets. The effectiveness of unconventional monetary policy is assessed by estimating the effects of exogenous innovations to central bank assets, conditioning on the state of the macroeconomy and, importantly, on financial turmoil and macroeconomic risks which we proxy by implied stock market volatility. The latter is key to disentangling the endogenous reaction

[4] Almunia *et al.* (2010) have used a similar approach to analyze the impact of monetary and fiscal policy in the Great Depression. Gavin and Theodorou (2005) show that adopting a panel approach in a macro framework helps to uncover common dynamic relationships which might otherwise be obscured by idiosyncratic effects at the individual country level. See also Goodhart and Hofmann (2008) or Assenmacher-Wesche and Gerlach (2008) for a discussion of these issues and applications of panel VAR analysis to the link between monetary policy and asset prices in OECD countries.

of central bank balance sheets to the global financial crisis and exogenous monetary policy shifts, similar to the importance of conditioning on commodity prices as an indicator of nascent inflation when identifying conventional monetary policy shocks (Sims 1992).

We find that an expansionary unconventional monetary policy shock leads to a significant but temporary rise in output and prices, a result that turns out to be robust to various perturbations of the model specification. The output effects are qualitatively similar to the ones typically found in the literature on the effects of conventional monetary policy (e.g. Christiano *et al.* 1999, Peersman and Smets 2003). The impact on the price level, on the other hand, seems to be less persistent and weaker. Furthermore, the individual country results indicate that the panel estimates do not obscure significant cross-country heterogeneity. Specifically, we find no major cross-country differences in the macroeconomic effects of shocks to central bank balance sheets, despite the different measures that were taken in response to the crisis.

The remainder of the paper is organized as follows: The next section discusses some stylized facts on the macroeconomy and unconventional monetary policy in the economies we consider. After a description of the panel VAR model and the data in Section 3, Section 4 presents the main results. Some robustness checks are performed in Section 5, whereas cross-country differences are discussed in Section 6. Finally, Section 7 concludes.

2 Central bank balance sheets and the crisis: some facts

The global financial crisis has been a major common economic factor in several advanced economies. Figure 1 shows the evolution of key macroeconomic variables, financial market volatility and indicators of the monetary policy stance over the period January 2007 until June 2011 for eight economies: Canada, the euro area, Japan, Norway, Switzerland, Sweden, the United Kingdom and the United States. The charts reveal the close correlation of aggregate output and price dynamics over this period. All economies were confronted with a significant fall in economic activity after the collapse of Lehman Brothers in September 2008, and an accompanying decline of inflation rates, in many cases to temporarily negative levels, shortly afterwards. By mid-2011, many economies did still not fully recover to

their pre-crisis level of economic activity.

Figure 1 reveals that there was also a very close correlation across economies of the evolution in financial market risk aversion, measured by the implied volatility index (VIX) for the major stock market index.[5] The VIX is considered to be a prime gauge for financial market risk aversion and a general proxy for financial turmoil, economic risk and uncertainty. Indeed, the charts show that the implied volatility indices started to creep up with the onset of the crisis in mid-2007 and shot up dramatically with the collapse of Lehman Brothers. After receding subsequently, they increased again during 2010 when concerns about the economic recovery mounted, and in early 2011 with the onset of euro area sovereign debt crisis.

There has also been a strong cross-country commonality in the conduct of monetary policy over this period. After the intensification of the crisis, policy rates were rapidly lowered towards their effective lower bounds in early 2009. In parallel, the assets on central bank balance sheets have in many economies grown to an unprecedented size reflecting unconventional monetary policy measures taken to provide liquidity to ailing financial sectors and to support faltering economies through lower long-term interest rates and financial market risk premia. The size of the balance sheets of the Federal Reserve and the Bank of England tripled, while that of the Eurosystem doubled. The Bank of Japan's assets, in contrast, increased only mildly over the crisis period. Most of the increase occurred in March 2011 when the Bank of Japan injected liquidity in response to the Tōhoku earthquake and tsunami. Among the smaller economies' central banks, the Swedish Riksbank, the Swiss National Bank and, to a lesser extent, the Bank of Canada, expanded the size of their balance sheets sharply, while the Norges Bank's financial assets increased only temporarily after the Lehman collapse.[6]

Also the monetary base expanded considerably in most economies. However, the last two charts of Figure 1 show that the expansion was in some countries over part of the

[5] Implied stock market volatility indices are forward looking measures of stock index volatility computed based on option prices and measure market expectations of stock market volatility in the next 30 days. For a more detailed discussion of the VIX and its interpretation, see Whaley (2009).

[6] For Norges Bank, we use total financial assets instead of total assets (ie. we exlude in particular the investments of the government pension fund) in order to focus on that part of the balance sheet that reflects unconventional monetary policy measures.

sample period smaller than the increase in central bank assets, in particular in Canada, the US, the UK and Switzerland. Central bank assets therefore appear to be a better gauge for central banks' unconventional monetary policy measures than the monetary base.

Figure 2 provides the composition of the eight central banks' assets and liabilities. The charts reveal that, while unconventional policies typically led to an increase in balance sheets, their design varied across economies and also within economies over time, reflecting differences in financial structure and the evolution of the crisis over time. This is evident from the composition of central banks assets and its changes over the sample period. For instance, the expansion of the Federal Reserve's and the Bank of England's balance sheet was initially driven by lending to the financial sector and subsequently by large-scale purchases of both private sector and government securities. The Eurosystem's unconventional monetary policy primarily focused on lending to financial institutions. In the wake of the euro area sovereign debt crisis and the subsequent introduction of the Securities Market Programme, security purchases however became a more important factor. The expansion of the Swiss National Bank's balance sheet was in turn mainly driven by purchases of foreign currency.

The liability side of central bank balance sheets also displays considerable heterogeneity across countries. In most countries, the monetary base accounts for the bulk of central bank liabilities, but there are also central banks with large other liability items, such as government deposits, central bank debt certificates or foreign currency liabilities. The figures also shed some light on the causes of the divergence between central bank total assets and the monetary base that emerged for some countries in Figure 1. The Bank of England, the Swiss National Bank and the Bank of Canada partly sterilized the effects of their unconventional policies on the monetary base. This was done in different ways. The Bank of England conducted short-term open-market operations while the Swiss National Bank issued short-term debt certificates. In the case of Canada, the increase in central bank assets was sterilized through an increase in government deposits.

Thus, while there was a high degree of commonality in central banks' response to the crisis, there was also a considerable degree of heterogeneity in the design of central bank balance sheet policies that needs to be taken into account and the relevance of which

should be assessed to the extent possible in the empirical analysis.

3 A panel VAR model to analyze the financial crisis

Structural VAR techniques have been extensively used as a tool to analyze the macroeconomic effects of conventional monetary policy innovations. Examples include Bernanke and Blinder (1992), Strongin (1995), Bernanke and Mihov (1998) and Christiano *et al.* (1999) for the United States or Peersman and Smets (2003) for the euro area. In this paper, we adopt a panel VAR approach to explore the dynamic effects of unconventional monetary policy shocks. The use of panel techniques allows us to obtain more efficient estimates relative to country-by-country estimations by also exploiting the cross-sectional dimension. On the one hand, we take into account the correlation amongst the residuals across countries to capture (unobserved) factors that are common to all economies while unconventional monetary policy shocks are simultaneously identified.[7] On the other hand, we use a mean group estimator in the spirit of Pesaran and Smith (1995). In contrast to the standard fixed effects panel estimator, the mean group estimator allows for cross-country heterogeneity and does not require that the economic structures and dynamics of the economies in the VAR are the same which could introduce estimation bias in dynamic models.[8] This allows us to take into account differences across countries in design and transmission of unconventional monetary policy measures.

[7] We do not allow for cross-country spillover effects of unconventional monetary policy measures because the sample period is too small to extend the empirical model in this direction. The possible relevance of such effects does however not invalidate our approach, which focuses on the domestic effects of domestic unconventional monetary policy measures.

[8] Nickell (1981) has shown that fixed effects panel estimation of dynamic models is biased when the time dimension of the panel is small. Pesaran and Smith (1995) have demonstrated that the fixed effects panel estimator is biased in dynamic panels even when the time dimension is large if the coefficients on the lagged endogenous variables differ across cross-sectional units. Restricting the heterogeneous coefficients to be the same across groups induces correlation between regressores and the error term as well as serial correlation in the residuals, thus giving rise to estimation bias even if instrumental variables approaches are used. In order to overcome this problem, Pesaran and Smith (1995) have proposed a mean group panel estimator where seperate regressions are estimated for each cross sectional unit and panel estimates are obtained by means of taking cross sectional averages of the estimation results. However, as shown by Hsiao *et al.* (1999), the mean group estimator is also biased in dynamic panels with small time dimension, which is essentially the reflection of the well-known finite sample autoregressive bias in time series models (Hurwicz 1950). Hsiao *et al.* (1999) document based on a Monte Carlo study measurable biases of the mean group estimator for sample sizes of up to T=20. In our application, T=42, which means that the bias will be small, though probably not entirely negligible.

3.1 Benchmark specification

The panel VAR model that we consider has the following representation:

$$Y_{i,t} = \alpha_i + A(L)_i Y_{i,t-1} + B_i \varepsilon_{i,t} \tag{1}$$

where $Y_{i,t}$ is a vector of endogenous variables, α_i a vector of constants, $A(L)_i$ a matrix polynomial in the lag operator L, and B_i the contemporaneous impact matrix of the mutually uncorrelated disturbances ε_i for economies $i = 1, ..., N$. In the benchmark specification, the vector of endogenous variables $Y_{i,t}$ comprises four variables: the log of seasonally adjusted real GDP,[9] the log seasonally adjusted consumer price index, the log level of seasonally adjusted central bank assets,[10] and the level of implied stock market volatility (VIX) of the national stock market index.[11]

This specification, while highly parsimonious for the sake of analytical tractability under the constraint of a rather short sample period, aims to grasp the main features of the crisis. First, the dynamics of aggregate output and prices are supposed to capture the macroeconomic dimension of the crisis.

Second, central bank assets represent the (unconventional) monetary policy instrument while policy rates are not included in the benchmark model. This reflects the notion that, with the reaching of the lower bound of policy rates and the widespread adoption of unconventional monetary policies, interest rate rules have implicitly been replaced by quantitative reaction functions in the spirit of McCallum (1988), where the main policy instrument is a quantitative aggregate.[12] In the benchmark VAR specification, we include central bank assets instead of the monetary base as the quantitative policy instrument since the analysis in Section 2 suggested that the former is a more accurate gauge of unconventional monetary policies during the crisis than the latter.[13]

[9] A monthly measure of real GDP was obtained based on a Chow-Lin interpolation procedure using industrial production and retail sales as reference series.

[10] Total financial assets in the case of Norges Bank.

[11] The specification of the VAR in levels allows for implicit cointegrating relationships in the data (Sims *et al.* 1990). A more explicit analysis of the long-run behavior of the various variables is however limited by the relatively short sample available.

[12] However, the results are robust to including policy rates in an extended specification of the panel VAR (see Section 5).

[13] Moreover, Borio and Disyatat (2010) suggest that, because of the close substitutability of bank reserves

Central bank assets proxy for the effects of the different unconventional monetary policy measures described in the previous section, i.e. large-scale lending to banks to bring down risk spreads in money markets, FX interventions to address currency appreciation or purchases of public or private securities to bring down long-term interest rates. This obviously fails to take into account possible composition effects, i.e. differences in the effectiveness of different types of unconventional monetary policies. However, if such differences are important, this should be reflected in the individual country results on which the mean group estimator will be based and which are reported in Section 6.

Third, the benchmark VAR model contains the implied stock market volatility index (VIX) for each economy as a general proxy for financial turmoil and economic risk over the sample period. The VIX, which is commonly referred to as a "fear index" (Whaley 2000) reflecting its capacity as an indicator for financial market risk aversion, should also capture uncertainty shocks that have probably been an important driver of macrofinancial dynamics during the crisis (see e.g. Bloom 2009, Bacchetta and van Wincoop 2010, Bruno and Shin 2012).

Conditioning on such an indicator is of key importance to disentangle exogenous innovations to central bank balance sheets from endogenous responses to financial market risk perceptions and uncertainty, as unconventional monetary policies were launched and balance sheets increased in direct reaction to financial and macroeconomic jitters. As was shown in Section 2, central bank assets increased dramatically with the intensification of the crisis when stock market volatility exploded. In fact, both variables spiked at exactly the same time, namely in October 2008. Failing to take into account the endogenous reaction of central bank balance sheets to financial turbulence and economic uncertainty could seriously bias the estimation results. For instance, the econometric model could potentially attribute the fall in output and prices that followed the collapse of Lehman Brothers to the increase in central bank assets although it was driven by the rise in risk aversion and financial market instability. The importance of the inclusion of the VIX as a proxy for financial turmoil and uncertainty in a VAR in order to properly identify

and other short-term central bank paper, the effectiveness of balance sheet policies does not hinge on an accompanying change in the monetary base. Notice, however, that the results are robust to using base money as the policy instrument as well as adding policy rates to the benchmark VAR model (see Section 5).

an unconventional monetary policy shock during the crisis can be seen as analogous to the importance of including indicators for future inflation, such as commodity prices, in conventional monetary policy VARs to identify a conventional monetary policy shock (see e.g. Sims 1992, Christiano *et al.* 1999).

3.2 Identification

An unconventional monetary policy shock is identified as an exogenous innovation to the central bank balance sheet. Isolating exogenous balance sheet shocks involves making identifying assumptions to estimate the parameters of the feedback rules which relate central bank actions to the state of the economy, i.e. the variables policymakers look at when setting their operating instruments (Christiano *et al.* 1999). To do so, we use a mixture of zero and sign restrictions on the contemporaneous impact matrix B of equation (1). Combinations of zero and sign restrictions have been used in the literature before (e.g. Eickmeier and Hofmann 2012, Peersman 2012). By imposing additional zero restrictions, the number of admissible impulse responses is reduced and hence the identification is sharpened, provided the zero restrictions are reasonable (Uhlig 2005). In our case, the use of zero restrictions in combination with sign restrictions further serves the purpose of disentangling real economy from unconventional monetary policy and other financial shocks without imposing a significant impact on the responses of macro variables, which should be left open as it is the research question asked by this paper.

The identifying restrictions we impose are the following. First, we assume that there is only a lagged impact of shocks to the central bank balance sheet on output and consumer prices. In other words, the contemporaneous impact on both variables is restricted to be zero. On the other hand, innovations to output and consumer prices are allowed to have an immediate effect on the balance sheet (and stock market volatility). This assumption, which is common in monetary transmission studies, disentangles monetary policy shocks from real economy disturbances such as aggregate supply and demand shocks without forcing the macroeconomic variables to respond in a certain direction.

Second, we assume that an expansionary unconventional monetary policy shock does not increase stock market volatility. This restriction is needed in order to disentangle ex-

ogenous innovations to the central bank balance sheet from their endogenous response to financial turmoil, and from financial market disturbances. It follows as a complementary restriction from the assumption that central bank assets increase in response to innovations to the VIX, reflecting the above consideration that central banks responded often immediately through unconventional policies to mounting financial market uncertainty. A recursive structure with central bank assets ordered after stock market volatility is inadequate and potentially biasing since monetary policy interventions should be allowed to immediately influence financial market sentiment.[14] The advantage of using a sign restriction is that such a zero constraint on the contemporaneous impact is not imposed. At the same time, the sign restriction reflects the notion that unconventional monetary policies had the effect of mitigating concerns about financial and economic instability captured by stock market volatility.[15] Indeed, there is widespread agreement that in particular central banks' unconventional monetary policy actions were crucial to mitigate the tail risks of a financial meltdown (BIS 2012).

The identifying assumptions are summarized in the table below. The sign restrictions are imposed on impact and the first month after the shock. The identification scheme therefore allows for the possibility that an unconventional monetary policy shock initially impacts primarily the VIX and affect central bank assets only with a lag. It can hence accommodate the fact that unconventional policies are usually announced before they are implemented. At the same time, the identified shocks will in particular capture the implementation of unconventional monetary policy actions as reflected in the size of the central bank balance sheet. Our analysis can therefore be seen as an assessment of the

[14] The need to allow for contemporaneous interaction between monetary policy and financial market variables in the context of the analysis of the transmission of conventional monetary policy shocks has been emphasised by Bjørnland and Leitemo (2009) and Eickmeier and Hofmann (2012).

[15] Put differently, non-standard monetary policy measures which did lead to increased volatility are not identified but captured by the remaining innovation in the VAR. Notice that the sign restriction is also consistent with the negative link between financial market liquidity and volatility established by Brunnermeier and Pedersen (2009) and evidence on the interaction between the VIX and conventional monetary policy presented in Bekaert *et al.* (2010).

overall "stock effect" of central bank balance sheet policies on the macroeconomy.[16]

Identification of an unconventional monetary policy shock

Output	Prices	VIX	Central bank assets
0	0	$\leqslant 0$	> 0

3.3 Estimation

The panel VAR is estimated over the sample period January 2008 – June 2011 and includes eight industrial economies: Canada, the euro area, Japan, Norway, Switzerland, Sweden, the United Kingdom and the United States. Data were taken from the BIS database, Datastream and national sources. Based on the usual lag-length selection criteria, the estimations include two lags of the endogenous variables.[17]

The mean group panel VAR is estimated in several steps. First, each equation of the reduced form VAR is estimated at the individual country level taking into account the correlation amongst the residuals of the same endogenous variable across economies (i.e. the correlation between all output residuals, between all price residuals, between all VIX residuals, and between all balance sheet residuals). This can accurately be done using the Zellner (1962) Feasible Generalized Least Squares (FGLS) estimator given the fact that we only have eight economies in our panel. Accordingly, (unobserved) factors that are common to all economies such as oil shocks or financial market disturbances which are not captured by the VIX are taken into account in the estimations. Estimating the equations separately by OLS, which is usually done for individual country VARs, would waste such information. The greater the correlation of the residuals across economies, the greater the efficiency gain of applying FGLS.

Second, we identify the unconventional monetary policy shocks of each individual economy by using a mixture of zero and sign restrictions as described in section 3.2. Specifically, since the shocks in equation 1 are mutually orthogonal, $E\left(\varepsilon_t \varepsilon_t^{'}\right) = I$, the variance-

[16] The importance of the stock effect of bond purchases, i.e. the negative impact on bond yields of higher bond holdings by the central bank, has been emphasised and demonstrated in a number of recent papers (e.g. D'Amico and King 2010, Meaning and Zhu 2011). Here, the concept of stock effect is applied more broadly pertaining to total assets held by the central bank.

[17] The results proved robust to different specifications of the lag length.

covariance matrix Ω of an individual country VAR system is equal to $BQQ'B'$, where B is the Choleski decomposition of Ω, and Q an orthonormal matrix of the form:

$$Q = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \cos(\theta) & -\sin(\theta) \\ 0 & 0 & \sin(\theta) & \cos(\theta) \end{bmatrix} \tag{2}$$

with $QQ' = I$. Since B is the Choleski factor of Ω, innovations to output and prices do have an immediate effect on stock market volatility and the balance sheet, whereas the contemporaneous impact of the third and fourth shock in the system on output and prices is restricted to be zero. One of them is an innovation to the VIX, and the other an exogenous shift to the central bank balance sheet, which are further disentangled by the sign restrictions.

Notice that there are an infinite number of possible Q depending on the value of θ. Hence, we draw a random θ in the range $[0, \pi]$, where θ is the same for all countries,[18] and generate the corresponding impulse response functions for each individual economy:

$$R_{t+k} = A(L)^{-1} BQ(\theta)\varepsilon_t \tag{3}$$

If the impulse response functions of one of the two remaining shocks satisfy the sign restrictions for all countries simultaneously, i.e. $R^{VIX}_{t+k} \leqslant 0$ and $R^{TA}_{t+k} > 0$, the draw is kept. Otherwise the draw is rejected. We then average the impulse response functions from the individual economies to get a mean group impulse response function. We repeat this procedure by means of bootstrapping until we have 5,000 mean group impulse response functions.[19] In the figures, we report the 16th and 84th percentiles of this exercise, as is standard in the sign restrictions literature. The impulse response bands in the figures reflect both model uncertainty (draw of θ) and sampling uncertainty (bootstrapping draw),

[18] The common θ implies that the candidate decompositions for all economies are from the same structural model, resulting in a mean decomposition which is also from that model. See Fry and Pagan (2007) for issues related to mixing multiple models when using sign restrictions, and Peersman (2005) for a detailed explanation of the method.

[19] On average, about 23 draws are needed to have a successful decomposition for all individual countries.

and should not be interpreted as conventional confidence bands.

4 Benchmark panel VAR results

Figure 3 shows the impulse responses for an unconventional monetary policy shock obtained from the panel VAR. The impulse responses indicate that the shock is characterized by an increase in the central bank balance sheet of about 3% which fades out after about six months.[20] In line with the imposed sign restrictions, implied stock market volatility falls on impact by about 1 percentage point, but the response remains negative for almost one year.

The responses of output and prices indicate that unconventional monetary policy measures are effective in supporting the macroeconomy. Both output and prices display a significant increase. Output is found to rise with a peak effect after about six months and to gradually return to baseline after about 18 months. Compared to the existing evidence on the transmission of conventional monetary policy shocks that are associated with a change in the short-term interest rate, the response pattern of output is qualitatively very similar. The impact on prices is, however, different. We find a temporary significant effect with a peak coinciding with that of the output response, while the impact of interest rate shocks on the price level is found to be very sluggish with a peak only after about two years or even later.[21]

When we compare the magnitudes of the effects, it appears that unconventional monetary policy shocks have relatively larger output and smaller price effects than conventional monetary policy shocks. More precisely, the peak effect of an unconventional monetary policy shock on output is estimated to be about three times larger than the peak effect on prices. In contrast, studies on the transmission of interest rate shocks (e.g. Christiano *et al.* 1999, Peersman and Smets 2003, Eickmeier and Hofmann 2012) usually find the effect

[20] The finding that central bank assets return to baseline is consistent with the response pattern of short-term interest rates after a conventional monetary policy shock. It reflects the feedback effects of lower stock market volatility and improved macroeconomic conditions through the estimated implicit reaction function for central bank assets.

[21] At this stage, it is not possible to pin down whether this difference is the result of the relatively short sample period of our analysis compared to the longer datasets that are used in the existing literature on conventional monetary policy.

of a monetary policy shock on output to be only about 1.5 times larger than the impact on the price level. A similar relatively subdued effect on prices has also been obtained for the Bank of Japan's quantitative easing between 2001 and 2006 (e.g. Schenkelberg and Watzka 2011). One potential explanation for this weaker price level response could be that the unconventional monetary policy shocks were estimated over a recession or economic stagnation period where the aggregate supply function is potentially convex because of downward rigidity in nominal wages and prices (see e.g. Ball and Mankiw 1994). In such a situation, changes in aggregate demand, also those driven by monetary policy, would have a stronger effect on output and a weaker effect on prices. This explanation is also commonly put forward to explain why monetary policy shocks have a larger effect on output and a smaller effect on the price level in recessions (e.g. Peersman and Smets 2002, Weise 1999).

Across the eight economies covered by our panel analysis, the average increase of the size of central banks assets over the sample period was about 100%. When we take the panel evidence on the effects of interest rate shocks by Assenmacher-Wesche and Gerlach (2010) as a base for comparison, a back of the envelope calculation suggests that this doubling of balance sheets has an impact on output which is approximately equivalent to a 300 basis points cut in policy rates.

While these numbers are also very similar to those obtained by studies assessing the impact of unconventional monetary policy measures implemented by major central banks in response to the crisis,[22] it is important to note that the massive expansion of central bank balance sheets in the wake of the crisis did not represent an exogenous unconventional monetary policy shock. This becomes clear when we consider the variance decomposition of the mean group panel VAR reported in Figure 4.[23] The decompositions indicate that

[22] For the United States, Chung *et al.* (2011) estimate that the Federal Reserve's programmes (LSAP1 and LSAP2) will raise the level of real GDP almost 3% by the second half of 2012, a stimulus that would have required cutting the federal fund rates by approximately 3 percentage points relative to baseline from early 2009 to 2012. For the United Kingdom, a recent Bank of England study (Joyce, Tong and Woods 2011) concludes that the bond purchases increased the level of GDP by 0.5–2% at the peak suggesting that the effect of quantitative easing was equivalent to a 150–300 basis point cut in the Bank Rate.

[23] The variance decomposition is performed based on the median target method of Fry and Pagan (2007). The shock labelled as "VIX shock" is implicitly identified as a by-product of our identifying restrictions for the unconventional monetary policy shock. It is a shock that increases the VIX and the central bank balance sheet and does not affect output and prices on impact. The impulse responses to this shock, which we do not report, show that it is associated with a short-lived sharp increase in the VIX and the central

exogenous balance sheet shocks account for only a small fraction of output and price variability. They are even not the main contributor to the forecast error variance of central bank balance sheets. Central bank assets are instead mainly driven by real economy shocks and innovations to the VIX. The latter disturbances explain approximately 40% of the forecast error variance. The endogenous reaction to shocks to aggregate uncertainty was therefore an important factor behind the evolution of central bank balance sheets and probably mitigated substantially the macroeconomic fallout of these shocks during the crisis.[24] That said, the decomposition analysis further shows that volatility shocks also explain a considerable part of the forecast error variance of output and prices (between 30% and 40%), supporting the notion that risk shocks were important drivers of macroeconomic dynamics during crises.

5 Robustness analysis

5.1 Variations to the benchmark model

In order to assess the robustness of our results to alternative modelling choices, we consider five variations to the benchmark VAR. Specifically, we assess robustness of our results to (i) using the Fixed Effects (FE) estimator instead of the Mean Group estimator, (ii) using the monetary base as the quantitative policy instrument instead of central bank assets, (iii) using industrial production instead of real GDP as the measure of aggregate output, (iv) including a dummy variable for October 2008 when both the VIX and central bank assets spiked and (v) using a weighted mean group estimator, weighting the country impulse responses by the size of their economy,[25] instead of the standard unweighted mean group estimator.

Figure 5 shows the impulse response for the alternative model specifications (red lines) together with those of the benchmark model (shaded areas). The first column of the figure shows that our findings are qualitatively robust with regard to the type of panel

bank balance sheet and a temporary strong and highly significant decline in output and prices.

[24] Historical decompositions at the individual country level, which we do not report for the sake of brevity, further reveal that in particular the sharp increase in central bank balance sheets after the collapse of Lehman Brothers was almost entirely driven by innovations to the VIX variable.

[25] The country impulse responses were weighted by GDP at 2005 Purchasing Power Parities.

estimator used. The effects based on the FE estimator are somewhat more persistent and quantitatively somewhat larger. This finding is consistent with differences between mean group and fixed effects estimation results identified by previous studies (e.g. Assenmacher-Wesche and Gerlach 2008) and reflects the problems associated with the Fixed Effects estimator in dynamic panels outlined in more detail in Section 3.

The benchmark results also turn out to be robust to the use of the monetary base as the quantitative policy instrument (see second column of Figure 5). The effects of a shock to the monetary base on output and prices are very similar to the baseline case. For all variables, the impulse response ranges of the two models overlap for all response horizons. Quantitatively the estimated effects of a base money shock are somewhat larger which however primarily reflects the slightly larger size of the underlying shock as reflected in the larger impact effect on the monetary base.

When industrial production is used as the measure of output instead of real GDP (third column of Figure 5), the results are essentially unaffected. The only difference is that the reaction of output is somewhat larger. This finding is consistent with a higher responsiveness of industrial production to monetary shocks that is also found in the literature on the transmission of interest rate shocks.

Including a dummy for October 2008 does also not affect the results in any material way (see fourth column of Figure 5). The impulse response ranges are virtually indistinguishable from the baseline case. The only noticeable difference is the slightly smaller estimated impact on central bank balance sheets. Therefore, the coincident sharp increase in stock market volatility and central bank balance sheets in the wake of the Lehman collapse in October 2008 does not drive our results.

Finally, the weighted mean group estimates are also very similar to the benchmark unweighetd estimates (fifth column of Figure 5). The impulse response ranges overlap for all variables for every response horizon. Quantitatively, the estimated effects on output and prices are slightly larger for the weighted mean group estimator, reflecting the slightly larger effects we obtain for some big economies, as discussed in more detail in Section 6.

5.2 Model extensions

We also assess the robustness of the benchmark results to the inclusion of additional variables that might have a bearing on the analysis. Specifically, we consider two extensions of the benchmark model: (i) a version including the policy rate and (ii) a version including the outstanding debt of the central government.

While policy rates have been at their effective lower bounds most of the time in the sample period, the analysis still includes the policy rate cuts that occurred during 2008 and early 2009 and a few rate hikes later on. There is hence the risk that the unconventional monetary policy shocks capture in part the effects of these policy rate cuts. In order to assess the relevance of this potential caveat, we add the policy rate to the benchmark VAR and identify the central bank balance sheet shock with the additional restriction that it does not affect the policy rate on impact. This is done to avoid that the unconventional monetary policy shock is associated with a change in the policy rate. Figure 6 shows the impulse responses for the balance sheet shock obtained from this extended model together with the impulse responses from the benchmark model. The charts show that there is virtually no significant difference. The bands are very similar in shape and overlap for all variables. The central bank balance sheet shocks identified in the benchmark model thus do not appear to be materially contaminated by the effects of policy rate changes.

In a second model extension, we consider potential overlaps of central bank and government balance sheet policies. Fiscal authorities in many of the economies covered by our analysis responded to the financial crisis by adopting a number of support measures for the financial sector and stimulus packages for the economy. Some of these measures (of course not those that took the form of guarantees) can also be interpreted as balance sheet policies as they were associated with an increase in the public debt that was similarly dramatic as the increase in central bank balance sheets. These expansions of government debt could contaminate the unconventional monetary policy shock we identify in the benchmark model if shocks to public debt would have the same short-term effects as central bank balance sheet shocks, i.e. if they would also be associated with an increase in central bank assets and a fall in stock market volatility, whilst having a delayed impact on output and prices.

In order to address this potential caveat, we estimate an extended model including the outstanding debt of the central government in the model.[26] For the identification, we assume in addition to the benchmark identifying restrictions that the public debt does not react on impact to the central bank balance sheet shock. We further assume that innovations to public debt can have a contemporaneous impact on output and prices. These restrictions are consistent with the recursive identification schemes commonly adopted in studies on the macroeconomic effects of fiscal policy shocks. The impulse responses to a central bank balance sheet shock in this extended model, which are shown in Figure 7, are very similar to those from the benchmark model. The only notable difference is that the price response is now insignificant, but the response bands of the two models overlap. Public debt is found to fall significantly in response to the central bank balance sheet shock. This probably reflects positive feedback effects of the shock-induced increase in output on public finances.

6 Individual country estimates

Since the panel analysis is based on a mean group estimator, it also yields individual country estimates. We can thus directly assess the degree of cross-county heterogeneity in the dynamic effects of central bank balance sheet shocks. The individual country results could also shed some light on the differences in the effectiveness of different types of unconventional monetary policies. If certain types of unconventional monetary policies, e.g. large-scale bond purchases, would have stronger macroeconomic effects, then this should also be reflected in the estimated impulse responses for those countries that heavily relied on this specific measure.

The individual country results are reported in Figure 8. Specifically, the dotted (red) lines represent the estimated impulse response bands for each individual economy, whereas the shaded areas those of the panel VAR. The dynamic effects of a shock to central bank assets turn out to be qualitatively similar across countries and comparable to the panel

[26] Monthly data on outstanding central government debt are available for all countries except for Switzerland where quarterly data were interpolated using a Cubic spline. The data were obtained from national central banks and national debt management agencies.

results. In particular, the panel VAR and the individual-country impulse responses overlap most of the times. For most economies, we find a significant positive temporary impact on economic activity and also the magnitude of the effect appears to be fairly similar. The effect on the price level is, however, somewhat more dispersed across countries. In only half of the countries the impact on prices seems to be significant.

Inspecting the impulse responses in more detail, the dynamic effect of an unconventional monetary policy shock are very similar in the U.S., the euro area, Canada, and the UK, except for the insignificant price level response in the latter country. Interestingly, the euro area results are very similar both qualitatively and quantitatively to those obtained by Peersman (2011) using a different shock identification scheme and a sample that also covers the pre-crisis period. For Switzerland and Sweden, the output effects are somewhat more persistent than in the other economies, which is probably the result of the higher persistence of the shock in these economies as reflected in the longer lasting increase in central bank assets. On the other hand, the output responses are hardly statistically different from zero in Japan and Norway. This finding may be due to the relatively small changes in central bank assets in these economies over the sample period (see Section 2), which probably makes it more difficult to pin down the effects of an unconventional monetary policy shock.

As a robustness check, we have compared the individual country estimates obtained when the monetary base is used as the unconventional monetary policy instrument with those from the baseline model. The comparison, which is shown in Table A.1. in the Appendix, suggests that also the individual country results do not change materially when the monetary base is used as the policy instrument. The impulse response ranges for the different countries obtained from the two models are very similar in shape and essentially always overlap, suggesting that the differences are not statistically significant.

Overall, the qualitatively similar results at the country level suggests that the panel analysis does not seem to obscure considerable cross-country heterogeneity. This finding could also be interpreted as indicating that, despite the heterogeneity in the design and calibration of central bank balance sheet policies, their effectiveness was quite similar across countries, possibly because central banks designed these policies to the specific

needs of their respective financial sectors and economies.

7 Conclusions

This paper has examined the macroeconomic effectiveness of unconventional monetary policies adopted in the wake of the financial crisis by exploring the dynamic effects of a shock to the central bank balance sheet on output and the price level with a panel VAR estimated on monthly data from eight advanced economies over the crisis period. We find that an exogenous increase in central bank balance sheets at the zero lower bound leads to a temporary rise in economic activity and the price level. The qualitative response pattern of output is very similar to that obtained by previous studies on the effects of interest rate shocks, while the reaction of the price level is weaker and less persistent. The estimations also suggest that the macroeconomic effects of unconventional monetary policies are quite similar across countries. This implies that the panel results do not mask considerable cross-country heterogeneity in the macroeconomic effects of unconventional monetary policy measures, despite the differences in design and calibration. This possibly reflects that the different central banks tailored their unconventional policy measures with similar success to the specific needs of their respective financial sectors and economies.

These results suggest that the unconventional monetary policy measures adopted by central banks in the wake of the global financial crisis provided temporary support to their economies. However, this does not imply that an expansion of central bank balance sheets will in general have positive macroeconomic effects. The set-up of the analysis is specifically tailored to the crisis period, when unconventional monetary policy measures were actively used to counter financial and economic tail risk. The results therefore do not in general pertain to the possible effects of central bank balance sheet policy in non-crisis periods.[27] Moreover, our results also suggest that in order to bring about a significant monetary stimulus a massive expansion of central banks balance sheets is required, the

[27] It is further important to note that our analysis does not capture potential negative side-effects of prolonged monetary easing brought about by expanded central bank balance sheets in conjunction with low policy rates, such as delaying private and public sector balance sheet repair in the economies hardest hit by the crisis, global monetary policy spillover effects and longer-term risks for central banks' credibility and operational autonomy. See BIS (2012) for a more comprehensive discussion of these side-effects.

sheer size of which would appear to put limits on the usability of balance sheet policies as a regular policy instrument.

Finally, there are a number of caveats related to our analysis that need to be borne in mind. First, for the sake of tractability, the analysis does not explicitly assess the effectiveness of different types of unconventional monetary policies. The individual country results do not indicate that such composition effects are a major distorting factor, but a more careful analysis could be done in future research. Second, the analysis does not allow for cross-country spillover effects of unconventional monetary policy measures because the sample period is too small to extend the empirical model in this direction. The possible relevance of such effects does however not invalidate our approach, which focuses on the domestic effects of domestic unconventional monetary policy measures.

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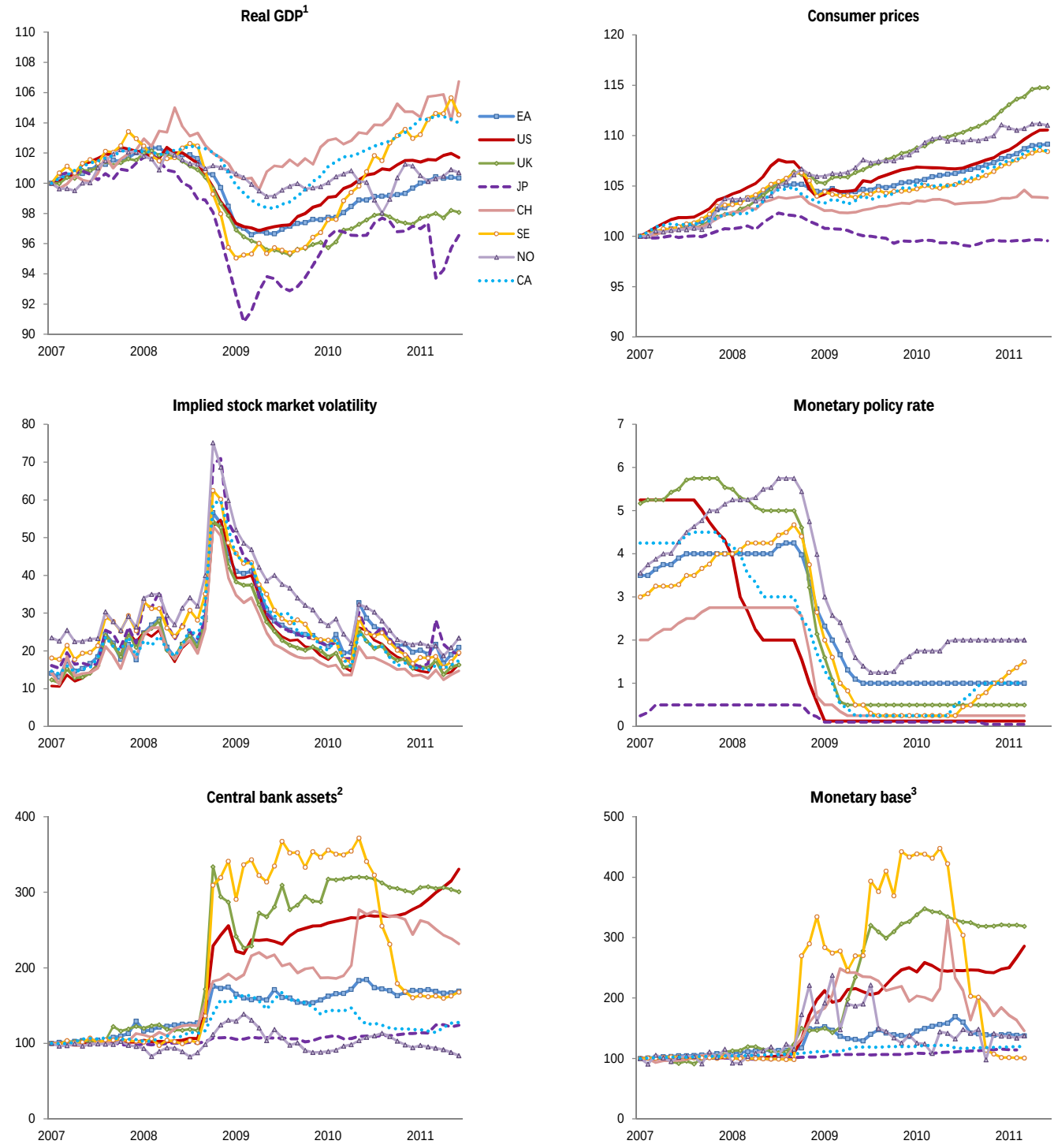
Figure 1 - Macroeconomic dynamics, financial market volatility and monetary policy



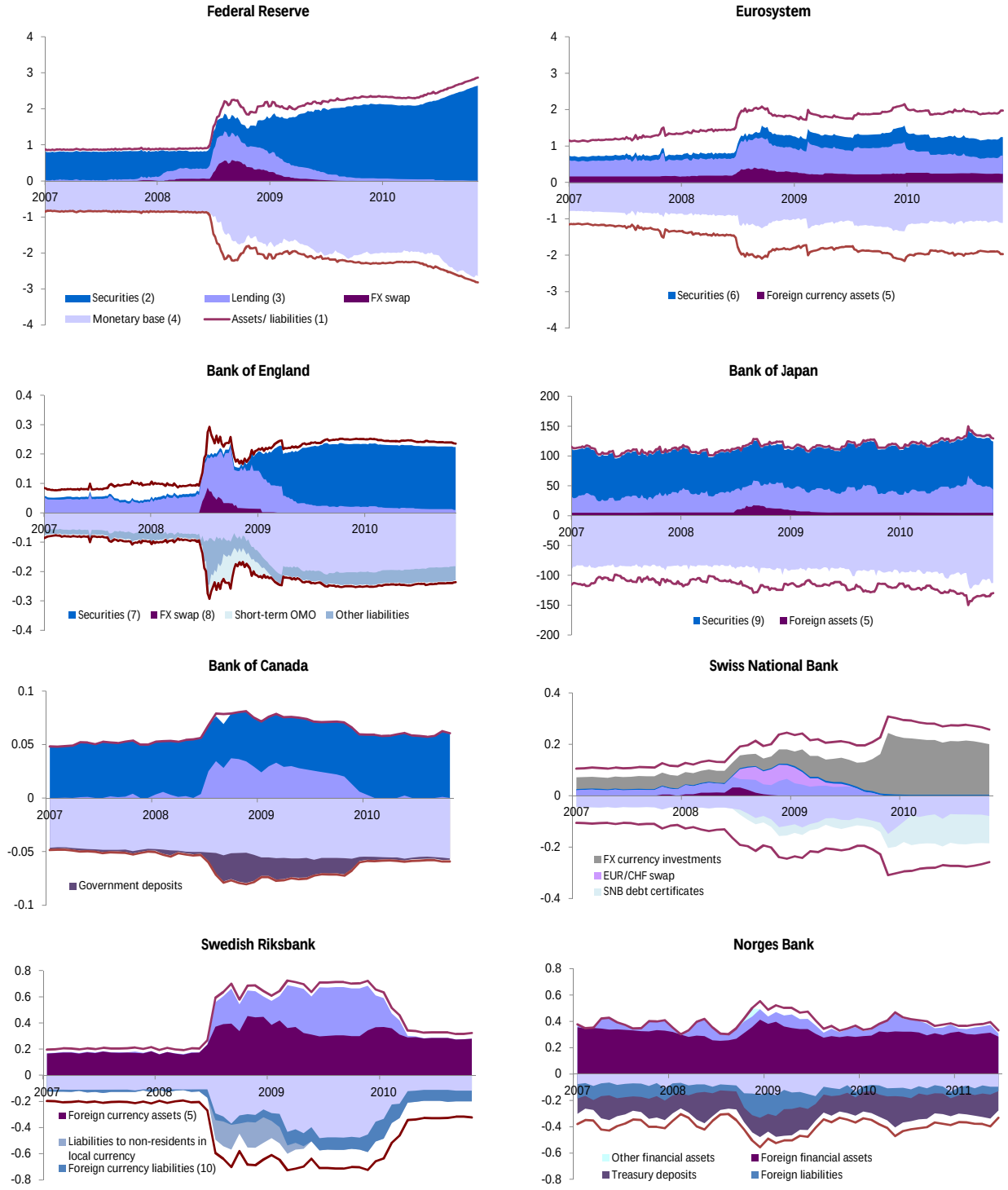
EA = Euro area, US = United States, UK = United Kingdom, JP = Japan, CA = Canada, CH = Switzerland, SE = Sweden, NO = Norway

Index of real GDP, the CPI, central bank total assets and the monetary base normalized to 100 in 2007M1.

[1] Monthly GDP series derived based on Chow-Lin interpolation procedure using industrial production and retail sales as reference series. [2] Total assets. For Norges Bank total financial assets. [3] Sum of currency in circulation and banks' deposits with the central bank. For the Eurosystem, including the deposit facility; for the Riksbank, including the deposit facility and Riskbank certificates.

Sources: Datastream; national data.

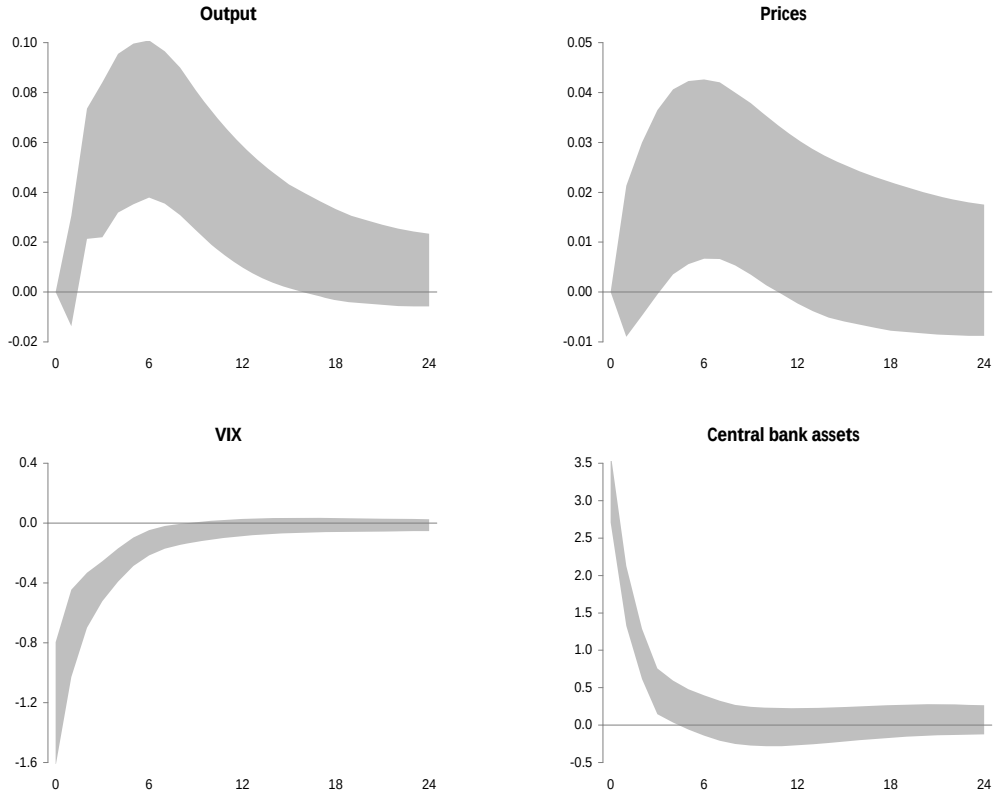
Figure 2 - Central bank assets and liabilities (trillions of respective currency units)



(1) Total assets/liabilities. For Norges Bank total financial assets/liabilities. (2) Securities held outright. (3) For the Fed: Repurchase agreements, term auction credit, other loans and Commercial Paper Funding Facility. (4) Defined as the sum of currency in circulation and banks' deposits with the central bank. For the Eurosystem, including the deposit facility; for the Riksbank, including the deposit facility and Riskbank certificates. (5) Defined as the sum of claims on residents and non-residents denominated in foreign currency; including US dollar liquidity auctions. (6) Securities issued by euro area residents, in euros. (7) Bonds and other securities acquired via market transactions and securities holdings of Bank of England Asset Purchase Facility Fund. The accounts of the Fund are not consolidated with those of the Bank. The Fund is financed by loans from the Bank which appear on the Bank's balance sheet as an asset. (8) Outstanding amount of US dollar liquidity auctions. (9) Defined as JGS and corporate bonds. (10) Defined as the sum of liabilities to residents outside Sweden denominated in foreign currency and liabilities to residents inside Sweden denominated in foreign currency.

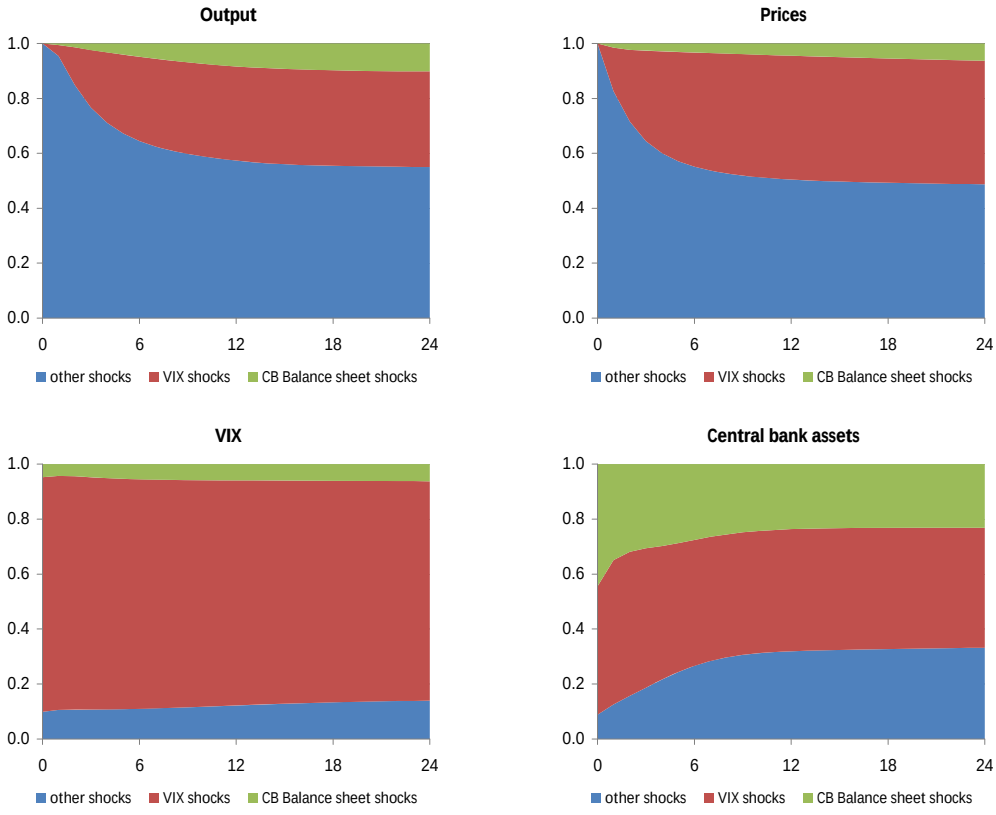
Sources: Datastream; national data.

Figure 3 - Impulse responses to a central bank balance sheet shock: mean group panel VAR estimation



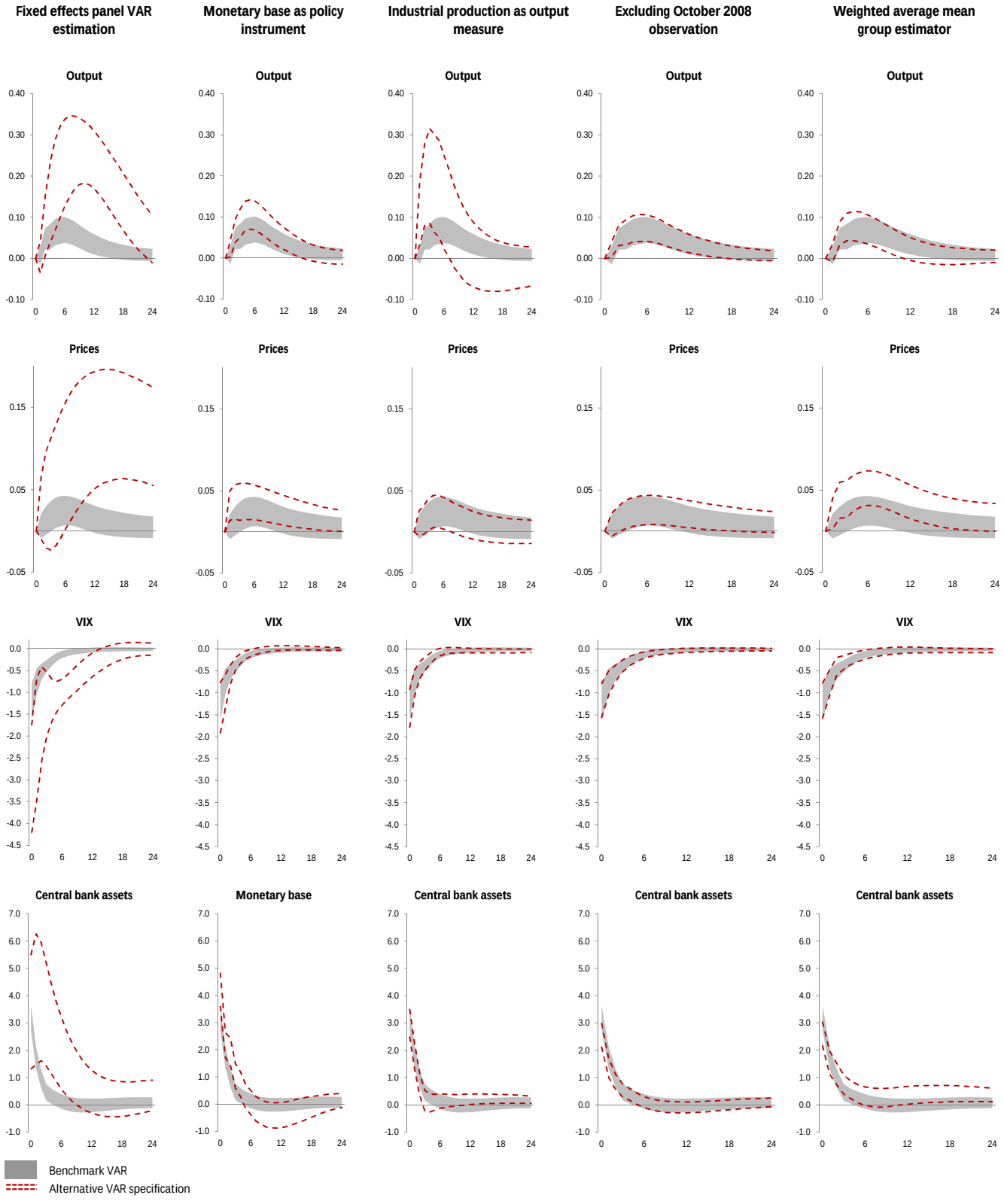
16th and 84th bootstrap percentiles, monthly horizon

Figure 4 - Forecast error variance decompositions



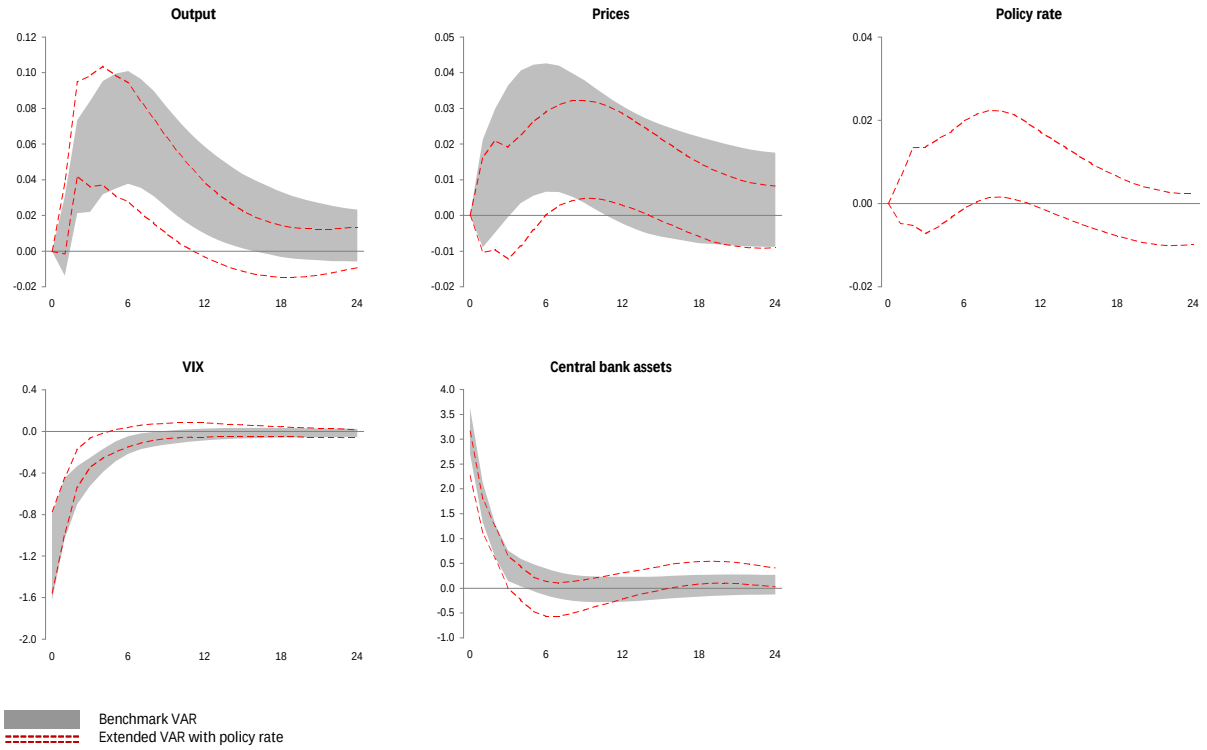
Based on the median target method (Fry and Pagan 2007), monthly horizon

Figure 5 - Robustness checks: Variations to the benchmark model



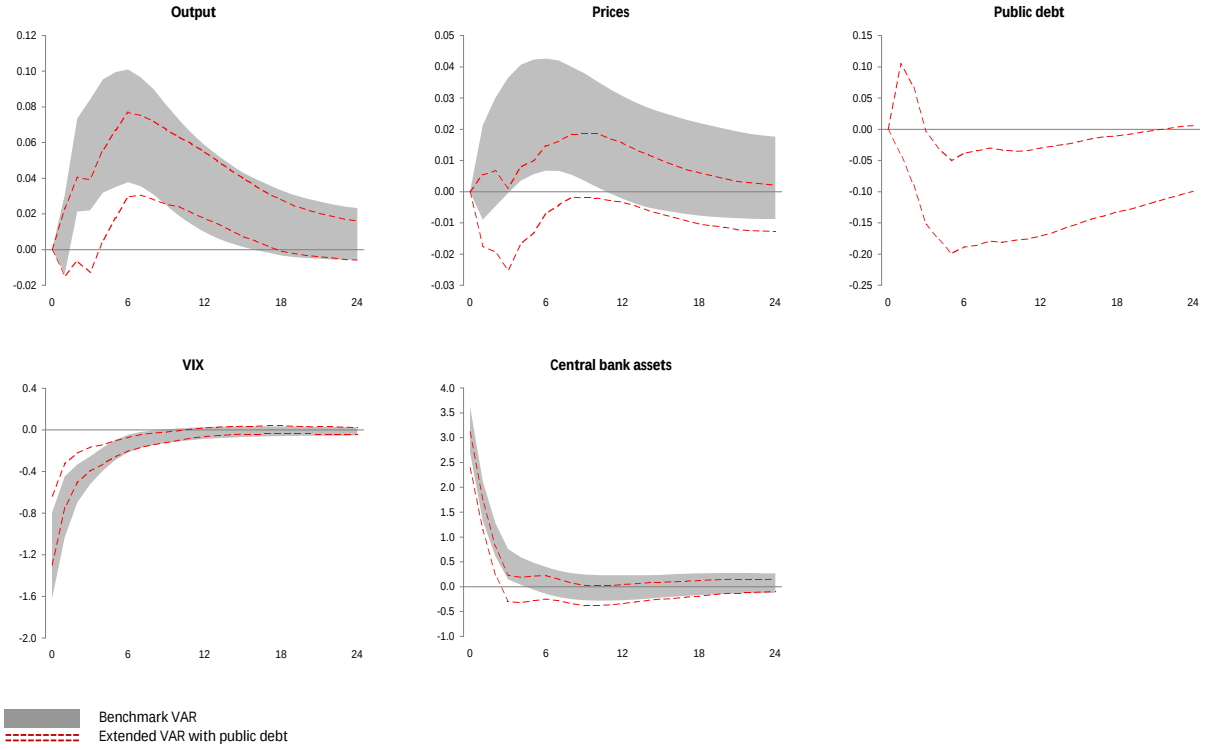
16th and 84th bootstrap percentiles, monthly horizon.

Figure 6 - VAR model with the monetary policy rate



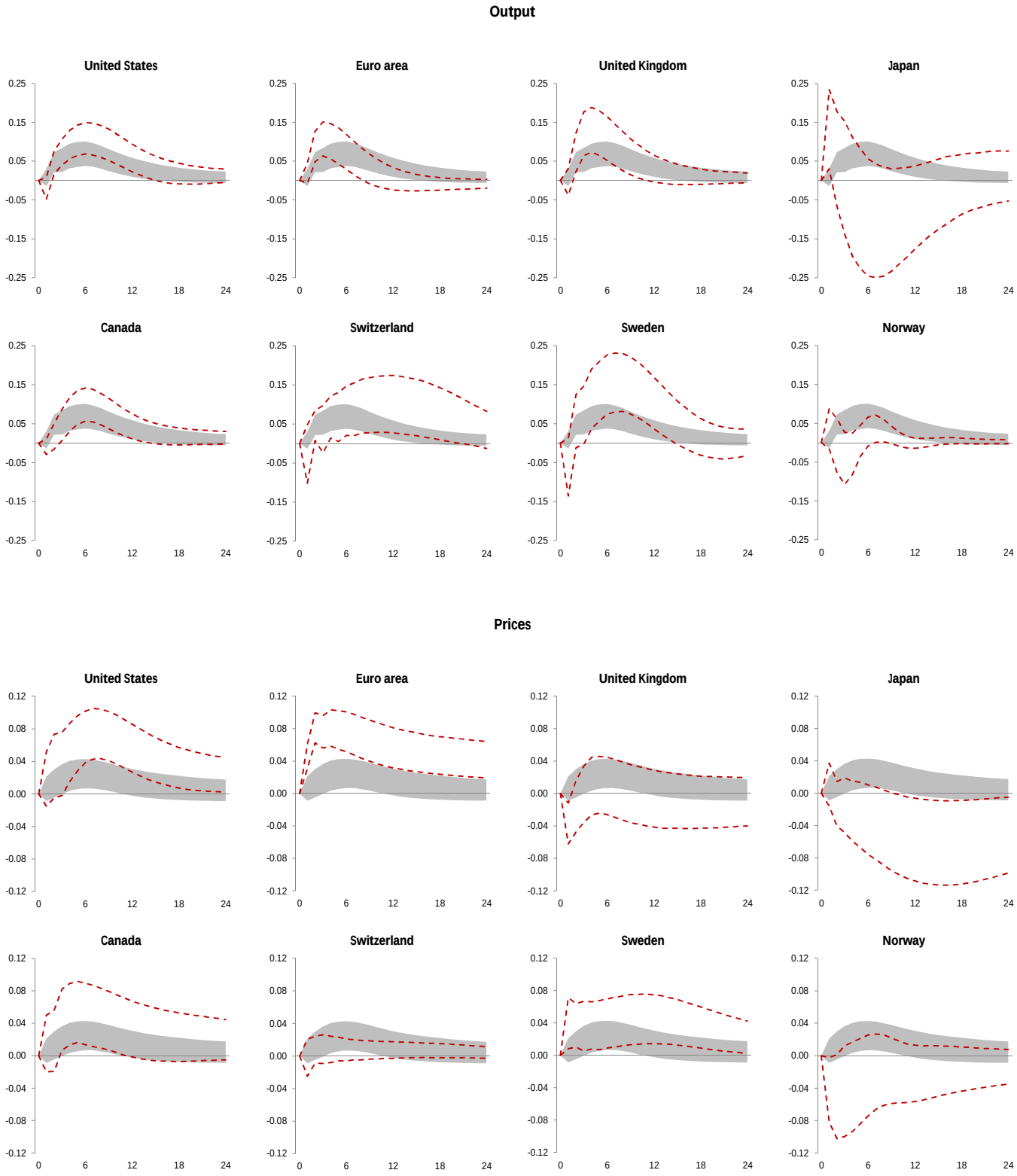
16th and 84th bootstrap percentiles, monthly horizon.

Figure 7 - VAR model with public debt



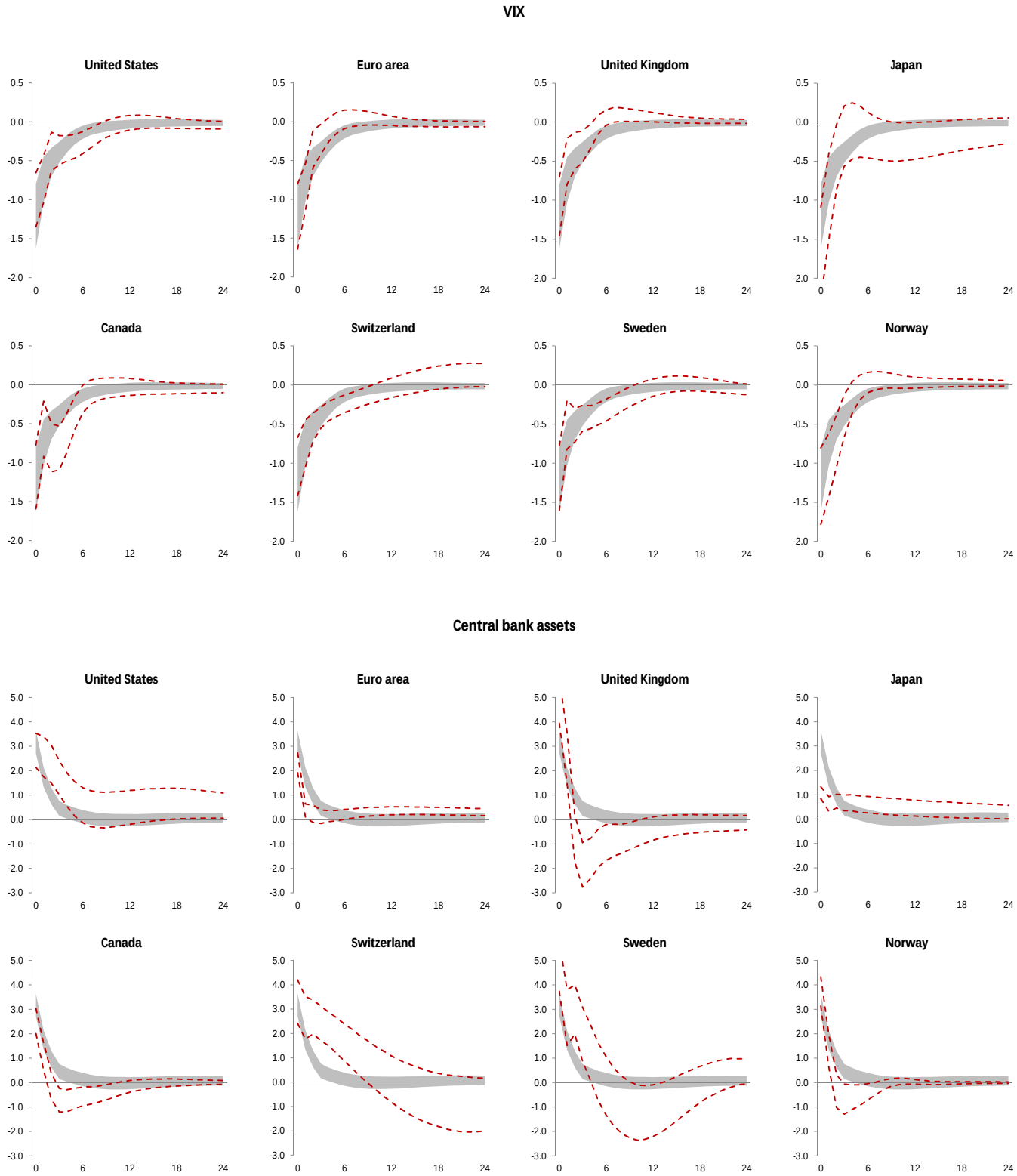
16th and 84th bootstrap percentiles, monthly horizon.

Figure 8 - Impulse responses to an unconventional monetary policy shock: individual country results



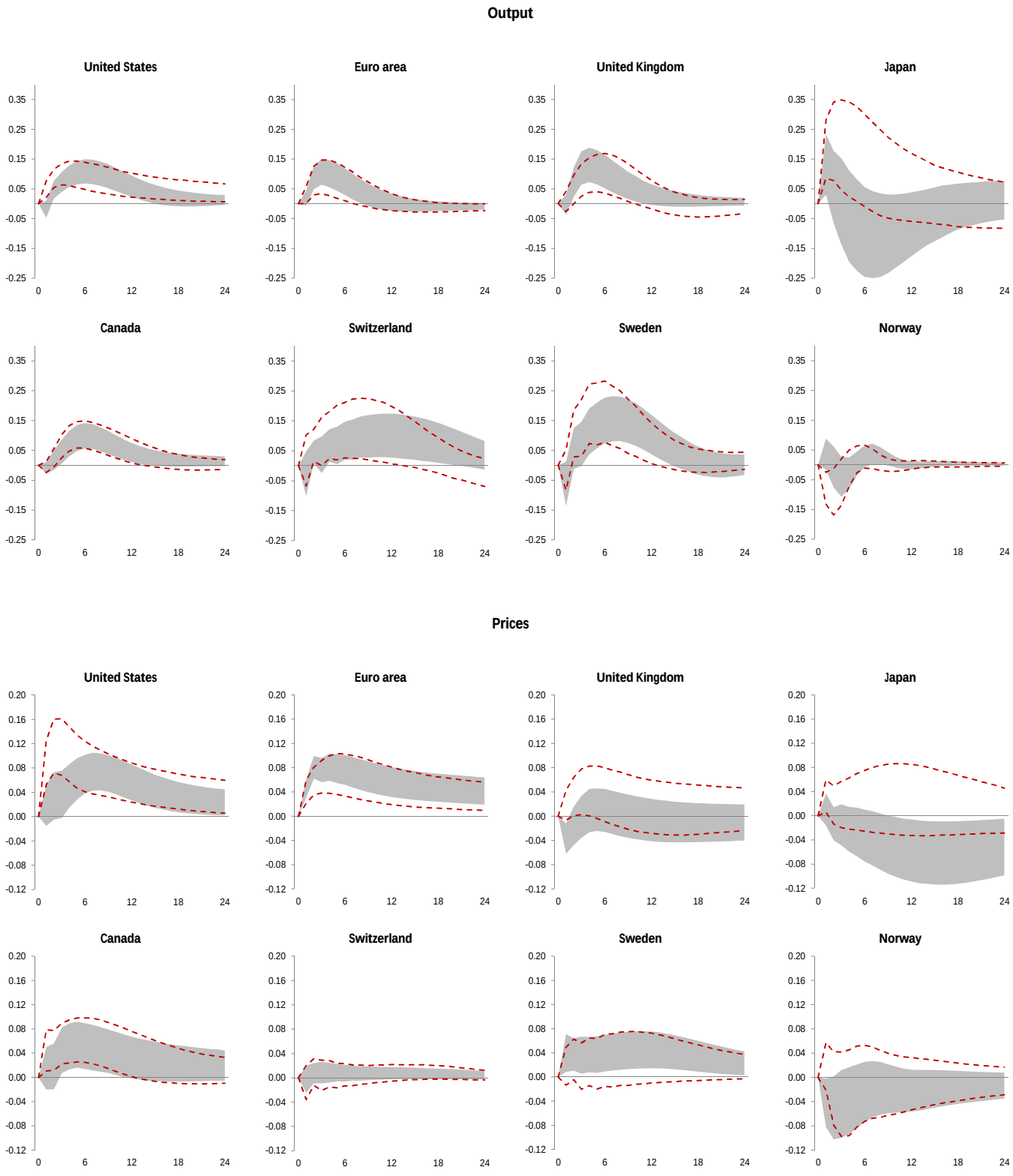
16th and 84th bootstrap percentiles, monthly horizon.

Figure 8 (continued) - Impulse responses to an unconventional monetary policy shock: individual country results



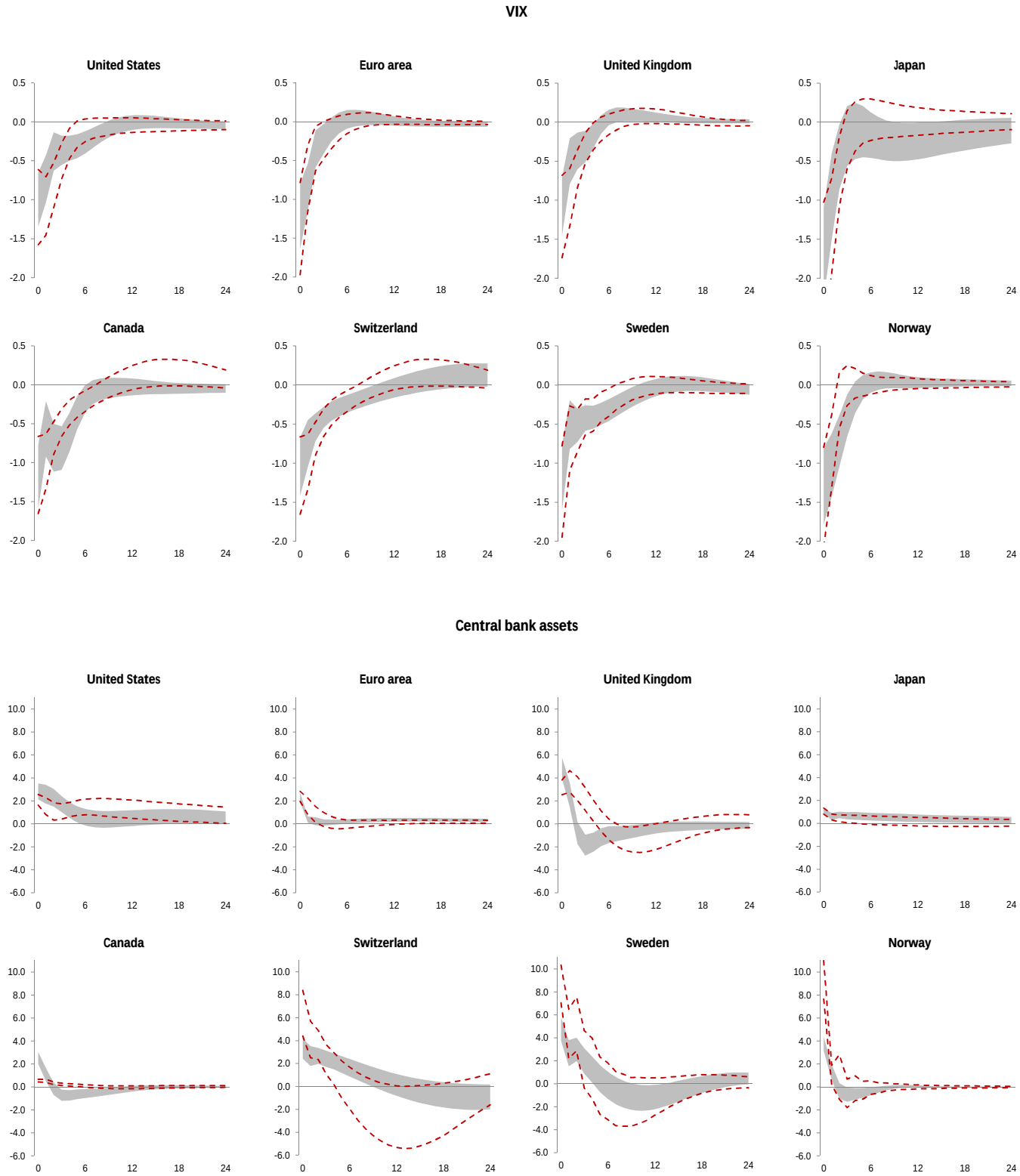
16th and 84th bootstrap percentiles, monthly horizon.

Figure A.1 - Individual country results when base money is used as unconventional monetary policy instrument



16th and 84th bootstrap percentiles, monthly horizon.

Figure A.1 (continued) - Individual country results when base money is used as unconventional monetary policy instrument



16th and 84th bootstrap percentiles, monthly horizon.