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WORKING PAPER

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 policy 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. The results suggest 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 response pattern of output is thus very similar to that usually found for interest rate shocks, while the reaction of the price level is less persistent. Looking at individual country results reveals that the effects of balance sheet shocks are very similar across countries.

JEL classification: C32, E30, E44, E51, E52
Keywords: unconventional monetary policy, zero lower bound, panel VARs

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1 Introduction

After policy rates had reached their lower bounds during 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. Central bank balance sheets basically replaced policy rates as the central banks' main policy instrument.[1] These balance sheet policies are often regarded as having been essential for stabilizing the macroeconomy and financial markets during the turmoil. The formal evidence on their macroeconomic effectiveness is, however, still sketchy. The literature has so far mainly focused on the financial market impact of unconventional monetary policy measures using high frequency financial data. Only very few papers go further and estimate the macro effects of unconventional policies (e.g. Chung *et al.* 2011, Lenza *et al.* 2011; Peersman 2011). This is however done based on models estimated over non-crisis periods, which may not be adequate for assessing macroeconomic dynamics and monetary transmission during a financial crisis. In particular, it is not clear whether the effects in normal times are similar as in a liquidity trap, i.e. a situation in which nominal interest rates are very low, possibly zero, and inflation is well below target, possibly negative (Benhabib *et al.* 2001; Bernanke and Reinhart 2004; Svensson 2003). On the other hand, there are a number of papers exploring the effectiveness of the Bank of Japan's policy of quantitative easing at the zero lower bound between 2001 and 2006. It is however questionable whether the experience of the Bank of Japan during that period can be generalized.

This paper takes a different approach by assessing the effects of unconventional monetary policies on the macroeconomy from a cross-country perspective, i.e. by analyzing jointly eight advanced economies which were at or near the zero lower bound in the crisis period: Canada, the euro area, Japan, Norway, Switzerland, Sweden, the United Kingdom and the United States. Of crucial importance in this context is the fact that the crisis was an important common factor in business cycle and financial market dynamics of these economies, and that the monetary policy response was widely associated with significant increases in central bank balance sheets and policy rates reaching their effective lower

[1] For an overview and categorisation of the various unconventional monetary policy measures taken by central banks during the crisis, see e.g. Borio and Disyatat (2009) and Stone et al. (2011).

bound. As such, there is a high degree of commonality that justifies the adoption of panel estimation techniques. By exploiting both the time dimension and the cross-section dimension of the economies that adopted unconventional monetary policies during the crisis, we can enhance the efficiency and power of the empirical analysis.[2]

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 the economies we consider, i.e. January 2008 - 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. The effectiveness of unconventional monetary policy is assessed by exploring the dynamic effects of exogenous innovations to the central bank balance sheet at or near the lower bound of the interest rate, conditioning on the state of the macroeconomy and, importantly, financial risk proxied by implied stock market volatility. While we choose the size of the central bank's balance sheet as our benchmark gauge of central bank liquidity supply, the results are robust to the use of the monetary base as the policy instrument.

The analysis shows that an expansionary balance sheet shock leads to a significant but temporary rise in output and prices. The output effects turn out to be qualitatively very similar to the ones typically found in the literature on the effects of conventional monetary policy shocks (e.g. Bernanke and Blinder 1992; Christiano *et al* 1999; Peersman and Smets 2003). The effects on the price level, on the other hand, are estimated to be somewhat less persistent. These results turn out to be robust to various perturbations of the model specification. Since the panel analysis is based on a mean group estimator, it also yields individual country estimates, so that we can directly assess the degree of cross-country heterogeneity in the dynamic effects of balance sheet shocks. The outcome of this comparison reveals that the individual country results are very similar to the panel results. This suggests that our focus on the panel analysis does not obscure considerable

[2] Gavin and Theodorou (2005) show that adopting a panel approach in a macro framework like our own 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.

cross-country heterogeneity. At the same time, it implies that despite the heterogeneity in the design and calibration of unconventional monetary policies, their effectiveness was probably very similar across countries.

The remainder of the paper is organized as follows: The next section discusses the existing empirical evidence and some stylized facts on unconventional monetary measures in the economies we consider. After a description of the econometric model and the data in Section 3, Section 4 highlights the main panel VAR results. Some robustness checks are performed in Section 5, whereas cross-country differences are discussed in Section 6. Finally, Section 7 summarizes the most important conclusions and the policy implications of our findings.

2 Unconventional monetary policies: some facts

2.1 Existing evidence

Most studies on the effectiveness of unconventional monetary policies focus on financial market impacts exploiting the availability of high frequency data. These works use event study techniques or regression analysis to quantify the effect of specific unconventional policy measures such as liquidity measures or asset purchases on risk spreads and yields in financial markets. The focus of these studies has been on the effects of central banks' liquidity measures on money market spreads in the first stage of the crisis (e.g. Christensen *et al.* 2009, Taylor and Williams 2009, Thornton 2010a) 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 *et al* 2011, Wright 2011). Overall, the evidence produced by these papers suggests that unconventional monetary policies were effective in reducing financial market spreads or yields, but the estimated quantitative effects vary widely across the different studies.[3] A number of studies have also presented evidence suggesting that the effectiveness of balance sheet

[3] 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.

policies depends on whether they are associated with an increase in total liquidity supply to financial markets.[4]

Only a few papers have attempted to come up with an assessment of the macroeconomic effects of recent unconventional monetary policy measures (e.g. Chung *et al.* 2010, Peersman 2011, Lenza *et al.* 2011). The main drawback of these assessments is that they are based on models that are estimated using pre-crisis observations. Baumeister and Benati (2010) aim to overcome this caveat by estimating the effects of unconventional monetary policy shocks based on a time-varying parameter VAR. However, since their unconventional monetary policy shock is forced to be associated with a change in the long-term government bond yield, it does not capture all of the measures that were taken during the crisis.

There are also a number of studies assessing the effectiveness of the Bank of Japan's quantitative easing policy between 2001 and 2006 (Baba *et al.* 2005a 2005b, Bernanke *et al.* 2004, Girardin and Moussa 2008, Schenkelberg and Watzka 2011). However, while the quantitative easing episode in Japan and the current global situation are similar to the extent that interest rates had reached their effective lower bound and central bank balance sheets became the prime monetary policy instrument, there are also a number of important differences. In Japan, quantitative easing was adopted in order to revive the economy from chronic economic stagnation and deflation, while recent measures were taken to fight an acute financial crisis. Moreover, Japan's crisis was at the time an isolated event, while the current crisis is of a global nature. Hence, it would appear *a priori* at least questionable to base an assessment of recent unconventional monetary policy measures on the Japanese experience with quantitative easing.

The evidence produced so far has hence mainly focused on the effects on financial market spreads. The macro effects of unconventional policies are typically evaluated based on models tailored to non-crisis periods, which may not be adequate for assessing macroeconomic dynamics and monetary transmission in crisis times. This paper takes a different approach by assessing the macroeconomic effects of balance sheet policies based exclu-

[4]Specifically, Taylor and Williams (2009) and Thornton (2010a) present evidence suggesting that the Federal Reserve's Term Auction Facility (TAF) was initially not effective in bringing down money market spreads because the effects of the programme on total liquidity supply was sterilized by government securities sales.

sively on observations from the period of the global financial crisis using data from a cross section of industrialized economies.

2.2 Central bank balance sheets and the global crisis

The global financial crisis was a key common factor in advanced economies' business cycles and financial market sentiment over the last four years. Figure 1 shows the evolution of key macroeconomic variables, financial market sentiment and indicators of the monetary policy stance since 2007 for eight advanced 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 shortly afterwards. Most economies even experienced deflation. The economic recovery since early-mid-2009 was very sluggish and interrupted by a number of backlashes, in particular in mid-2010 and again more recently with the sovereign debt crisis in the euro area. By mid-2011, many economies have still not fully recovered to their pre-crisis level of economic activity.

Figure 1 reveals that there was also a very close correlation across economies of the evolution of financial market sentiment, measured by the implied volatility index (VIX) for the major stock market index.[5] The VIX, which is commonly referred to as the "fear index" (Whaley 2000), is considered to be a prime gauge for financial market uncertainty and risk. 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 renewed concerns about the stability of the global financial system mounted, and recently with the onset of euro area sovereign debt crisis.

Reflecting this commonality of the experience of the crisis, there is also a strong cross-country commonality in the conduct of monetary policy over this period. After the in-

[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).

tensification of the crisis, policy rates were rapidly lowered and reached essentially in all economies their effective lower bounds in early 2009. In parallel, 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 faltering economies. 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 balance sheet, in contrast, increased only mildly over the crisis period. Most of the increase there in fact occurred in March 2011 when the Bank of Japan injected liquidity in response to the Tōhoku earthquake and tsunami.[6] 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 total assets increased only temporarily after the Lehman collapse. Reflecting the increases in balance sheet size, also the monetary base expanded considerably in most economies. However, the last two charts of Figure 1 show that the expansion was often not proportional to the increase in central bank total assets. Some central banks sterilized in part the effects of their unconventional policies on base money, while others took measures on the liability side of the balance sheet that had additional expansionary effects on the monetary base.

Figure 2 provides a breakdown of the eight central banks' balance sheets and their composition over the past four and a half years. The charts reveal that, while unconventional policies commonly led to an increase in central bank 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. 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 later by large-scale purchases of both private sector and government securities. The Eurosystem's unconventional monetary policy primarily focused on lending to financial institutions, reflecting the bank-based nature of the Eurosystem's financial system. In the wake of the euro area sovereign debt crisis and the subsequent introduction of the Securities Market Programme, security purchases however

[6] In terms of GDP, the size of Bank of Japan's balance is however larger than that of the other three major central banks. The Bank of Japan's total assets amount to about 30% of Japanese GDP, while the balance sheets of the Federal Reserve, the Bank of England and the Eurosystem amount to about 20% of the GDP of the respective economies.

became a more important factor in the Eurosystem's balance sheet. The expansion of Swiss National Bank's balance sheet was in turn mainly driven by purchases of foreign exchange.

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 in the empirical analysis.

3 Benchmark panel VAR model

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 (1995) 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. 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.[7] As discussed in Section 2.2, central bank responses, in particular the composition of measures, were different in the crisis period. Very likely, there is also cross-country heterogeneity in the monetary transmission mechanism.

The benchmark specification of the panel VAR model that we consider has the following

[7] Fixed effects estimators are inconsistent in dynamic panels if the coefficients on the endogenous variables differ across countries. In particular, restricting the coefficients to be the same across groups induces serial correlation in the residuals when the regressors are autocorrelated (Holtz-Eakin *et al.* 1988). This serial correlation does not vanish with instrumental variables. In contrast, a mean group estimator provides a consistent estimate of the mean effects by averaging across countries. See also Assenmacher-Wesche and Gerlach (2010) for a discussion of this approach within panel VARs.

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 comprises the log of seasonally adjusted real GDP,[8] the log seasonally adjusted consumer price index, the log level of seasonally adjusted total central bank assets, and the level of implied stock market volatility (VIX) of the national stock market index.[9] We do not include the policy rate in the benchmark specification since these rates reached the zero lower bound (or were constant at a very low level) in the economies analyzed over this period. However, as will be shown in Section 5, the results are robust to the inclusion of this variable.

One way to interpret the conduct of monetary policy during the crisis is that, with the reaching of the lower bound, interest rate rules have implicitly been replaced by quantitative rules where the main policy instrument is a quantitative aggregate (Bullard 2009). In the benchmark VAR specification, we choose central bank total assets instead of the monetary base as the gauge of total liquidity provision of central banks. We thus follow Borio and Disyatat (2009) who suggest that, because of the close substitutability of bank reserves and other short-term central bank paper, the effectiveness of balance sheet policies does not hinge on an accompanying change in the monetary base. The robustness checks in Section 5 reveal, however, that using base money or central bank total assets as the policy instrument does not change the results of the analysis.

We identify an unconventional monetary policy shock as an exogenous innovation to the central bank balance sheet. Isolating exogenous balance sheet shocks involves making assumptions about the variables that enter the central banks' balance sheet policy feedback rules. The VAR equation for the balance sheet variable can be interpreted as an implicit quantitative reaction function in the spirit of quantitative policy rules proposed

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

[9] 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.

by McCallum (1988). The specification of the VAR implies that balance sheet policies reacted to the state of the macroeconomy economy reflected in the dynamics of aggregate real economic activity and the aggregate price level. This is consistent with the standard specification of monetary policy VARs in the literature.

Our VAR specification further implies that balance sheet policies reacted to implied stock market volatility. This is consistent with the fact that the measures taken by the monetary authorities during the financial crisis were not exclusively driven by the dynamics of output and prices, but importantly also by concerns about financial instability. For instance, as discussed in Section 2, central bank balance sheets increased dramatically with the intensification of the crisis in October 2008 when concerns about a collapse of the entire financial system and the global economy spiked, well before this was reflected in output and consumer price measures. Ignoring the endogenous response of central banks to financial market disturbances could seriously bias the estimation results. The econometric model could potentially attribute the subsequent fall in output and prices to the rise in central bank balance sheets although this was just the reaction to the rise in risk perceptions and financial market instability that heralded the recession.

In order to capture the endogenous responses of central bank balance sheets to financial market risk perceptions and uncertainty, we have thus included in the VAR the implied stock market volatility index (VIX) of the respective major national stock indices as part of the information set of policymakers during the crisis period. As discussed in Section 2, this variable represents a reasonable proxy for financial market instability and uncertainty during the global financial crisis. This notion is also supported by recent research suggesting that financial crises and their macroeconomic consequences are driven to a significant extent by shocks to aggregate uncertainty and risk perceptions which are reflected in stock market volatility (see e.g. Bloom 2009, Bacchetta and van Wincoop 2010).

To identify exogenous balance sheet shocks, we impose a mixture of zero and sign restrictions on the contemporaneous impact matrix B of equation (1). First, we assume that there is only a lagged impact of shocks to the central bank balance sheet (and VIX shocks) 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 nominal shocks from real economy disturbances such as aggregate supply and demand shocks.

Second, in order to disentangle exogenous innovations to the balance sheet from endogenous responses to financial market disturbances, we assume that central banks reacted to increased financial market instability and risk perceptions (captured by a rise in the VIX) by expanding their balance sheets. This assumption reflects our above considerations that central banks responded with expansionary balance sheet policies to mounting financial market instability and uncertainty which can be reasonably approximated by the VIX. As a complementary identifying restriction, an exogenous expansion of the balance sheet, in turn, is assumed not to increase implied stock market volatility. From a conceptual point of view this restriction can be motivated in a number of ways. First, a volatility dampening effect of central bank balance sheet expansion can reflect the existence of a "confidence" effect whereby the expansion of liquidity provision by the central bank mitigates concerns about financial instability and macroeconomic risk which dampens financial market volatility.[10] Second, an increase in central banks' liquidity supply would in principle increase financial market liquidity which in turn lowers financial market volatility as a result of the well established negative link between market liquidity and volatility (Brunnermeier and Pedersen 2009). Finally, a negative association between central bank liquidity supply and the VIX can be motivated by theoretical arguments in the spirit of the monetarist transmission process suggesting that an increase in liquidity provision reduces financial and credit market risk premia which are proxied by the VIX.[11] The sign restrictions are imposed on impact and the first period after the shock and can

[10] See Kimura and Small (2006) who also provide evidence on the dampening effect of the Bank of Japan's quantitative easing policy on financial market volatility in Japan.

[11] The sign restrictions are also consistent with evidence on the interaction between the VIX and conventional monetary policy, i.e. the dynamics of the Federal Funds rate, presented in Bekaert et al (2010). Notice also that exogenous unconventional policies which do not result in a decline in the VIX are simply not captured by the estimated innovation.

be summarized as follows:

Identification of an (unconventional) central bank balance sheet shock

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

The benchmark 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.[12]

The mean group panel analysis is based on the following procedure. 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 (GLS) 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 also 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 GLS. Second, we draw a random possible decomposition B of the variance-covariance matrix at the individual country level with the restriction that the candidate decompositions for all economies should come from the same structural model, which guarantees that also the mean group decomposition is obtained from the same model at a later stage.[13] Third, the random possible decompositions are used to construct impulse response functions for each individual economy. If the impulse

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

[13] Practically, this means that the rotation matrix to generate a possible decomposition of the variance-covariance matrix has to be the same across countries. See Peersman (2005) for the derivation of such possible decompositions, and Fry and Pagan (2007) for issues related to mixing multiple models when using sign restrictions.

response functions satisfy the imposed restrictions for all economies simultaneously, the draw is kept. Otherwise the draw is rejected. Finally, we average the impulse response functions from the individual economies to get a mean group impulse response function. We repeat this procedure a sufficient number of times by means of bootstrapping until we have 5000 mean group impulse response functions.[14] In the figures, we report the 16th and 84th percentiles of this exercise.

4 Benchmark results

Figure 3 shows the impulse responses for a balance sheet shock obtained from the panel VAR. The impulse responses indicate that the central bank balance sheet shock is characterized by an increase in the balance sheet of about 3% which fades out after about six months. 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 suggest that central bank balance sheet shocks do indeed have a positive effect on the macroeconomy. Both output and prices display a significant temporary increase. Output is found to rise with peak effect after about six months and a gradual return to baseline after about 18 months. The effect on the price level is smaller and less significant. It peaks after six months and is significant for less than a year. Compared to the evidence produced by the broad literature on the transmission of "conventional" monetary policy shocks associated with a change in the short-term interest rate, the response pattern of output is qualitatively very similar. The reaction of prices is somewhat different as interest rate shocks are commonly found to have a longer lasting negative effect on the price level.

Quantitatively, the peak effect of a balance sheet shock on output and prices is respectively 0.06% and 0.025%. In order to put these estimates in perspective, we can compare them with the quantitative effects of interest rate shocks estimated in the literature. For instance, Peersman and Smets (2003) estimate peak effects of interest rate shocks on real

[14] On average, about 23 draws are needed to generate a succesful decomposition for all individual countries.

GDP and prices in the US and the euro area of about 0.15% and 0.1%. They further estimate a typical interest rate shock to be associated with an increase in the short-term interest rate of about 0.35 percentage points. Given that we estimate an average balance sheet shock to be associated with a 3% increase in the balance sheet, this implies that an exogenous doubling of the central bank balance sheet would have macroeconomic effects comparable to those of an interest rate cut in the order of magnitude of roughly 300 basis points.

It is however important to note that the massive (actual) expansion of central bank balance sheets in the wake of the crisis did not represent an exogenous balance sheet shock. This becomes clear when we look at the variance decomposition of the mean group panel VAR reported in Figure 4.[15] The decompositions reveal that exogenous balance sheet shocks account for only a small fraction of output and price variability. They are even not the main driver of the forecast error variance of the central bank balance sheet. Instead, the VIX shock, which we identify as a by-product of our identification strategy, turns out to be the main driver of central bank balance sheet dynamics.[16] About 40% of the forecast error variance of central bank balance sheets is explained by VIX shocks. The endogenous reaction to shocks to aggregate uncertainty was therefore an important factor behind the evolution of central bank balance sheets during the crisis.[17] 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 perceived risk shocks are important drivers of macroeconomic dynamics during crises.

[15] The variance decomposition is performed based on the median target method of Fry and Pagan (2007).

[16] The VIX shock is identified as a by-product of our identifying restrictions for the balance sheet 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 bank balance sheet and a temporary strong and highly significant decline in output and prices.

[17] 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 the reaction to VIX shocks.

5 Robustness analysis

5.1 Variations of the benchmark model

In order to assess the robustness of our results to alternative modelling choices, we consider three variations of the benchmark VAR. Specifically, we replicate the analysis of the previous section using respectively a different econometric estimator, a different quantitative policy instrument, and a different output measure. Figure 5 shows the impulse response bands obtained when (i) the VAR is estimated using the Fixed Effects estimator instead of the Mean Group estimator, (ii) the VAR is estimated using the monetary base as the quantitative policy instrument instead of central bank assets and (iii) when industrial production replaces real GDP as the measure of aggregate output.

The first column of Figure 5 shows that our findings are qualitatively robust with regard to the type of panel estimator used. The effects estimated based on the Fixed Effects 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 in shape. The somewhat stronger effects reflect the bigger size of the base money shock (4%) compared to the balance sheet shock in the benchmark specification (3%).

Finally, when industrial production is used as the measure of output instead of real GDP (third column of Figure 5), the results are essentially unaffected except for the reaction of output which comes out 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.

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 most of the economies over the sample period, the analysis still includes the policy rate cuts that occurred during 2008 and early 2009. There is hence the risk that the balance sheet shocks we identify capture in part the effect 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. 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 or mentionable difference. The bands are very similar in shape and overlap for all variables. The central bank balance sheet shocks identified in the benchmark model are thus not contaminated by the effects of interest rate cuts.

In the 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. These measures 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 central bank balance sheet shock we identify in the benchmark model if shocks to public debt would have the same 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. In order to address this potential caveat, we estimate and extended model including the outstanding debt of the central government in the model.[18] For the identification, we assume in addition

[18] Monthly data on outstanding central government debt are available for all countries except for Switzer-

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, so the difference is not statistically significant. 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 as a by-product individual country estimates. We can thus directly assess the degree of cross-county heterogeneity in the dynamic effects of balance sheet shocks. 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 the central bank balance sheet turn out to be very similar across countries. The panel VAR impulse response and the individual-country impulse response overlap most of the times, suggesting that they are not different in a statistically significant way.

We find in all economies a significant positive temporary impact on economic activity and in most cases also on the price level. A few individual country results are worth highlighting. In Japan and Norway, the output reaction is only marginally significant, while the price response is insignificant, in Japan even significantly negative at longer horizons. This finding probably reflects the fact that, as was discussed in Section 2, these two countries used balance sheet policy to a much lesser extent than the other economies

land where quarterly data were interpolated using a Cubic spline. The data were obtained from national central banks and national debt management agencies.

covered by the analysis, which makes it difficult to pin down the effects of balance sheet shocks. In the case of Japan, this is also reflected in the response function of central bank assets, which shows that the size of the average balance sheet shock is just 1%, compared to an average shock size of 3% in the panel. In Switzerland and Sweden, the dynamic effects of balance sheet shocks in particular on output are somewhat more persistent than in the other economies. This reflects in part the larger size and persistence of the shock in these economies reflected in the impulse responses of central bank assets.

Overall, the similarity of the individual-country results suggests that the panel analysis does not obscure considerable cross-country heterogeneity. At the same time, it implies that despite the heterogeneity in the design and calibration of balance sheet policies, their effectiveness was probably very similar across countries.

7 Conclusions

This paper assesses the effects of exogenous shocks to the central bank balance sheet on the macroeconomy by estimating a panel VAR using monthly data from eight advanced economies over the crisis period. The panel approach exploits not only the time dimension but also the cross-sectional dimension of the economies that were affected by the global crisis and adopted balance sheet policies in response to it. The mean group estimator used for the panel VAR analysis accommodates potential cross-country heterogeneity and yields individual country results as a by-product.

The results suggest 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 response pattern of output is thus very similar to that obtained by previous studies for the effects of interest rate shocks, while the reaction of the price level is somewhat less persistent. These findings turn out to be robust to a number of robustness checks. In particular, the main findings do not change when the monetary base instead of the balance sheet is used as the quantitative policy instrument. The results are also robust when controlling for the effects of policy rate movements or changes in public debt reflecting the measures taken by fiscal authorities over the sample period.

The individual country results turn out to be very similar to the panel results. This suggests that the panel results do not obscure considerable cross-country heterogeneity. It also points to a similar effectiveness of balance sheet policies across countries, despite the heterogeneity in their design and calibration.

It is important to note that the analysis of this paper focuses on the short-term effects of balance sheet policies and does not capture potential negative effects that could arise in the longer term. A prolonged period of ultra-accommodative monetary policy with low levels of policy rates and expanded central bank balance sheets could create distortions by delaying necessary balance-sheet adjustment and repair in the private and public sector, as in the case of "zombie lending" in Japan (Caballero *et al.* 2008). It could further cause moral hazard if agents perceive that central banks will always ease monetary policy aggressively in a crisis (e.g. Diamond and Rajan 2009) and lead to an increase in inflation expectations (e.g. Thornton 2010b). These issues are potentially important avenues for future research. Addressing them is however beyond the scope of this paper.

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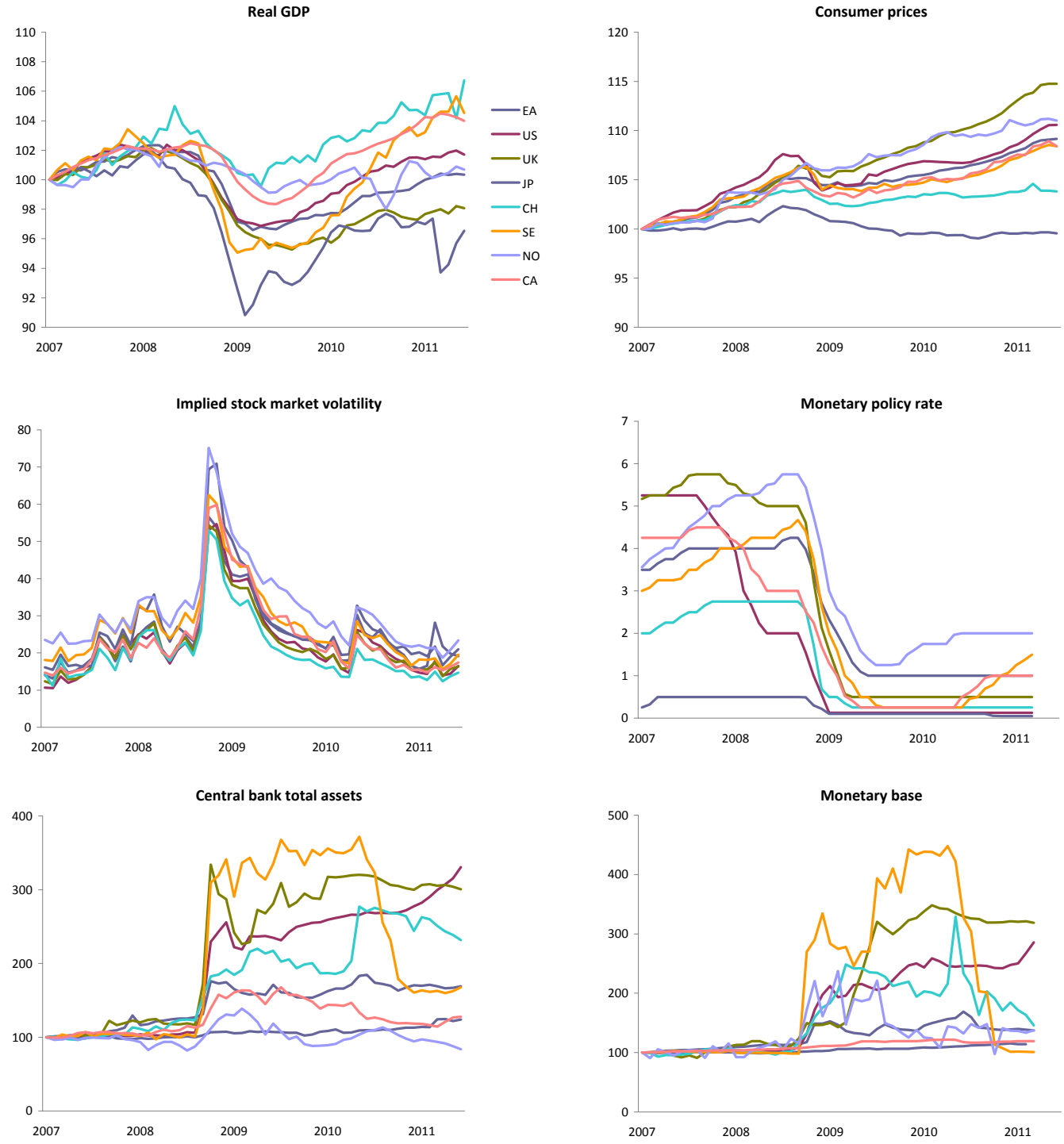
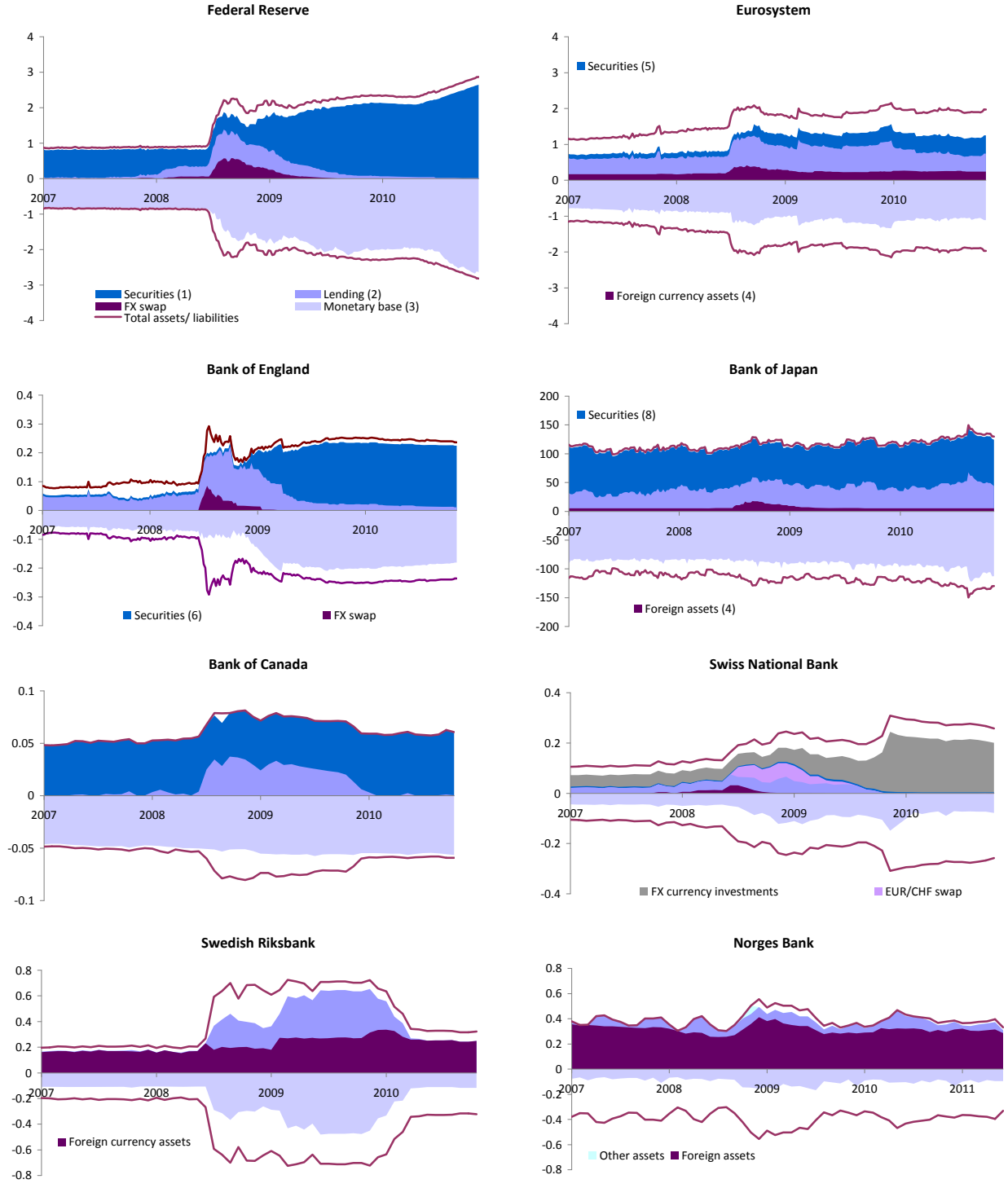
Figure 1 - Macroeconomic dynamics, financial market volatility and monetary policy



Note: 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.
Monthly GDP series derived based on Chow-Lin interpolation procedure using industrial production and retail sales as reference series.

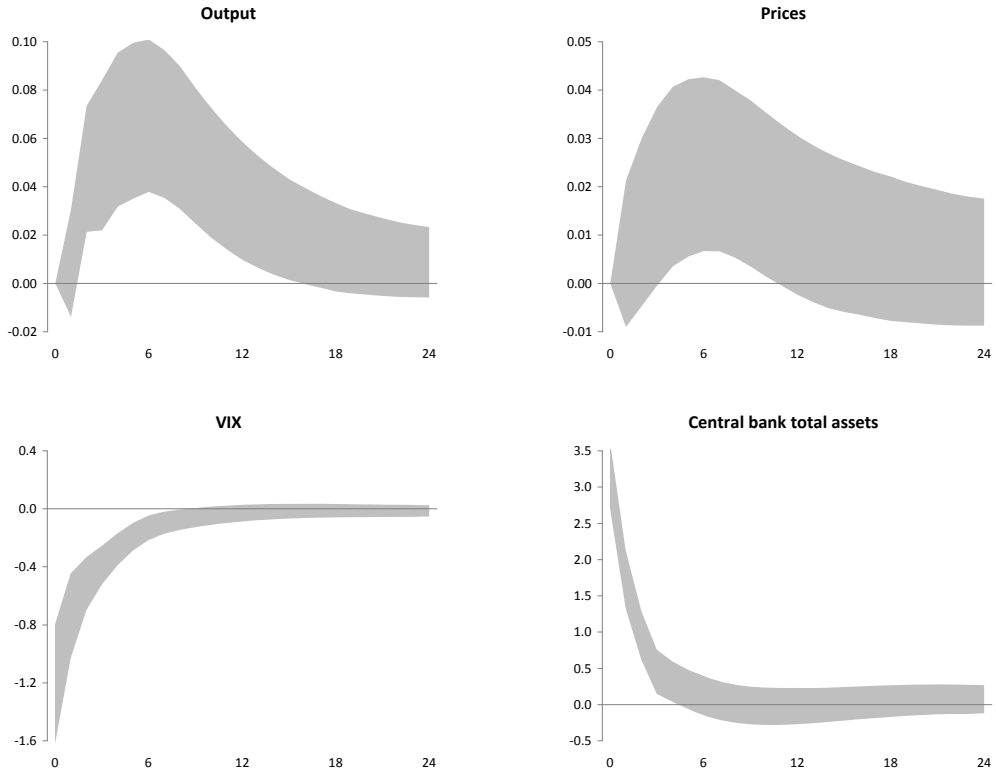
Figure 2 - Central bank assets and liabilities (trillions of respective currency units)



(1) Securities held outright. (2) For the Fed: Repurchase agreements, term auction credit, other loans and Commercial Paper Funding Facility. (3) 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. (4) Including US dollar liquidity auctions. (5) Securities issued by euro area residents, in euros. (6) 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. (7) Outstanding amount of US dollar liquidity auctions. (8) Defined as JGS and corporate bonds.

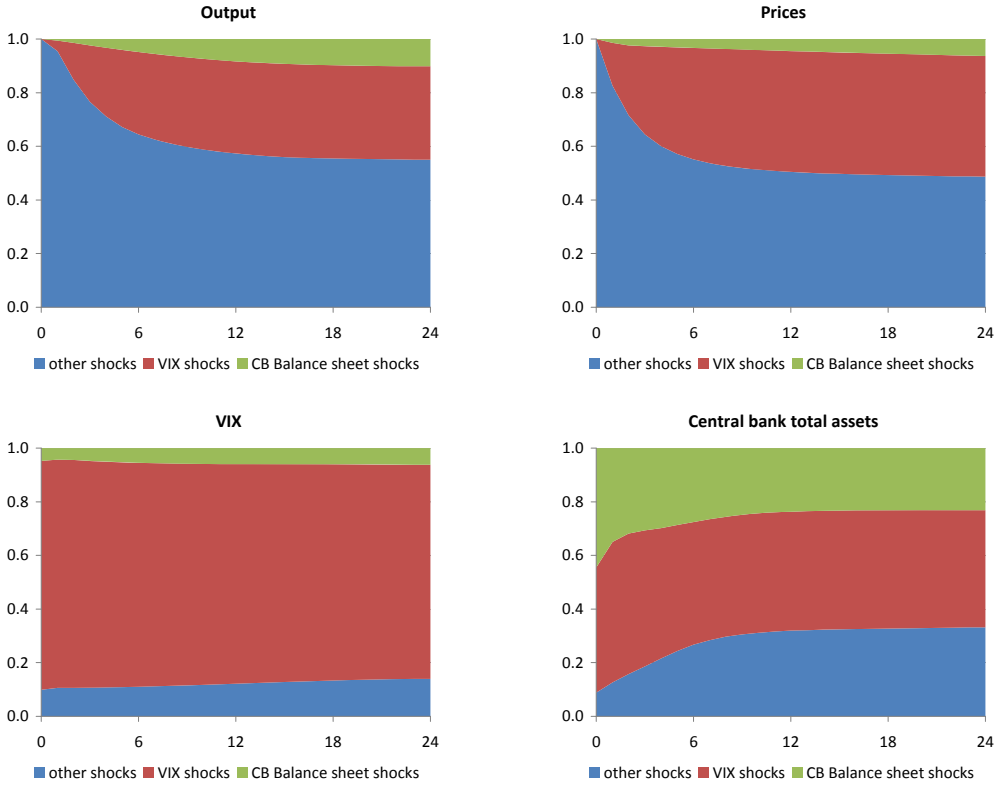
Sources: Datastream; national data.

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



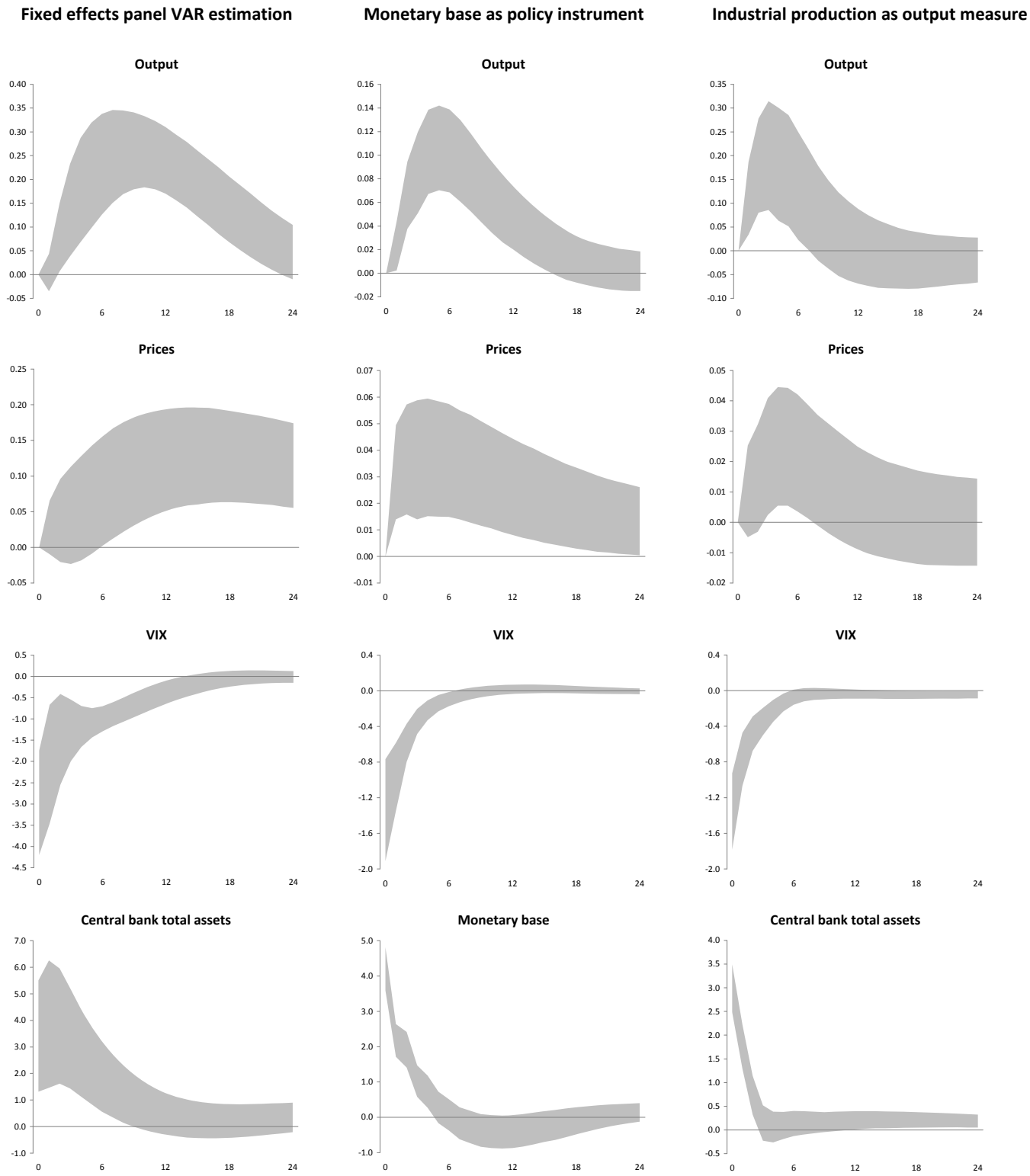
Note: 16th and 84th bootstrap percentiles, monthly horizon

Figure 4 - Forecast error variance decompositions



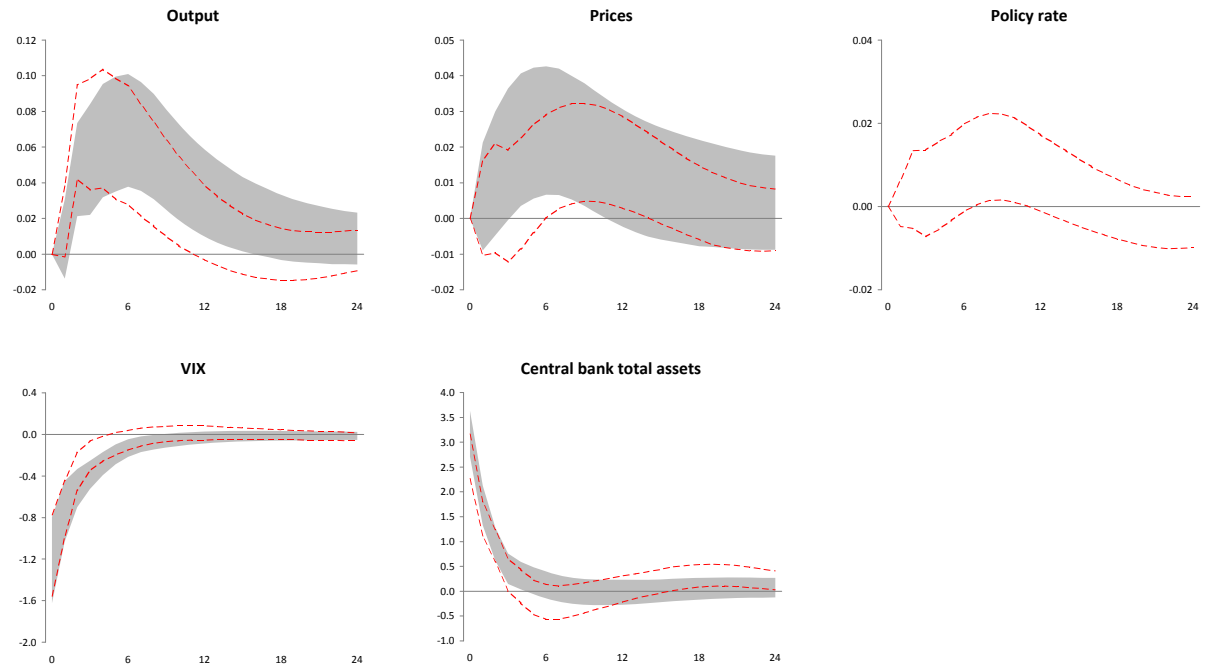
Note: Based on the median target method (Fry and Pagan 2007), monthly horizon

Figure 5 - Robustness checks: Variations of the benchmark model



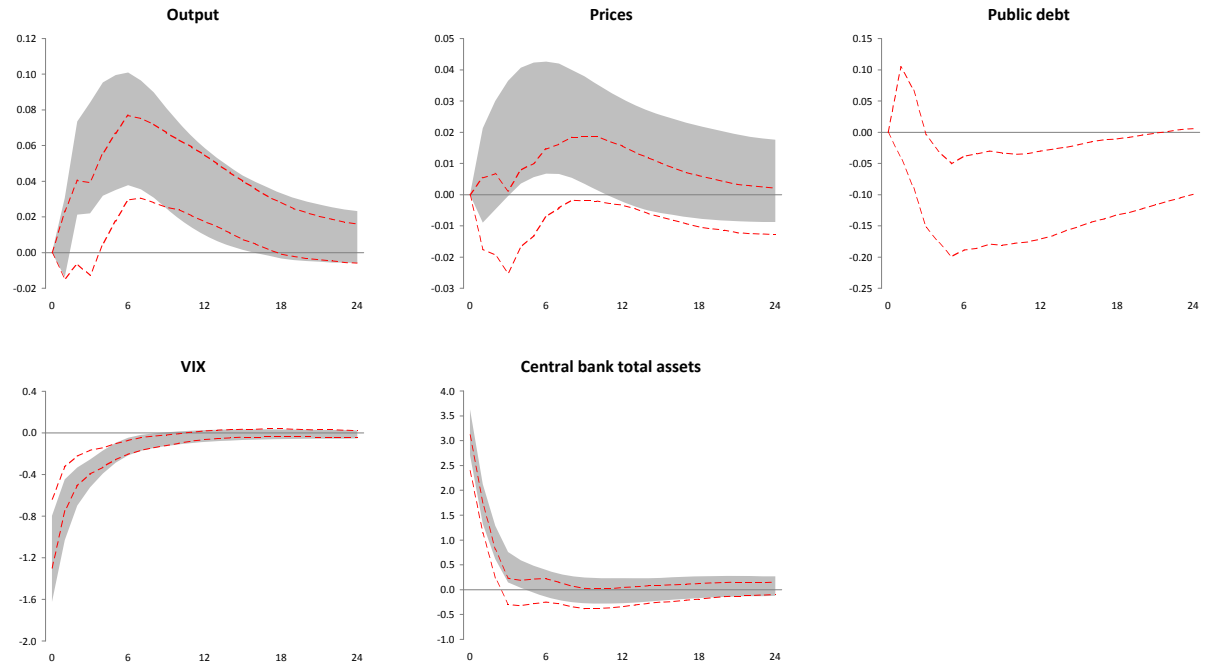
Note: 16th and 84th bootstrap percentiles, monthly horizon

Figure 6 - VAR model with the monetary policy rate



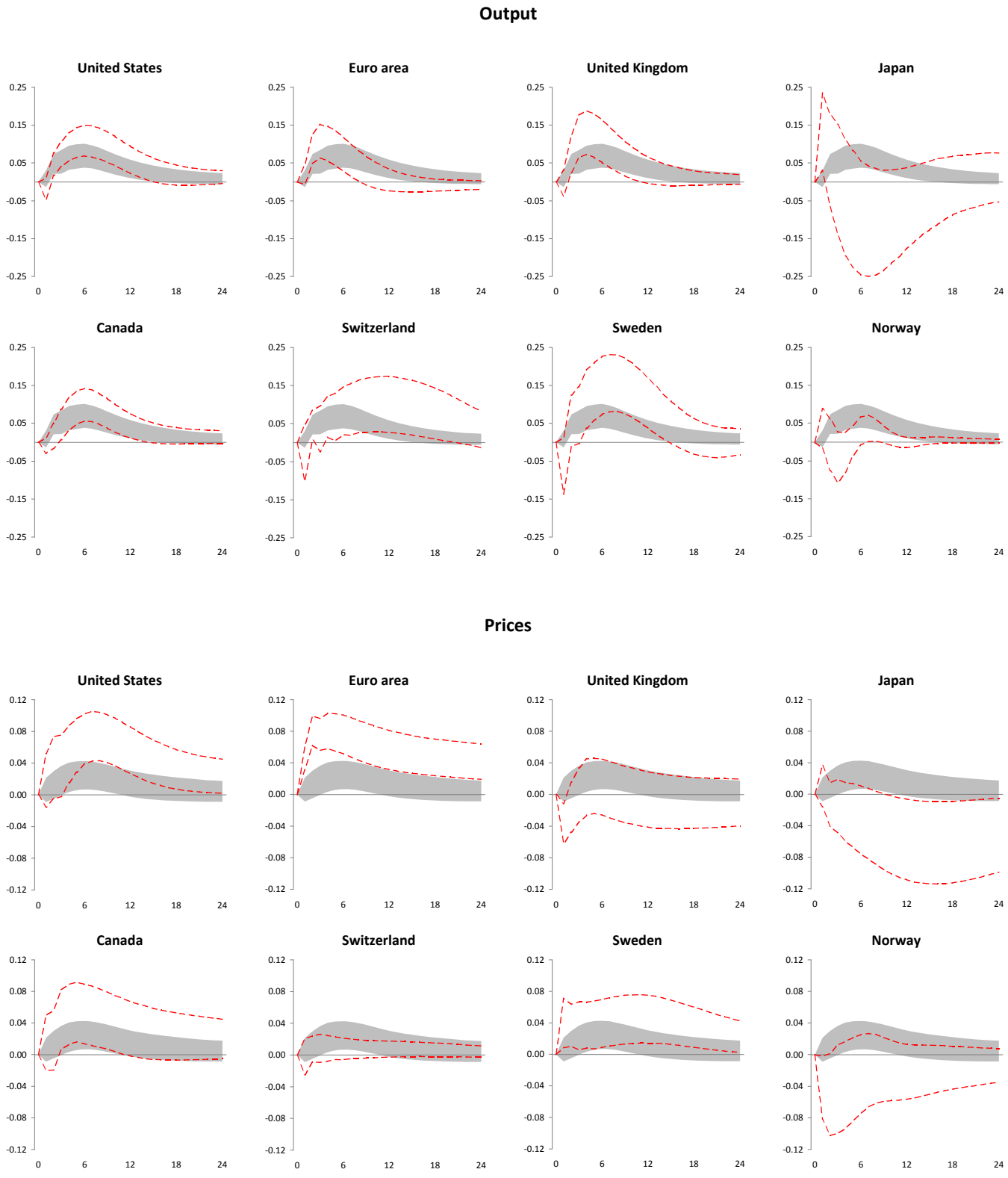
Note: 16th and 84th bootstrap percentiles, monthly horizon

Figure 7 - VAR model with public debt



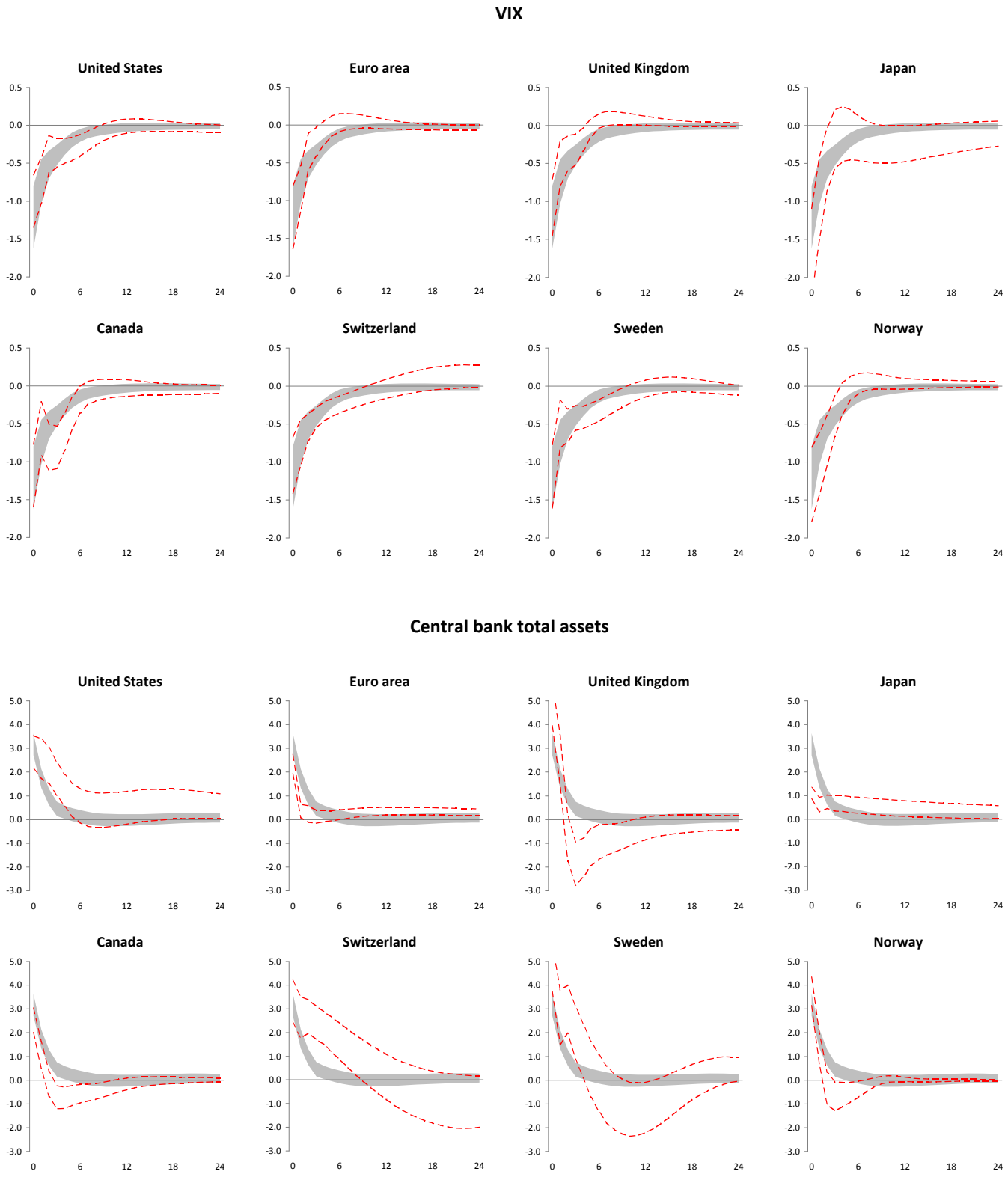
Note: 16th and 84th bootstrap percentiles, monthly horizon

Figure 8 - Impulse responses to central bank balance sheet shock: individual country results



Note: 16th and 84th bootstrap percentiles, monthly horizon

Figure 8 (continued) - Impulse responses to central bank balance sheet shock: individual country results



Note: 16th and 84th bootstrap percentiles, monthly horizon