Heterogeneous Macro and Financial Effects of ECB Asset Purchase Programs

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Abstract

Central banks resorted to asset purchase programs to replace conventional policy measures, which became ineffective after interest rates approached the zero lower bound. We investigate their effects on financial markets and focus on heterogeneous transmission using a Bayesian structural vector autoregression analysis. Since financial markets react directly to policy announcements, we base our identification scheme on market surprises at the announcement time. We find evidence of a stimulating effect on the economy, declining government bond yields, increasing stock prices, increasing value-growth spread and a reduction in stress in corporate and sovereign debt markets after an asset purchase shock. We disentangle the effect among industry sectors and EMU countries and find that the effect is heterogeneous, with financial stocks and the economy of Southern European countries being the most positively affected.

Keywords: *Unconventional monetary policy, financial markets, heterogeneity, structural vector autoregression*
JEL: *E44, E52, E58, F37, G15*

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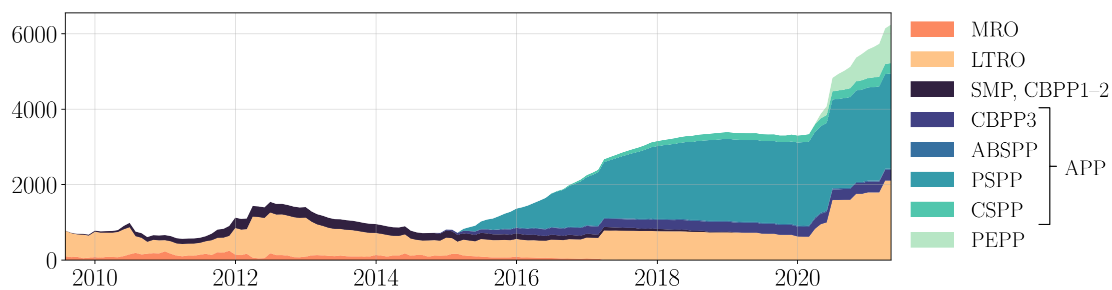
1 Introduction

The past two decades have witnessed the introduction of new types of central bank policy interventions in Europe. After the financial crisis of 2007–2008, the European Central Bank (ECB) adopted several conventional and unconventional measures to stabilize financial markets and bank lending, and to support monetary policy transmission mechanisms. Starting July 2009, the ECB started several bond purchase programs. Following other central banks in quantitative easing,[1] the ECB announced on January 22, 2015, its first large-scale asset purchase program (APP). The goal of this program is to promote price stability and to reduce deflation risk by easing financial conditions for both households and firms as the interest rate approached the effective zero lower bound. This APP is as of yet the ECB's largest, concerning trillions of Euros. Figure 1 shows the balance sheet of the ECB over time. The figure shows a steep increase of balance sheet assets starting 2015—reaching a value over 50% of the Euro-zone GDP in 2020.

Figure 1: Balance sheet European Central Bank in billions of Euros



Note: Liquidity purposes: long-term refinancing operations (LTRO) and main refinancing operations (MRO). Monetary purposes: securities market program and covered bond purchase programs (SMP, CBPP1–2), corporate sector purchase program (CSPP), public sector purchase program (PSPP), asset-backed securities purchase program (ABSPP) and CBPP3, and the pandemic emergency purchase program (PEPP).

This study contributes to the growing literature documenting the effect of the ECB's asset purchase programs on the European (macro) economy and financial markets, and to what extent this effect is heterogeneous. As the balance sheet of the ECB continues to

[1]Examples are the Federal Reserve's large scale asset purchase programs in the US taking place between 2008–2012, Bank of Japan's quantitative easing policy (2001–2018) and the Bank of England's quantitative easing program in 2009–2010. See Rogers et al. (2014) for an overview of these programs.

grow and given the possible need of additional purchase programs in the future (European Parliament, 2020), it is vital to understand the transmission of such programs. According to the ECB, these APPs ensure price stability, but also help firms to have better access to credit, boost investment, and support economic growth by job creation. The ECB further emphasizes that they are shaped by fragmentation within the Euro zone and that their effectiveness depends on spillover effects between countries (see, e.g., Burriel and Galesi, 2018). We focus on government bond yields, stocks, sovereign debt and corporate debt markets. Specifically, we consider sector-specific stock indices to shed light on the effect across stocks, and country-specific data to analyze the transmission across countries.

We study the dynamic effect of ECB's asset purchase programs using a Bayesian structural vector autoregression (SVAR) analysis. We use a novel modification of the methodology in Jarociński and Karadi (2020) to accommodate sign and zero restrictions to identify an asset purchase (AP) shock. This modification allows us to isolate asset purchase announcements, and to naturally exclude supply and demand shocks. We use market surprises in response to central bank monetary policy announcements to identify an AP shock. We assume that financial markets react directly to an asset purchase announcement, that is, an AP shock is associated with a positive surprise in stock prices and a negative surprise in interest rates. Expansionary monetary policy leads to lower interest rates, resulting in higher stock prices as the expected value of future dividends increase and the lower interest rates decrease the discount rate. To isolate unconventional policy shocks from statements of the central bank which are not directly related to monetary policy, we also define an information shock as positive co-movement between interest rate and stock price changes. We analyze the dynamic effect of both structural shocks using impulse response analysis. Our Bayesian estimation approach allows us to take into account estimation uncertainty. We measure the long-term effect of the programs introduced after the financial crisis until March 2021.

We find that an asset purchase shock induces an increase in real GDP and the consumer price index. Regarding financial markets, we find an immediate decrease of 4 basis points in the 1- and 10-year European government bond yields in the Euro area. Asset purchases stimulate the stock market, with the most profound effect being 0.6% after three months. We also find evidence of heterogeneous transmission. The ratio in value to growth firms increases by 0.6%, indicating that value stocks profit more from asset purchases than growth stocks, as value stocks are more affected by improved financial conditions. Asset purchases have a reassuring effect, as they decrease corporate credit spreads and lower volatility in the sovereign bond markets. Next to that, we document a depreciation of the Euro against other major currencies and a drop in lending rates for both households and corporations. A central bank information shock stimulates financial markets, but these effects tend to be short-lived. These results are robust to changes in model, hyperparameter and prior specification.

We study heterogeneity across countries in a country-specific global vector autoregression (GVAR) setting, which takes into account spillover effects, and document mild heterogeneity in transmission. Each European economy is stimulated in terms of output and prices, with Southern European countries being stimulated the most. These economic effect are amplified by spillovers. All European stock markets are stimulated by an increase of 0.5–1%. There is an even stronger heterogeneity in terms of government bond yields. Yields of countries with higher credit ratings tend to go up after an asset purchase announcement, which is likely because of the flexibility in the APPs, as the ECB is allowed to adjust its purchases based on market conditions. Next to that, these yields are close to zero in our sample period and have therefore limited room to decrease compared to other countries. Asset purchases reduce volatility in Southern European sovereign debt markets the most. The positive economic effects are amplified by spillover effects, but the spillover effects reduce the impact on financial markets. Central bank information shocks are more homogeneous and short-lived compared to asset purchase shocks. To the best of our knowledge, we are first to identify an asset purchase shock in GVAR setting based on market surprises.

Our results are in line with the theory on monetary policy transmission and the empirical literature. We find evidence for the portfolio rebalancing channel, which suggests an increase in demand for assets relative to supply after an AP announcement. This demand surplus pushes prices up and yields down, mitigating risk for banks such that lending rates will decrease. The reduction in European government bond yields point towards the signaling channel, as an asset purchase announcement signals that the interest rate stays low. Hence expectations in short-term rates decline, which pushes yields down. The lagged reduction in risk premium on high yields and stress indices points towards the re-anchoring channel, as asset purchase announcements help guiding inflation expectations, pushing investors to riskier assets in search for yield.[2]

Furthermore, several policy recommendations can be obtained from our analysis. Even though the asset purchase programs are designed to guide inflation expectation levels of the Euro zone as a whole and not focus on particular countries, we find a stronger effect on Southern European countries. The asset purchases lead to stabilization of these countries and therefore the Euro area in general, although there has been criticism regarding the APPs (Viterbo, 2021). However, our results the ECB should be cautious regarding the possible side-effects of these programs, such as excessive risk taking by investors, as we find increasing stock prices and a declining credit spread. Another side effect could be stemming from low lending rates, which might keep non-viable firms alive at the cost of more productive firms, as we document a decrease in lending rates.

The paper is structured as follows. Section 2 discusses the related literature. In Section 3 we introduce the data, and in Section 4 we discuss the methodology. Section 5 presents the results, and Section 6 concludes.

2 Literature

Because of the large impact of large scale asset purchase programs (LSAPs), the literature about this topic is vast. In this section, we discuss the two strands that are particularly relevant for our research, being the identification of an asset purchase shock, and the trans-

[2]We elaborate on the transmission channels in Section 2.2.

mission channels of such a shock.

2.1 Identification of an asset purchase shock

Traditional monetary policy works through adjusting policy rates. Conventional monetary policy shocks can therefore be identified by tracking the central bank's policy rate. However, near the zero lower bound, central banks cannot longer provide stimulus using interest rates. The central bank implements alternative (unconventional) monetary policies to stimulate the economy, such as LSAPs. These programs are extensive and typically cover multiple elements. Identification of shocks caused by such unconventional monetary policy is thus more complex than simply tracking a policy rate. Other variables must be used to identify such shocks.[3]

One way to identify an asset purchase shock is through the central bank's balance sheet in an SVAR setting. For the Euro area, Gambacorta et al. (2014), Boeckx et al. (2017) and Lewis and Roth (2019) identify an AP shock using sign restrictions, in combination with contemporaneous zero restrictions on output and prices.[4] They find a positive effect on output and prices, but the effects are heterogeneous among Euro countries. Recent research challenges the premise if the increase in balance sheet of central banks correctly identifies unconventional monetary policy. Elbourne and Ji (2019) replace the central bank's balance sheet by random numbers and find similar results as Boeckx et al. (2017). They argue that identification based on balance sheet expansion does not identify unconventional monetary policy shocks. Yet Boeckx et al. (2019) claim that the identification of these shocks by balance sheet data is valid as they show qualitative and statistical differences between the random numbers shock and the original unconventional monetary policy shock. Therefore, the validity of balance sheet identification remains ambiguous.

[3] Rossi (2020) provides an overview of research related to the identification and estimation of unconventional monetary policy shocks in vector autoregressive settings.

[4] Other papers also identify unconventional monetary policy shocks as an increase in the balance sheet in other economies. For example, Weale and Wieladek (2016) and Hesse et al. (2018) focus on the US and UK, Schenkelberg and Watzka (2013) on Japan.

Another way to identify an AP shock is through financial market responses. As financial markets respond directly to announcements, Kuttner (2001) proposes to identify monetary policy shocks as financial market movements in a short window around central bank announcements as this allows for isolating the unexpected component of a policy announcement (Nakamura and Steinsson, 2018). Multiple event studies are conducted to analyze the price movements around central bank announcements. For the US see, for example, Bernanke and Kuttner (2005) and Gürkaynak et al. (2005). Altavilla et al. (2019) study price changes of a broad class of assets and find that quantitative easing affects stocks and the yield curve, most prominently at the 10-year maturity, and that these effects are lasting. Fratzscher et al. (2016), Georgiadis and Gräb (2016) and Krishnamurthy et al. (2018) investigate the impact of various asset purchase programs of the ECB in an event study setting, and find decreasing government bond yields, increasing stock prices and depreciation of the Euro relative to other major currencies.

Financial market responses are also used in an SVAR setting as external instruments, or included as exogenous variables. Gertler and Karadi (2015) employ a proxy VAR approach and use interest rate surprises as external instruments to identify a monetary policy shock. Paul (2020) includes these surprises as exogenous variables in the SVAR in a time-varying setting. He shows that both approaches are equivalent and result in consistent estimates of the true relative impulse response functions. Jarociński and Karadi (2020) include price changes in interest rate futures and a stock index around a monetary event in their VAR model to investigate the macroeconomic effects of policy announcements in the US and Euro area. They use the co-movement between these financial market responses to distinguish between two types of shocks—a monetary policy shock and an information shock. These are labeled as an *Odyssean* shock where the central bank commits to future action, and a *Delphic* shock, an announcement containing forward guidance such as macroeconomic forecasts or possible future monetary policy (Campbell et al., 2012). Breitenlechner et al. (2021) use the aforementioned approach to identify unconventional monetary policy shocks in the US.

We propose a novel identification method based on Jarociński and Karadi (2020). We identify an asset purchase shock and a central bank information shock based on the co-movement of these surprises. By re-ordering variables we naturally impose the initial responses of output and prices to zero. This is often assumed in monthly VAR studies (e.g., Bernanke and Blinder, 1992; Peersman and Smets, 2001; Boeckx et al., 2017), such that AP shocks are isolated from supply or demand induced shocks. Inspired by Weale and Wieladek (2016), we also construct an asset purchase volume variable containing the cumulative value of an announced package at the date of announcement. This variable is restricted to increase in case of an asset purchase shock. We further include financial variables in our baseline VAR, such as government bonds, stock indices, and stress measures to shed more light on the transmission of these shocks. We leave these responses unrestricted.

2.2 Transmission of an asset purchase shock

In monetary economics, the dynamic impact of (unconventional) monetary policies are often assessed through the concept transmission channels.[5] That is, asset purchases themselves do not produce effects but work their way into the economy via transmission channels. Andrade et al. (2016) group the transmission mechanisms of asset purchase programs in three groups. The portfolio rebalancing channel implies that if investors have preferred habitats (Vayanos and Vila, 2009), asset purchases affect yields sensitive to interest rate risk or yields at maturity, through the impact of the purchases on duration and scarcity. Therefore, long-term yields decline because of a reduction in the term premium rather than a reduction in the expected path of short-term interest rates. As a result, investors increase private debt and investments in the equity market since long-term government bonds are less attractive. Another aspect of this channel is the capital relief that asset purchases provide. The higher bond prices increase a bank's valuation through their bond holdings, which allows them to issue risky loans and reduce lending rates. Empirical evidence for this

[5]See, e.g., Woodford (2011) and Beyer et al. (2017) for an overview of monetary policy transmission mechanisms.

channel has been documented, such as Bechtel et al. (2021) who find evidence for scarcity in safe assets through a decrease of 6% in accessible safe assets as a consequence of the ECB's asset purchases. Further, Li and Wei (2012) and Eser et al. (2019) find a reduction in the 10-year treasury yield of 100 basis points for the US and 95 for the Euro area, respectively.

The second channel is the signaling channel. Eggertsson et al. (2003) emphasize that an announcement of the ECB regarding unconventional monetary policy enhances the credibility of interest rates staying at the zero lower bound for long. In other words, it signals a low interest rate. Hence, after the announcement expectations about the future short-term rate decline according to this channel. Yields of all maturities decrease through the average expected short rates component, rather than the term premium. Bauer and Rudebusch (2014) find evidence for this signaling effect in the US.

Last, the re-anchoring channel implies that asset purchase announcements can help to guide inflation expectations and ensure price stability. Even though the short-term interest rates are at the lower bound, the asset purchases show that the ECB is committed to stimulating the economy. The announcement assures investors, which then leads to less uncertainty about future output and inflation. This can lead in a reduction in durable consumption uncertainty for households or taking on greater risks by investors. As a result, consumption could increase and the risk premium declines. Krishnamurthy and Vissing-Jorgensen (2011) document a decrease in inflation uncertainty and a decrease in default risk premia as a consequence of quantitative easing in the US.

Though short-term effects of asset purchase programs are well documented, less is documented about the long-term effects of these unconventional measures on financial markets. Mamaysky (2018) investigates the horizon on which assets respond and finds that government bonds respond quickly to AP announcements, but equity and equity implied volatility respond slower in the US, UK and EU.

The portfolio rebalancing channel suggests that other non-targeted assets are also affected by asset purchase programs through the lowering of borrowing costs. Thus, possible heterogeneity might arise. Up to now, this form of heterogeneity has only been analyzed in the setting of an event study. For example, Henseler and Rapp (2018) find that value and growth stocks respond differently to an AP announcement using firm level European data. Haitsma et al. (2016) and Fratzscher et al. (2016) document a stimulating effect on stocks—the banking sector specifically. Our study casts light upon this issue in the broader perspective of SVAR models that capture the propagation of shocks in a system of connected macroeconomic and financial variables.

Financial market fragmentation within the Euro zone makes it challenging to conduct effective and fair monetary policy. Georgiadis (2015) and Burriel and Galesi (2018) show there is heterogeneity in the transmission of conventional and unconventional monetary policy within the Euro zone, respectively. Corradin et al. (2021) document an asymmetric impact on government bond yields in Europe in response to the pandemic emergency purchase program in 2021. German and French government bond yields increase, whereas Italian and Spanish yields decrease. However, the ECB has found ways to accommodate heterogeneity in their unconventional monetary policy measures. Their asset purchase programs are flexible and adjustable according to market conditions.[6] Altavilla et al. (2020) corroborate this as they document less heterogeneity in unconventional monetary policy transmission compared to conventional monetary policy transmission. We use our identification approach based on market surprises combined with sign and zero restrictions in the GVAR setting of Burriel and Galesi (2018) to investigate the transmission across eight European countries. This approach enables us to analyze heterogeneity with respect to asset classes and with respect to countries in one encompassing model.

[6]See, for example, the speech of Cœuré (2019) on *heterogeneity and the ECB's monetary policy* and `https://www.ecb.europa.eu/mopo/implement/app/html/index.en.html`.

3 Data

We use data on European level and country-specific data for Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal and Spain. We consider monthly data ranging from July 2009 to March 2021. We focus on data starting 2009, since the ECB started implementing unconventional monetary measures in 2009 as a response to the financial crisis of 2007–2008 (Giannone et al., 2011; Rogers et al., 2014). Section 3.1 discusses the asset purchase programs the ECB conducted during our sample period, and the variables we use to identify structural shocks. Section 3.2 describes the dependent variables. Table IA.2 in Appendix B reports a detailed description and sources of the data.

3.1 Unconventional monetary policy measures

On July 2009, European central banks started to buy covered bonds under the ECB's first one-year covered bond purchase program, worth 60 billion Euro. Before this program ended, the ECB executed its securities market program in May 2010, under which the Eurosystem bought European government bonds with a par value of 220 billion Euro. This program was followed by another 16 billion Euro covered bond purchase program in November 2011.

On January 2015, the ECB governing council announced its first large-scale asset purchase program. The APP consists of four programs—a corporate sector purchase program, public sector purchase program, asset-backed securities purchase program and a covered bond purchase program. Under APP the Eurosystem banks mainly bought government bonds and bonds issued by national and European institutions, but also corporate and covered bonds, and asset-backed securities at a planned pace of roughly 60 billion Euro per month. The ECB ended the APP in December 2018. In November 2019, the ECB restarted the APP, buying assets at a monthly pace of 20 billion Euro. In March 2020, the ECB started a temporary pandemic emergency purchase program (PEPP) in response to the COVID-19 outbreak. The PEPP consists of multiple envelopes with a total value of 1,850 billion Euro.

Under the PEPP, private and public sector securities are purchased. For more details on the scope and duration of these asset purchase programs, see Figure 1 and Appendix A.

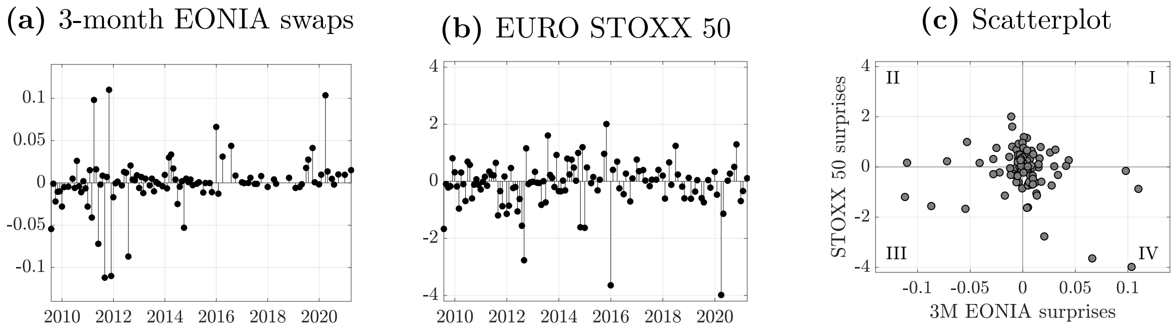
3.1.1 Central bank announcements

We obtain central bank announcement surprises in the Euro area from the Euro Area Monetary Policy Event-Study Database (EA-MPD) of Altavilla et al. (2019), which contains the price changes of assets to European policy events. The ECB Governing Council meetings dedicated to monetary policy changed from a four-week cycle to a six-week cycle per January 2015. A monetary event usually contains a press statement at 13:45 followed by a one-hour press conference with Q&A, starting at 14:30. The monetary window in which the price changes are measured starts about 10–15 minutes before the press statement and ends 10–20 minutes after the press conference, which is in total 85–100 minutes. This narrow window minimizes the chance of capturing price fluctuations due to other factors, such as a pre-announcement drift (Lucca and Moench, 2015). There are in total 110 central bank monetary events in our sample.[7]

The surprises we focus on are the surprises in the 3-month overnight index swap based on the EONIA rate and in the EURO STOXX 50, which consists of the fifty largest most liquid stocks in the Euro area. Figures 2a and 2b show these surprises over time. The most extreme surprises in the 3-month EONIA swaps are centered around 2011 and 2012, where conventional measures where still in place and the first asset purchase programs were announced before the short-term interest rates attained the zero lower bound. The positive surprise of 10 basis points on March 12, 2020 in the overnight interest rate swaps can be attributed to the additional uncertainty as a consequence of the worsening COVID-19 situation in Europe. Later that month, the PEPP was announced. The extreme surprises in the STOXX 50 are

[7] The timing of these meetings within a month is challenging. Until 2015, every ECB meeting was in the beginning of the month and therefore the time between data and the policy announcement is similar. After the change to a six-week cycle, meetings also took place in the beginning and near the end of the month. We only have a small number of meetings at the end of the month in our sample—not enough to analyze this separately. We leave this for further research.

Figure 2: Market surprises in percentage points



Note: Figures 2a and 2b show the change in the 3-month overnight index swap based on the EONIA rate and the change in the EURO STOXX 50 index around a monetary event, respectively. Figure 2c shows both these changes, where each dot represents an ECB announcement. Source: EA-MPD.

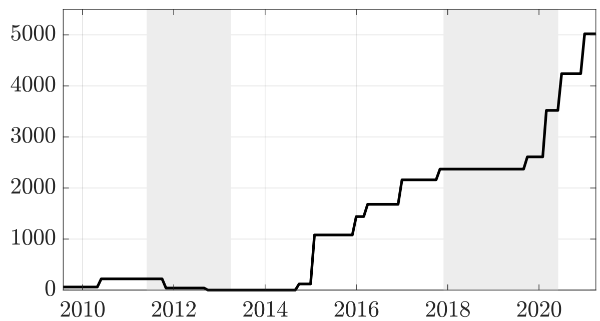
more evenly distributed over time, and the negative surprises are larger in magnitude than the positive.

In order to gain insight into financial market responses to a central bank monetary policy announcement, we show the scatterplot in Figure 2c. The figure shows that the surprises are quite evenly distributed over the quadrants, where 26 surprises lie in the second quadrant and 25 lie in the fourth quadrant—the quadrants which exhibit negative co-movement. In the quadrants with positive movements we find 22 positive surprises and 23 negative surprises, the first and third quadrant, respectively. The surprises in the second quadrant are associated with AP shocks, as for example the asset purchase announcement on September 4, 2014 and January 22, 2015.

3.1.2 Announced volume of asset purchases

We further construct a variable capturing the announced volume of the asset purchase program in the spirit of Weale and Wieladek (2016). In the month of the announcement, we calculate the cumulative value of the announced package, regardless whether the program starts in that month or later. An alternative approach to measure the announcement volume is to use the ECB's securities held for monetary policy purposes as in Lewis and Roth (2019), which contains purchases under unconventional monetary policy such as asset pur-

Figure 3: ECB's Asset purchase announcement series, volume in billions of Euro



Note: Shaded areas correspond to the OECD based recession indicators for the Euro area from the period following the peak through the trough.

chase programs. There are however timing issues with such a balance sheet variable, as the announcement and implementation of the program can be months apart (e.g., the announced package on January 22, 2015 was implemented in March 2015). By calculating the cumulative announced value of the packages we overcome this timing problem. If an announcement is related to a re-calibration of a program, we calculate the cumulative corrected value of this announcement. These asset purchase announcements are shown in Figure 3 in billions of Euros. The series shows a steep increase on January 2015, where an 18 month asset purchase program consisting of monthly purchases worth of 60 billion Euros was announced. On March 2020, there is also a steep increase as additional asset purchase packages and the PEPP were announced.

3.2 Variables of interest

We are interested in the effect of the asset purchase programs on a broad array of macroeconomic and financial variables. We consider output and prices as macroeconomic indicators. As in Gambacorta et al. (2014), Boeckx et al. (2017), Lewis and Roth (2019) we use the interpolation method of Chow and Lin (1971) to construct a proxy for economic output. Specifically, we interpolate quarterly real GDP based on 19 Euro countries using the monthly industrial production index, both seasonally adjusted. Prices are for the Euro area modeled by the seasonally adjusted Harmonized Index of Consumer Prices.

For financial variables, we use stock and bond data. Particularly, we use the European government bond yield with 1- and 10-year maturity, which is a composed Euro area government bond yield based on all issuers with AAA rating. For stock prices we consider the Morgan Stanley Capital International (MSCI) index of Europe.[8] To investigate the effect of an asset purchase shock on different types of stocks we include the spread ratio of the MSCI EU value and growth indices. We include BBB bond spread to capture financial conditions of the corporate debt market in the Euro zone, and a sovereign stress index of the Euro zone. This stress index is measured by the GDP-weighted Sovereign Composite Indicator of Systemic Stress (CISS), proposed by Hollo, Kremer, and Lo Duca (2012). Sovereign CISS is an indicator for contemporaneous stress in sovereign debt markets, ranging between 0 and 1. Kremer (2016) highlights the importance of including CISS indices in a macro-financial SVAR setting, as CISS contributes to the dynamics of the macroeconomy and monetary policy.

In our baseline setting we include eleven variables—two surprises, the AP volume announcement series and the macroeconomic and financial variables. We take the natural log of output, prices, announcement series, and the stock price indices and ratios. To shed more light on the transmission of shocks, we consider the nominal effective exchange rate, lending rate for corporations and households, and the 5 year–5 year forward inflation expectation rate and add these one by one to the baseline model. In order to investigate stock market heterogeneity, we add various sector-specific MSCI indices to the baseline model. For the country-specific analysis we consider each country's real GDP, CPI, 1 and 10-year government bond yields, MSCI index, MSCI value-growth ratio and sovereign stress index.

[8] We also consider alternative measures, e.g., EURO STOXX 50 and EURO STOXX 600 indices, these are highly correlated with a correlation of above 0.9 and thus yield same results.

4 Methodology

First, in Section Section 4.1, we introduce the structural VAR model we use to analyze the effect of asset purchase shocks and central bank information shocks. We then describe the identifying restrictions we impose on this model and our Bayesian estimation method. Last, we introduce the GVAR framework we use to investigate country-specific effects—which is a multi-country model consisting of multiple domestic VAR models and one common VAR model. We use the same identification and estimation approach for the GVAR as for the Euro area baseline setting.

4.1 Euro area baseline setting

Let Y_t denote the vector containing all N variables. In the spirit of Jarociński and Karadi (2020), we partition Y_t in three groups, where h_t are the surprises, and z_t and x_t are the combined macroeconomic and financial variables, in which z_t are the N_z macro and/or financial variables on which the contemporaneous impact of the exogenous shocks are restricted to be zero and x_t are the macro and/or financial variables responding to the exogenous shocks. We can thus write $Y_t = (z_t', h_t', x_t')'$. In the baseline setting we study a vector autoregression (VAR) of order p

$$\begin{pmatrix} z_t \\ h_t \\ x_t \end{pmatrix} = \begin{pmatrix} \mu_z \\ 0 \\ \mu_x \end{pmatrix} + \sum_{\ell=1}^{p} \begin{pmatrix} B_\ell^{zz} & B_\ell^{zh} & B_\ell^{zx} \\ 0 & 0 & 0 \\ B_\ell^{xz} & B_\ell^{xh} & B_\ell^{xx} \end{pmatrix} \begin{pmatrix} z_{t-\ell} \\ h_{t-\ell} \\ x_{t-\ell} \end{pmatrix} + \begin{pmatrix} u_t^z \\ u_t^h \\ u_t^x \end{pmatrix}, \qquad \begin{pmatrix} u_t^z \\ u_t^h \\ u_t^x \end{pmatrix} \sim \mathcal{N}(0, \Sigma), \tag{1}$$

where we use μ to denote the intercept, thus $\mu = (\mu_z', 0', \mu_x')'$, and B_ℓ similarly denotes the coefficient matrices corresponding to lag ℓ. The surprises are modeled to have zero mean and no dependency on other variables, imposed by the zeros in B_ℓ, such that these surprises are exogenous. In practice, we set $p = 2$ based on the literature and the Hannan-Quinn criterion, which provides a good compromise between model parsimony and in-sample fit.

In order to conduct structural analysis, we consider the following SVAR representation of Equation (1), such that

$$A_0 Y_t = a + \sum_{\ell=1}^{p} A_\ell Y_{t-\ell} + \varepsilon_t, \qquad \varepsilon_t \sim \mathcal{N}(0, I_N), \tag{2}$$

where a is the intercept vector, A_0 denotes an invertible coefficient matrix capturing the contemporaneous effects, and A_ℓ denotes the $N \times N$ coefficient matrices corresponding to lag ℓ. Here, ε_t are structural shocks. We can link the disturbances $u_t = (u_t^{z\prime}, u_t^{h\prime}, u_t^{x\prime})'$ and ε_t through $u_t = A_0^{-1}\varepsilon_t$. The variance-covariance matrix Σ of u_t contains $N(N-1)/2$ unknown parameters because of symmetry. However, A_0 contains N^2 unknown parameters. The system of Equation (2), where shocks can affect variables at the same time, is therefore not identified and additional identifying restrictions need to be imposed.

To identify the shocks of interest, we follow Uhlig (2005) and Rubio-Ramirez et al. (2010) and define an $N \times N$ orthogonal rotation matrix Q, which we use to transform the structural parameters from Equation (2) into the reduced-form parameters from Equation (1). That is, $u_t = PQ\varepsilon_t$, with P being the lower triangular Cholesky factor of Σ with non-negative diagonal elements. It follows that $A_0^{-1} = PQ$. Given a candidate solution for A_0^{-1}, we can calculate the impulse response functions (IRF) in a standard way. We impose restrictions on these IRFs to identify S structural shocks of interest. These restrictions are discussed in the next section.

The VAR approach in Equation (1) with restricted coefficient matrix can be interpreted as a VARX model with h_t as (lagged) exogenous variables. Paul (2020) shows that the VARX approach yields consistent estimates of the true relative impulse responses, even if the surprises are contaminated by independent measurement errors. Our approach is akin the internal instrument approach of ordering instruments first in a VAR (Plagborg-Møller and Wolf, 2021), when the instruments are uncorrelated with z_t and x_t, and its own lags (see Noh, 2018; Paul, 2020).

Other methods are to use a proxy VAR with external variables (see, e.g., Stock and Watson, 2012; Mertens and Ravn, 2013) or the local projection instrumental variable approach (Stock and Watson, 2018). Plagborg-Møller and Wolf (2021) show that the latter approach and the internal instrument SVAR approach estimate the same impulse response functions in population. They also show that the internal instrument approach gives valid IRFs even if the shock of interest is noninvertible—in contrast to the proxy VAR approach, where invertibility is required. Invertibility refers to the assumption that structural shocks can be recovered from past and current observations. As including ECB announcement surprises could lead to noninvertibility, we include these surprises in our VAR model rather than using them as external instruments. This also allows us to estimate the parameters in one step.

4.2 Identification

In order to identify structural shocks, we employ an identification scheme based on economic theory using short-term sign and zero restrictions on the impulse response functions, proposed by Canova and De Nicolo (2002) and Uhlig (2005). By ordering the variables as in (1), we naturally impose zero restrictions on the impulse responses of z_t to the S shocks of interest. In our baseline VAR, z_t contains the log of real GDP and the log of CPI, h_t surprises in the interest rate and stock price, and x_t contains asset purchase volume, 1- and 10-year government bond yields, the log of MSCI index, the log of the MSCI value-growth ratio, the BBB spread and the sovereign stress index at time t. We identify $S = 2$ structural shocks—an asset purchase shock and a central bank information shock. These correspond to the third and fourth column of A_0^{-1}. The identification of these shocks is given in Table 1.

We follow Kerssenfischer (2019) and Jarociński and Karadi (2020) and identify monetary policy shocks as financial market movements in a narrow time window around the ECB's announcement and press conference. Since the surprises are measured in a narrow window around the ECB's monetary event, it solely captures the reaction to the central bank announcement. An unconventional monetary policy shock such as an asset purchase program

Table 1: Identifying restrictions on the shocks

		Asset purchase shock	Central bank information shock
z_t	Output	0	0
	Prices	0	0
h_t	EONIA 3-months surprise	$-$	$+$
	STOXX 50 surprise	$+$	$+$
x_t	Announced AP volume	$+$	
	1-year government bond yield		
	10-year government bond yield		
	MSCI index		
	MSCI value-growth ratio		
	BBB spread (corporate debt)		
	Sovereign CISS (sovereign debt)		

Note: $+$ denotes that the impulse response is restricted to be increasing (non-negative) and $-$ decreasing (non-positive). 0 corresponds to the impulse response set at zero. No specification corresponds to impulse response being unrestricted. Grey shaded variables indicate surprises. All restrictions are imposed upon impact.

is, like a monetary policy shock, characterized by negative co-movement between changes in interest rates and stock prices. Specifically, the 3-month OIS decreases and stock prices increase in case of monetary expansion, regardless whether these are conventional or unconventional measures (Kerssenfischer, 2019). To ensure that such negative co-movement is associated with an AP shock, the announced asset purchase volume must increase as in Weale and Wieladek (2016) and Gambetti and Musso (2017), since an asset purchase shock implies an expansion of the ECB's balance sheet. This variable is incorporated in x_t, as are the other unrestricted variables.

We also follow the monetary policy literature by assuming that output and prices are not contemporaneously affected by policy measures. The responses of output and CPI are therefore restricted to be zero at impact. This restriction is also imposed by various other studies on monthly data, see e.g. Gambacorta et al. (2014), Boeckx et al. (2017) and Burriel and Galesi (2018). This also ensures that aggregated supply and demand shocks are excluded. The zero restrictions are imposed contemporaneously such that prices and output are allowed to respond one month after the shock.

To ensure AP shocks are of *Odyssean* nature, that is, announcements where the central bank commits to future actions, we define an additional structural shock as in Jarociński and Karadi (2020). We refer to this shock as a central bank information shock. This second shock is of *Delphic* nature—an announcement where the central bank brings news related to the economy or possible future monetary policy actions. According to Kerssenfischer (2019), Jarociński and Karadi (2020) and Andrade and Ferroni (2021) it is important to distinguish between these two types of shocks as these shocks have different effects on the economy, where the latter find evidence for in the Euro area. These shocks are characterized by positive co-movement between interest rates and stock prices. We further assume the response of output and prices are not contemporaneously affected by these type of shocks.

4.3 Estimation

We estimate the reduce-form parameters $(\mu, B_1, ..., B_p, \Sigma)$ of Equation (1) in a Bayesian fashion. In line with the vast Bayesian VAR literature (see, e.g., Litterman, 1986; Jarociński and Karadi, 2020), we choose a Minnesota type prior, e.g., $p(\mu, B_1, ..., B_p, \Sigma) = p(\mu, B_1, ..., B_p)p(\Sigma)$, where $p(\Sigma)$ follows an Inverse Wishart distribution and $p(\mu, B_1, ..., B_p)$ follows a normal distribution.[9] We use Gibbs sampling to generate draws from the posterior distribution by drawing from two conditional posterior distributions—the conditional posterior of Σ and the conditional posterior of $(\mu, B_1, ..., B_p)$, which follow the Inverse Wishart and normal distribution, respectively. Specifically, we draw from the Normal-Inverse-Wishart posterior over the orthogonal reduced-form parameterization, and transform the draws to a Normal-Generalized-Normal posterior over the structural parameterization, conditional on the zero and sign restrictions using an importance sampler proposed by Arias et al. (2018).

To obtain estimates for A_0^{-1}, we construct Q in the spirit of the QR decomposition method of Rubio-Ramirez et al. (2010). This algorithm also allows us to construct confidence bounds based on the multiple model draws. Specifically, for each posterior draw containing estimates

[9] Appendix D provides a sensitivity analysis on the prior hyperparameters and a discussion of conditional priors (Giannone et al., 2015).

of the reduced- form parameters, we construct a matrix Q and propose a candidate solution for $A_0^{-1} = PQ$. The $N \times N$ orthogonal matrix Q is constructed as

$$Q = \begin{pmatrix} I_{N_z} & 0 & 0 \\ 0 & Q_S & 0 \\ 0 & 0 & I_m \end{pmatrix} \tag{3}$$

where Q_S is a 2×2 orthogonal matrix obtained from a QR decomposition on matrix-valued Gaussian random variables. Here, I_{N_z} denotes an $N_z \times N_z$ identity matrix, and I_m denotes an identity matrix, where $m = N - N_z - 2$. As P denotes the lower triangular Cholesky factor of Σ, the effect of the two shocks on z_t upon impact is by construction restricted to be zero. If the proposed orthogonal IRFs match the sign restrictions in Table 1, we consider the structural responses.

Constructing Q such that the zero restrictions hold is not sufficient to draw independently from the set of all structural parameters, as the set of all structural parameters satisfying the zero and sign restrictions is substantially small. To obtain these independent draws, we determine importance weights following Arias et al. (2018) and re-sample the considered structural responses with replacements from the draws using these weights. Details on the estimation procedure, including prior and posterior distributions and determining the importance sampler weights are provided in Appendix C.

The reported results are based on a total of 1,000 posterior draws from the reduced-form parameters, with a burn-in period of 5,000 draws and storing every third of the following draws until we obtain 1,000 stable models. This results in 530 impulse responses.

The restrictions we impose provide set-identification, meaning that the impulse responses resulting from satisfying the restrictions are not unique. In case of unique IRFs, the SVAR is exactly identified. Rubio-Ramirez et al. (2010) show that this is the case when the total number of restrictions is equal to $N(N-1)/2$ and additional rank conditions are satisfied. As Giacomini and Kitagawa (2021) argue, in case of set-identified SVARs, the prior on the parameters can be decomposed into two components; the prior on the reduced-form parameters and a prior on the rotation matrix Q. The latter is not updated by data. Therefore, we also report the confidence bounds of Giacomini and Kitagawa (2021), which are robust to other priors on Q in Appendix D.

4.4 Country-specific GVAR framework

In order to investigate the country-specific effects of asset purchase programs, we consider the GVAR framework of Burriel and Galesi (2018), introduced in Pesaran et al. (2004) and extended by Dees et al. (2007), for 8 European countries. Each country's economy is modeled by a domestic VAR, and common European factors are modeled in a separate VAR. The framework allows for modeling direct effects of an asset purchase shock, and for cross-country interactions. The domestic VARX(p_i, q_i) for economy i is denoted by

$$Y_{it} = c_i + \sum_{\ell=1}^{p_i} C_{i,\ell} Y_{i,t-\ell} + \sum_{\ell=0}^{q_i} \Lambda_{i,\ell} Y^*_{i,t-\ell} + \sum_{\ell=0}^{q_i} \Gamma_{i,\ell} X_{t-\ell} + u_{it}, \tag{4}$$

where Y_{it} denotes the vector containing endogenous country-specific variables. We consider 7 domestic variables; output, prices, 1- and 10-year government bond yield, MSCI index, value-growth spread and sovereign stress index. Here, p_i denotes the lag length of these variables, q_i denotes the lag length of all exogenous variables and u_{it} are idiosyncratic country-specific shocks, which are assumed to be serially uncorrelated with zero mean and variance-covariance matrix Σ_{ii}. The intercept is c_i, $C_{i,\ell}$ are coefficient matrices of the endogenous variables, and $\Lambda_{i,\ell}$ and $\Gamma_{i,\ell}$ are coefficient matrices of exogenous variables $Y^*_{i,t-\ell}$ and $X_{t-\ell}$, respectively. The foreign-specific variables $Y^*_{i,t-\ell}$ capture relative spillover effects, based on trade relations between countries. Specifically,

$$Y^*_{it} = \sum_{j \neq i} w_{ij} Y_{jt}, \text{ where } \sum_{j \neq i} w_{ij} = 1. \tag{5}$$

The weights are trade-based weights and are assumed constant over time. We consider output as the spillover variable. We further model three common European variables X_t, two market surprises and the asset purchase announcement series, as a VARX(p_x, q_x) process

$$X_t = c_x + \sum_{\ell=1}^{p_x} \Psi_\ell X_{t-\ell} + \sum_{\ell=0}^{q_x} \Phi_\ell \widetilde{Y}_{t-\ell} + u_{xt}, \tag{6}$$

where c_x is the intercept, Ψ_ℓ and Φ_ℓ are coefficient matrices. Again, the idiosyncratic shocks u_{xt} are assumed to be serially uncorrelated with zero mean and variance–covariance matrix Σ_{xx}. The vector $\widetilde{Y}_t$ is a measure for the European economy—a GDP-weighted average of all countries' domestic variables.

In short, the GVAR allows for cross-country interactions through cross-country linkages by foreign-specific variables in Equation (4), non-zero contemporaneous dependence of shocks, e.g., $\Sigma_{ij} \neq 0$ for country i and j, and common European factors. Exploiting that $Y^*_{i,t}$ and $\widetilde{Y}_t$ are linear combinations of country-specific variables, we can combine Equation (4) and Equation (6) into one SVAR model as shown in Burriel and Galesi (2018), such that

$$H_0 \mathcal{Y}_t = h_0 + \sum_{\ell=1}^{\max_i (p_i)} H_\ell \mathcal{Y}_{t-\ell} + e_t, \tag{7}$$

where $\mathcal{Y}_t$ contains the stacked country-specific and common variables. In our setting, $\mathcal{Y}_t$ has 59 variables, as we consider 8 countries with 7 domestic variables for each, and 3 common variables. Here, e_t are residuals with variance-covariance matrix Σ_e. Provided that H_0 is invertible, we obtain the reduced-form VAR given by

$$\mathcal{Y}_t = k_0 + \sum_{\ell=1}^{\max_i (p_i)} K_\ell \mathcal{Y}_{t-\ell} + \eta_t, \tag{8}$$

where $\eta_t = H_0^{-1} e_t$ with $\mathbb{E}[\eta_t \eta_t'] = H_0^{-1} \Sigma_e \left(H_0^{-1}\right)' = \Omega$. We use the same partition as in Equation (1). That is, we stack the zero restricted variables for each country, followed by the common variables and the other responding country-specific variables. We also restrict the market surprises by imposing zero restrictions on coefficient matrix K_ℓ.

We estimate the model in a country-per-country fashion as in Pesaran et al. (2004) and Burriel and Galesi (2018), as the model in Equation (8) contains too many parameters to estimate as a whole. For each economy and the common factors, we estimate the reduced-form parameters in a Bayesian fashion described in Section 4.3. This Bayesian set up differs from Pesaran et al. (2004) and Burriel and Galesi (2018), as they use a bootstrap procedure to construct new samples. We impose the identifying restrictions of Table 1. We choose a parsimonious lag structure as in Burriel and Galesi (2018), we set $p_i = 2$ and $q_i = 0$ for every country, such that we only consider contemporaneous relation to the exogenous variables. Regarding the common factors, we consider both lags equal to 2.We consider the same Gibbs settings as described in Section 4.3, which results in 560 impulse responses.

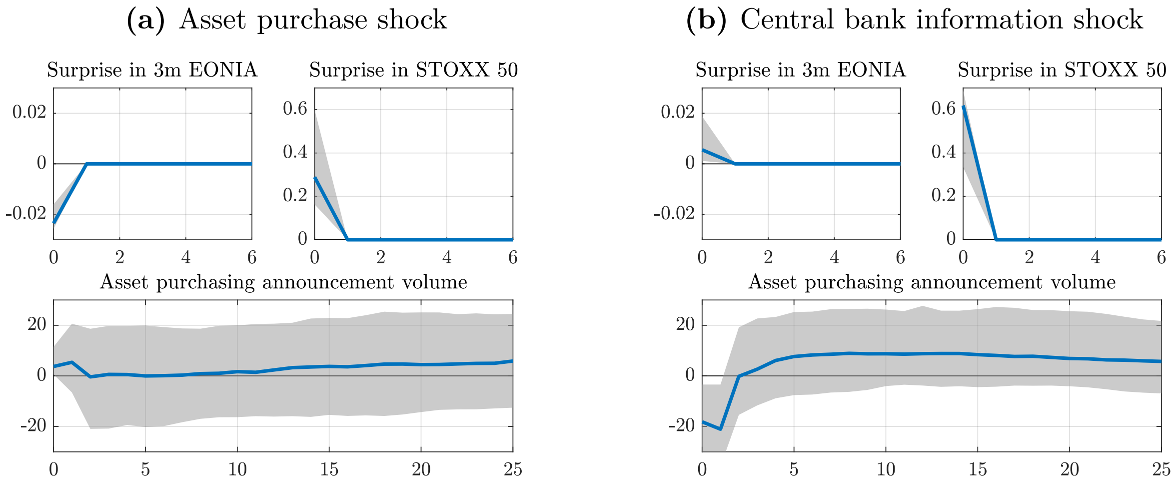
5 Results

We now turn to the results. In Section 5.1 we consider the impact of an asset purchase shock on the economy and financial markets of the Euro area in general. Section 5.2 focuses on heterogeneity in transmission in the stock market and across 8 European countries separately.

5.1 Euro area results

Figure 4 shows the impulse responses of the identifying variables of our baseline VAR—the 3-month EONIA price changes, EURO STOXX 50 price changes and announced asset purchase announcement volume. In our baseline model the market surprises are exogenous, and therefore their IRFs are zero after impact. The AP announcement volume satisfies our imposed non-negativity restriction for an AP shock, as the response is positive upon impact. We report the impulse responses of variables to a one-standard deviation asset purchase shock and a central bank information shock over a horizon of 25 months. The blue solid lines denote the median and the grey areas denote the 16th and 84th percentiles of the

Figure 4: Impulse response functions of the identifying variables



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

posterior distribution. We use these bounds to determine the "significance" of our results, even though we use Bayesian estimation methods. The figure shows that an asset purchase shock is characterized by a 2 basis point drop in the 3-month EONIA rate, a 29 basis point increase in EURO STOXX 50 in the monetary event window, and a 4% increase in announced asset purchase volume. A central bank information shock is characterized by a 1 basis point increase in the 3-month EONIA rate, a 61 basis point increase in EURO STOXX 50, and a drop in announced AP volume—indicating that the announcement contains a positive future economic outlook.

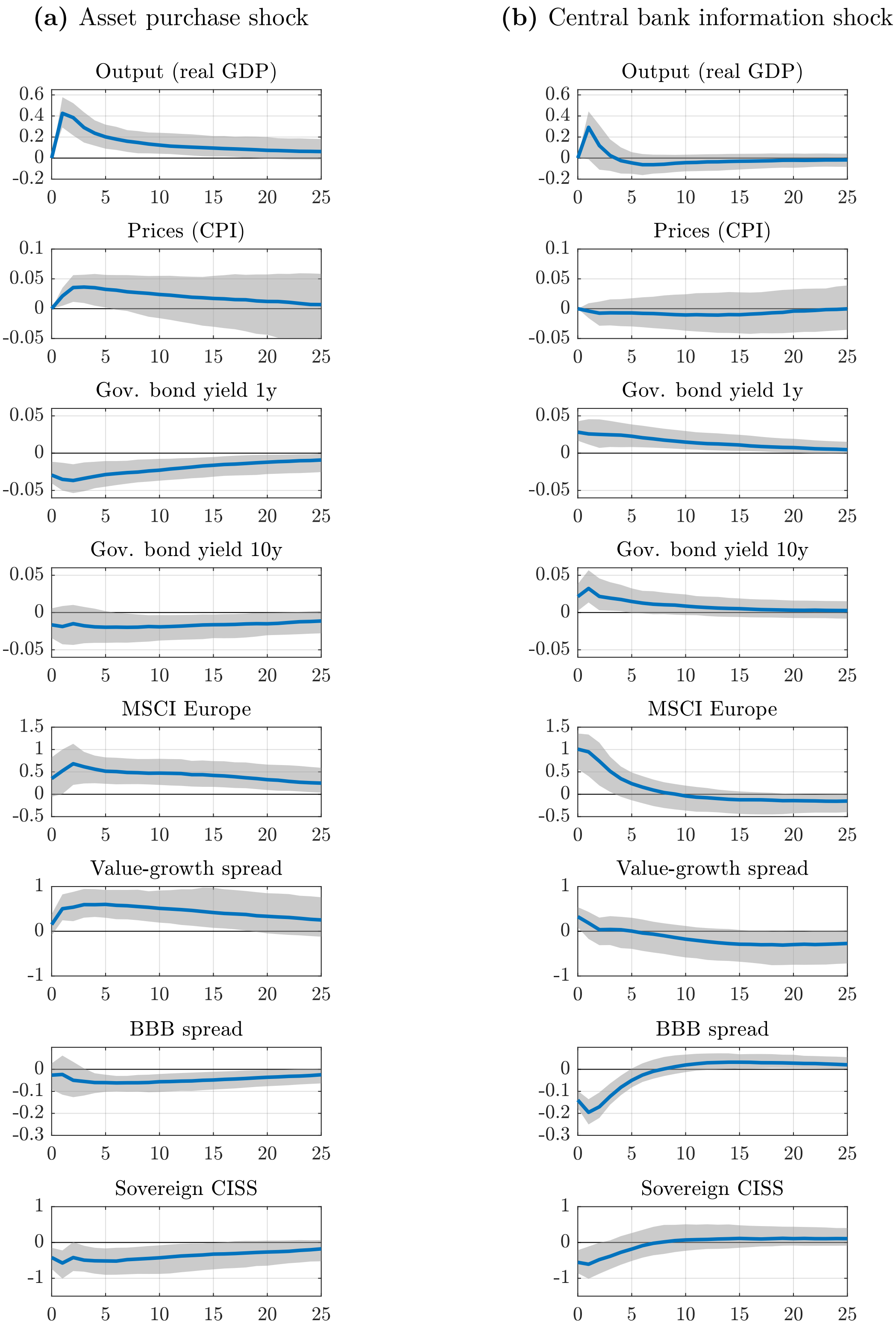
Figure 5 shows the responses of the macroeconomic and financial variables to an asset purchase shock and a central bank information shock. The output and consumer price dynamics show that the asset purchases of the ECB have a positive macroeconomic effect. In the first month this effect is the most prominent for output with a 41 basis point increase in real GDP. This effect decreases but remains significantly positive for over half a year. The increase in prices reaches its maximum of 3–4 basis points after two months and remains significantly positive for about half a year. Comparing the magnitude of the effects on output and prices to a conventional monetary policy shock, we find that an asset purchase shock has a lot more effect on output and less effect on prices. A central bank information shock has a negligible effect on output and prices.

Our macroeconomic results are in line with Gambacorta et al. (2014), Boeckx et al. (2017) and Lewis and Roth (2019), who document a stimulating effect of asset purchase programs on the economy. The delayed response of prices illustrates the sluggish response of prices (e.g., Alvarez et al., 2009). The difference in effects is line with the findings of Gambacorta et al. (2014) and Lewis and Roth (2019). Schenkelberg and Watzka (2013) also find this difference in magnitude between output and prices for a quantitative easing shock in Japan. This difference is larger than the transmission of conventional monetary policy shocks, as studied in Christiano et al. (1999) and Peersman and Smets (2001). Gambacorta et al. (2014) argue that the weak response of CPI could be due to the state of the economy in which unconventional measures are conducted, i.e., during a recession or a period of economic stagnation. This boils down to the argument that aggregated demand changes in general—also the ones induced by monetary policy—have a much stronger influence on output and less effect on prices (Weise, 1999). As the financial crisis caused a long period of economic stagnation, this could indeed be the case here too. Nonetheless, asset purchases indeed seem to stimulate the economy.

Regarding financial variables, we find that the 1-year AAA European government bond yield drops 4 basis points after the announcement and goes slowly back to zero. The 10-year yield drops about 2–3 basis points, but with more estimation uncertainty. It seems that the dynamic effect on short-term yields is somewhat more profound than on 10-year yields. For AA European government bonds this drop in yield is bigger in magnitude—a 13 and 7 basis point drop in yields for 1- and 10-year maturity, respectively. These results are reported in Appendix D. These results imply a heterogeneous effect of an AP shock on the yields for European countries.

The decline in government bond yields is in line with the portfolio rebalancing channel. This channel implies that relative asset demand increase after an AP shock—pushing yields

Figure 5: Impulse response functions of macroeconomic and financial variables



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

down. Next to that, our findings are in line with the signaling channel, which implies that short-term rates decline, as an asset purchase announcement signals low interest rates for a longer time. However, we do not find direct evidence for the long-term maturity aspect of the portfolio rebalancing channel, as this channel suggests a more profound decline in long-term maturity government bond yields. Although Jarociński and Karadi (2020) document a similar response of yields for short- and long-term maturity for a monetary policy shock in the US, this is not in line with the literature on the effect of asset purchase programs. For example, Eser et al. (2019) and Swanson (2020) find a larger reduction in the long-term yields for the Euro zone and the US, respectively. Nonetheless, long-term yields seem to increase slightly more compared to short-term yields in response to a central bank information shock. This indicates that new information about the future economic outlook of the ECB influences long-term bond yields more than an actual asset purchase announcement. This is in line with Andrade and Ferroni (2021), who find a larger effect of a *Delphic* shock on interest rates compared to the effect of an *Odyssean* shock in the EU.

We find that the European MSCI index reaches its largest increase of 0.6% after three months in response to an asset purchase shock. This effect lasts longer compared to the immediate 1% increase in response to a central bank information shock—which revers back to zero within half a year. The spread ratio of the MSCI value index and the MSCI growth index increases with 0.6%, meaning that value firm stocks are more positively affected by an asset purchase shock compared to growth stocks. For a central bank information shock, there is no significant response in the value-growth spread. These results indicate that there is firm heterogeneity in unconventional monetary policy transmission, but that the response to a central bank information shock is rather homogeneous.

The delayed increase in stock prices corroborates the findings in Mamaysky (2018), who find that the response of stocks to an AP announcement is slower compared to government bond yields. Heterogeneous unconventional monetary policy transmission is in line with Durante et al. (2020), who find evidence for heterogeneous transmission among firms. They document that young firms and firms producing durable goods react more to a monetary policy shock. The increase in stock prices is in line with the portfolio rebalancing channel and the signaling channel. The increase in value-growth spread can also be attributed to the portfolio rebalancing channel, as the financing conditions for firms borrowing on the bond market ease. As value firms borrow on the bond market, they profit from an AP shock.

The BBB spread does not respond initially, but decreases by 7 basis points after four months. This effect lasts for over a year. A central bank information shock triggers an immediate decrease of 20 basis in the BBB spread, but this effect reverts back to zero faster compared to an asset purchase shock. Sovereign stress decreases in a similar fashion as the BBB spread for both shocks, but for an asset purchase announcement this effect lasts longer. These findings show that asset purchase announcements and central bank information announcement do have a reassuring effect on both the corporate and sovereign debt market, and for an AP announcement this effect is long-lasting.

These findings are in line with the re-anchoring channel, i.e., AP announcements guide inflation expectations and ensure price stability. This channel implies that risk premia decrease as investors divert to riskier assets. This resonates with Boeckx et al. (2017) and Burriel and Galesi (2018), who assume that an asset purchase shock does not increase financial distress by restricting the response of the stress index to be non-positive.

Figure IA.9 in Appendix D shows the responses of different subcategories of the stress index. These sub-indices are one by one added to the baseline model. Asset purchase announcements seem to reassure all markets in a similar way as all indicators seem to decrease by roughly 0.2% within the first three months. Positive central bank information announcements seem to reassure financial and non-financial equity markets the most, as these drop by roughly 0.5%.

5.1.1 Impact on other variables

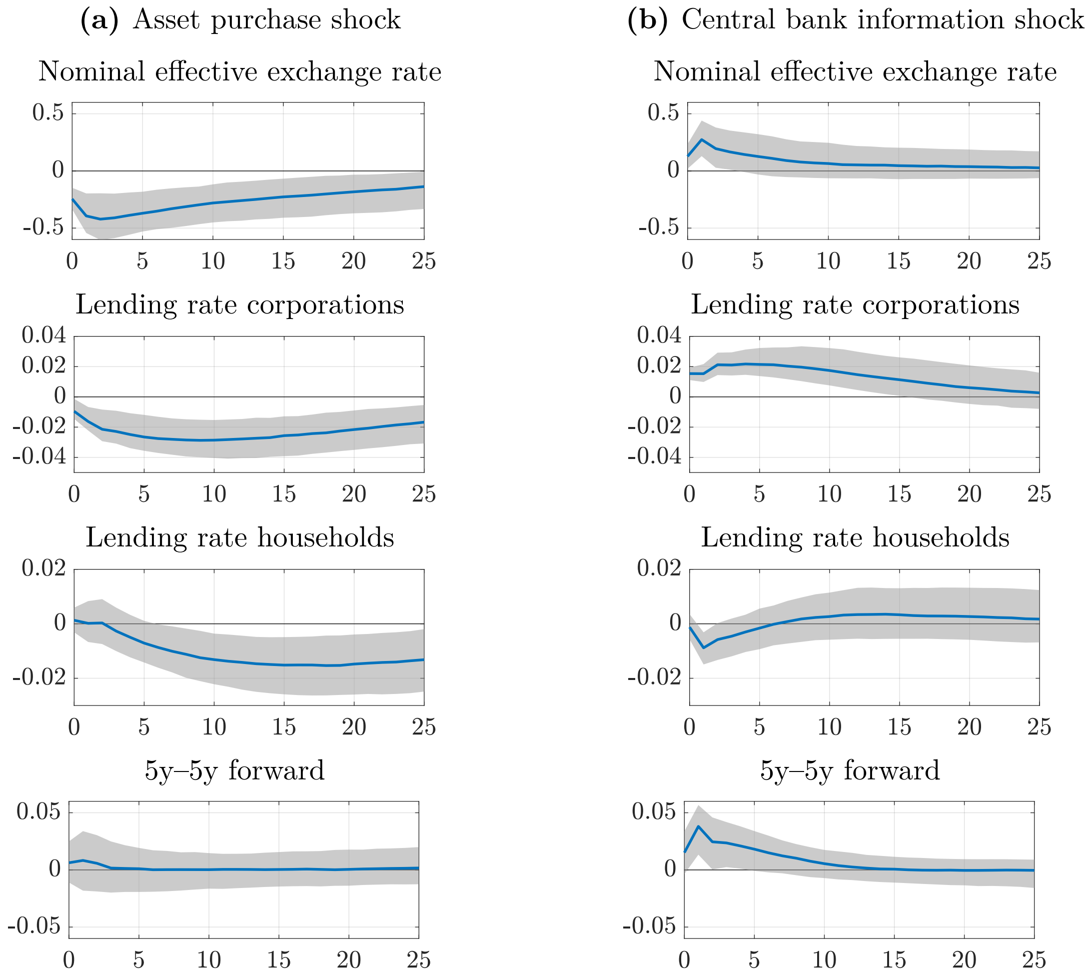
As we find evidence for all three transmission channels, we investigate to what extend these effects work their way into the economy. We add variables one by one to the baseline model. We include the exchange rate to investigate the strength of Europe's economy relative to other economies, lending rates to determine whether asset purchases indeed mitigate risk for banks, and a forward rate to study the term premium. Figure 6 reports the impulse responses of these added variables.

First we check the strength of the Euro relative to other currencies by considering the nominal effective exchange rate. The Euro depreciates in response to an asset purchase shock, and this effect seems to be long lasting. This corroborates the exchange rate effect described by Rogers et al. (2014), as the decreasing yields might cause an increased demand for non-domestic assets in search for yield. A positive central bank announcement results in a short-lived appreciation of the Euro relative to other major currencies. The results are virtually identical when considering the real effective exchange rate.

We find that lending rates to both corporations and households drop, with a more profound decrease in rates for corporations. However, corporate lending rates seem to be more sensitive in general as a positive announcement by the central bank is enough to increase the lending rate for corporations. This is in line with two channels. The portfolio balancing channel suggests that the demand relative to the supply increase for assets, decreasing yields and pushing prices up—as confirmed by our findings in Figure 5. This mitigates the risk for banks, allowing them to lower lending rates (Andrade et al., 2016). This also validates our finding of an increase in the value-growth spread. Second, the signaling channel also implies that the signaling of lower interest rates stimulates lower rates on long-term loans.

Figure 5 shows that the 10-year government bond responds similar to an asset purchase shock compared to the 1-year government bond yield. However, as Svensson (1994) point out, long spot rates may be contaminated with expectations about short-term movements in the interest rate. In order to analyze the effect on the term premium, we also consider the

Figure 6: Impulse response functions other variables



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

5 year forward rate 5 years ahead (5y–5y), as this is a common measure for the long-term market-based inflation expectations. The 5y–5y forward does not seem to respond to an AP shock, indicating that the term premium is not affected.[10] The term premium reduction implied by the portfolio rebalancing channel in response to an AP shock is not present. However, a central bank information shock seems to temporarily raise the term premium. Announcements containing non-monetary news can indeed move the term premium (Cieslak and Schrimpf, 2019; Hansen et al., 2019).

[10] Jarociński and Karadi (2020) also find that the term premium is not affected by a positive monetary policy shock in the US.

5.1.2 Robustness

We perform several robustness checks to analyze the baseline setting. We first analyze the baseline model by examining the model residuals and varying the lag order. Second, we use alternative hyperparameters on the Minnesota prior. Third, we analyze the influence of the implied prior on rotation matrix Q using the multiple prior robust approach of Giacomini and Kitagawa (2021). Next to that, we use alternative identification strategies to identify an asset purchase shock. We find that our results are to a large extend robust to model specification, hyperparameter selection, prior specification and alternative identification schemes. Results of these robustness checks are reported in Appendix D.

5.2 Heterogeneous transmission

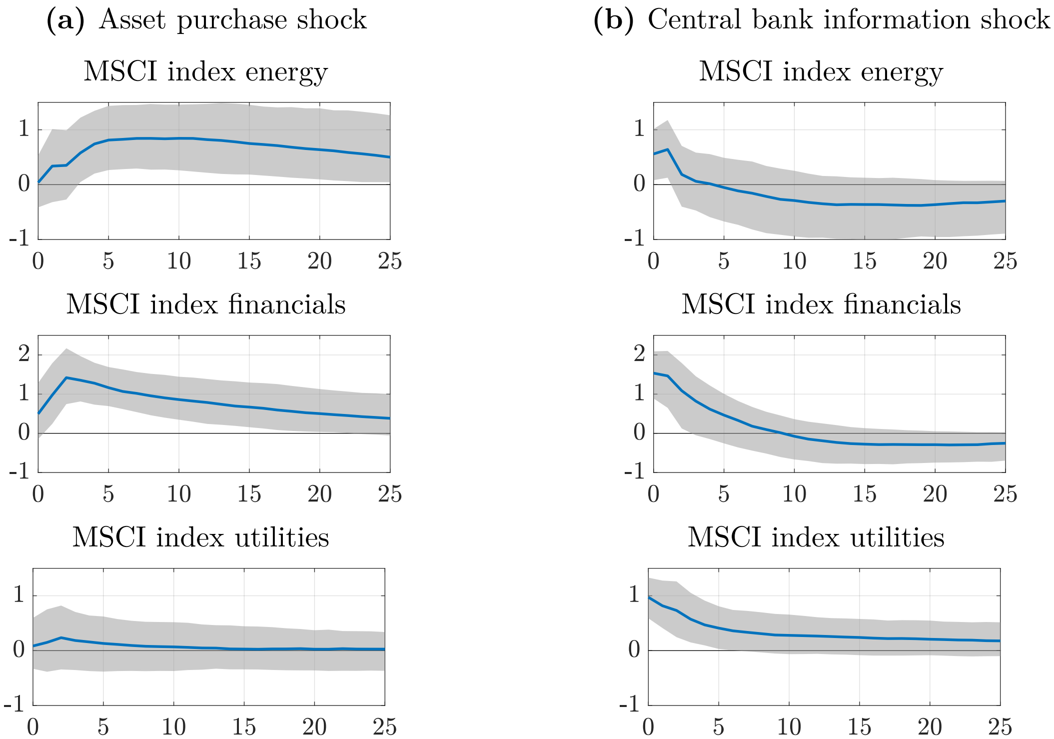
In order to investigate heterogeneous transmission of asset purchase shocks and central bank information shocks, we focus on heterogeneous stock market transmission and on heterogeneous transmission across countries.

5.2.1 Heterogeneous effects on the stock market

In our baseline setting we find that value firms are more positively affected by an asset purchase shock than growth firms. We analyze the possible heterogeneity in transmission across eleven industry sectors by considering sector-specific MSCI indices, according to the Global Industry Classification Standard. Figure 7 reports the impulse responses for the energy sector, financial sector and utilities sector. We report the impulse responses of these three specific sectors, as these sectors are fundamentally very different from each other. The energy sector is more vulnerable to business cycle fluctuations, the financials sector is according the literature affected the most by AP shocks, and the utilities sector is not susceptible to the business cycle. The responses of the remaining sectors are reported in Figure IA.10 in Appendix D.

We find that energy stocks increase by a maximum of 0.9% after half a year in response

Figure 7: Impulse response functions stock market sectors



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

to an asset purchase shock. The peak effect on financial stock prices is roughly 1.4%, three months after an AP shock. On the other hand, utility stocks are not affected. This is expected, as utility companies provide basic necessities such as gas, electricity and water. These companies are generally not affected by the state of the economy.

We find that the effect of an AP shock on the sectors industrials, consumer discretionary, information technology and real estate is positive, with an increase between 0.5 and 0.8%. Sectors such as materials, consumer staples, health care and communication services are not significantly affected by an asset purchase shock. As noted before, the positively affected stocks are generally sensitive to the business cycle, and therefore profit from the improved economic conditions. The stocks not affected are less prone to business cycle movements.

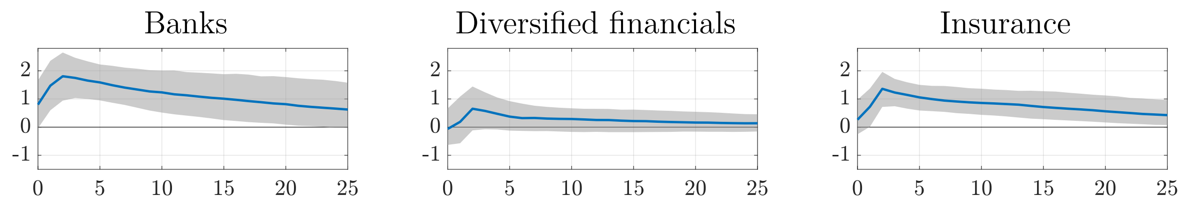
Regarding central bank information shocks, all sector-specific indices increase initially by 0.5 to 1.5%. This effect quickly fades away after three months. A positive central bank information shock therefore stimulates the whole stock market, regardless of the nature of business. The transmission of these shocks seem to be more homogeneous. This is probably due to the positive announcement, which encourages investors to invest.

To find out which industries within the energy sector and the financial sector are affected the most by an AP shock, we consider their more granular industry classifications. Figure 8 shows the impulse responses of these industries to an asset purchase shock. As the ECB bought bonds directly from banks under the APP, we expect the banking sector to be affected the most. This is indeed the case, as banking stocks increase by 1% directly after an AP shock. Banking stocks continue to rise for over a year, with a maximum increase of 1.8% after three months. Insurance stocks are also positively affected, with an increase of 1.4% after three months. The effect on the diversified financial industry is not significant. As the energy sector is highly cyclical, we expect that all industry groups within the energy sector to be positively affected by the stimulating effect of the asset purchase programs on the economy, as documented in Figure 5. Figure 8b corroborates this, as energy equipment and services stocks increase by 1.7% after three months, and oil, gas and consumable fuels is positively affected by 1% between 5 and 15 months. This lagged effect indeed point towards the stimulating effect of asset purchase programs on the economy.

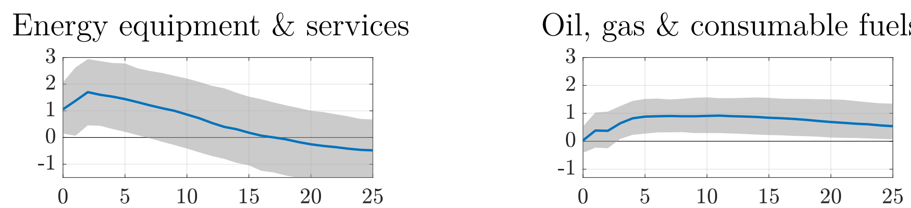
The strongest effect is present among financial stocks, in particular banking. This can be attributed to multiple covered bond purchase programs, starting July 2009. The ECB bought covered bonds issued by European banks under this program. The ECB launched the corporate sector purchase program as part of their APP in June 2016, where the ECB committed to buying corporate bonds by issued European non-bank corporations. This includes corporations in all kinds of sectors—not only corporations in sectors positively affected by an asset purchase shock. Therefore, the positive effect on other financial industries, energy, industrials, consumer discretionary, information technology and real estate does not necessarily come from the bond purchases, but could also be a consequence of improved financial conditions.

Figure 8: Impulse response functions industry groups of energy and financials to an asset purchase shock

(a) Industries in the financials sector



(b) Industries in the energy sector



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

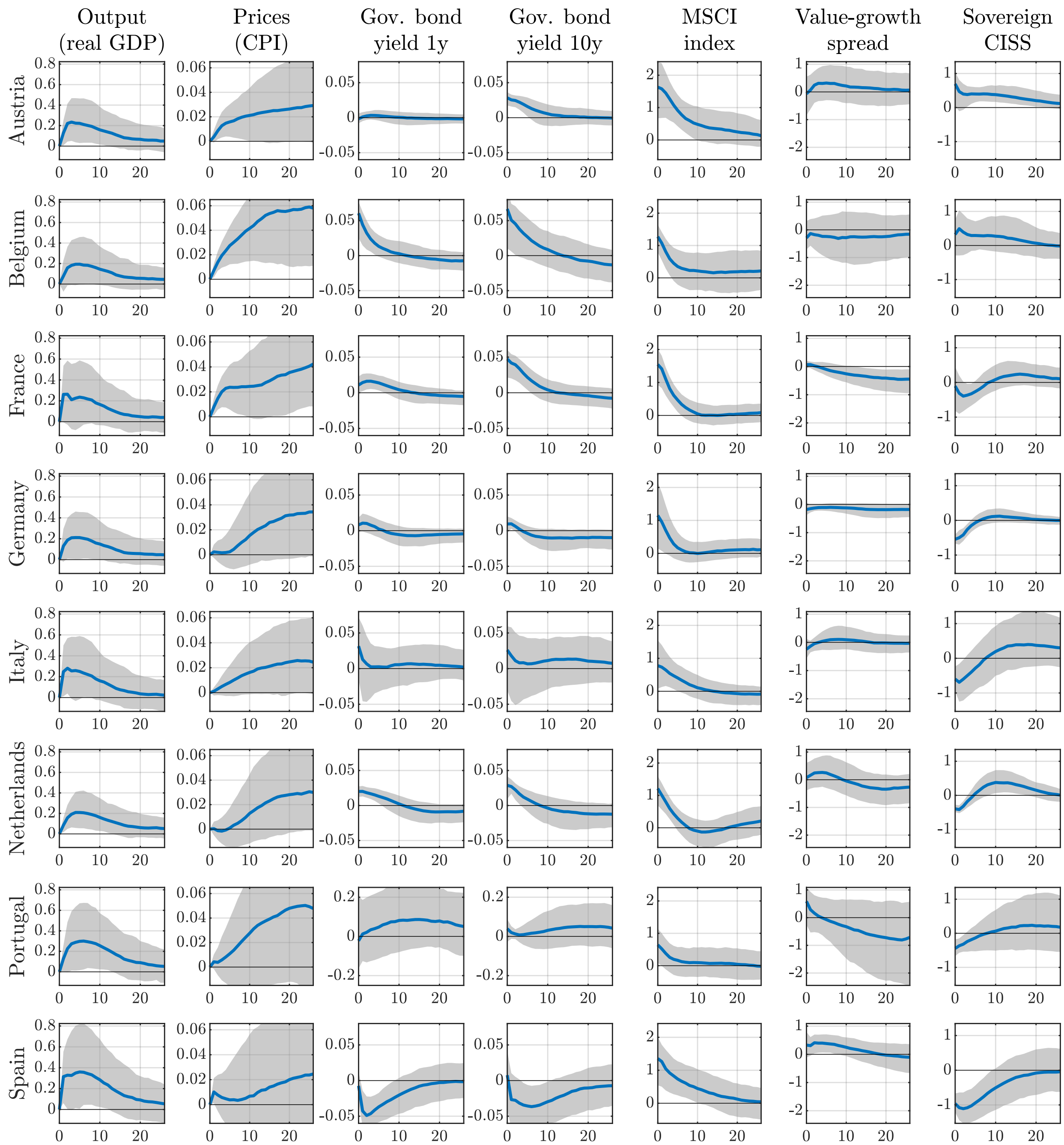
5.2.2 Heterogeneous effects across countries

In our baseline VAR model, we find that asset purchase announcements have positive effect on the economy and the stock market, and a decreasing effect on government bond yields. As the Euro area consists of different countries, it is likely that their economies are differently affected. We therefore investigate the degree of heterogeneity in transmission of shocks across European countries, and the spillover effects. The GVAR model seems to capture the complex dynamics between countries and common variables well, see Appendix D for details. Figure 9 contains the impulse responses to an asset purchase shock for 8 European countries; Austria, Belgium, France, Germany, Italy, the Netherlands, Portugal and Spain, as these are the largest economies in the Euro zone contributing to over 80% of the Euro zone GDP.[11] Each row corresponds to a country.

As on the European level, asset purchase shocks stimulate the economy of all countries.

[11] Greece is not analyzed in this setting as the documentation of Greek government bonds was temporarily suspended in our sample. However, Greek government bonds and stocks are mostly correlated to Portuguese bonds and stocks.

Figure 9: Impulse responses to an asset purchase shock



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

The effect of an asset purchase shock on output is roughly 20 basis points for Southern European countries, whereas for other European countries this effect is between 10 and 15 basis points. The effect on prices is similar across countries, 2–4 basis points, which is significant for Austria, Belgium and France.

In our baseline model, government bond yields decrease after an AP announcement shock. Remarkably, some government bond yields increase after the announcement. The 1-year government bond yield of Belgium, France and the Netherlands increase by 4, 1, and 2 basis points. For 10-year maturity, this increase is 5, 3, and 2 basis points, respectively.

The yields of these three countries are in our sample close to zero—bounded by the zero lower bound. These yields do not have a lot of room to decrease, whereas Spanish yields do. Further, some of the asset purchase announcements were disappointing to market participants. For example, on December 3, 2015, the ECB announced a 10 basis point deposit facility rate cut and APP extension, but investors seemed to be dissappointed.[12] This market disappointment can drive yields up for certain countries. Nonetheless, an AP shock does seem to bring the yields closer to each other, unifying the European Union more.

This result is in line with Corradin et al. (2021), who find heterogeneous transmission in government bond yields in Europe after announcements related to the PEPP in 2020. They find a large reduction in Italian and Spanish yields, as there is lower default risk for these countries. Next to that, they find a positive effect on French and German yields, as the market expected an interest rate cut rather than bond purchases. Their model assigns this increase to an increase in future expected short-term interest rates and the term premium. Similarly, Demir et al. (2022) investigate the effect of the ECB's unconventional monetary policy on European government bond yields. They find a significant impact on all yields across maturities. The market component of these yields is decreased. The risk component yields of Southern European countries decrease more, at the cost of a slight increase in yields of the core countries.

[12] See, for example, https://www.theguardian.com/business/2015/dec/03/ecb-launches-new-stimulus-package-eurozone.

All country-specific MSCI indices increase by 0.3–1% in response to an asset purchase shock, and remain positive for about half a year. There does not seem to be a significant difference across value and growth stocks across countries.

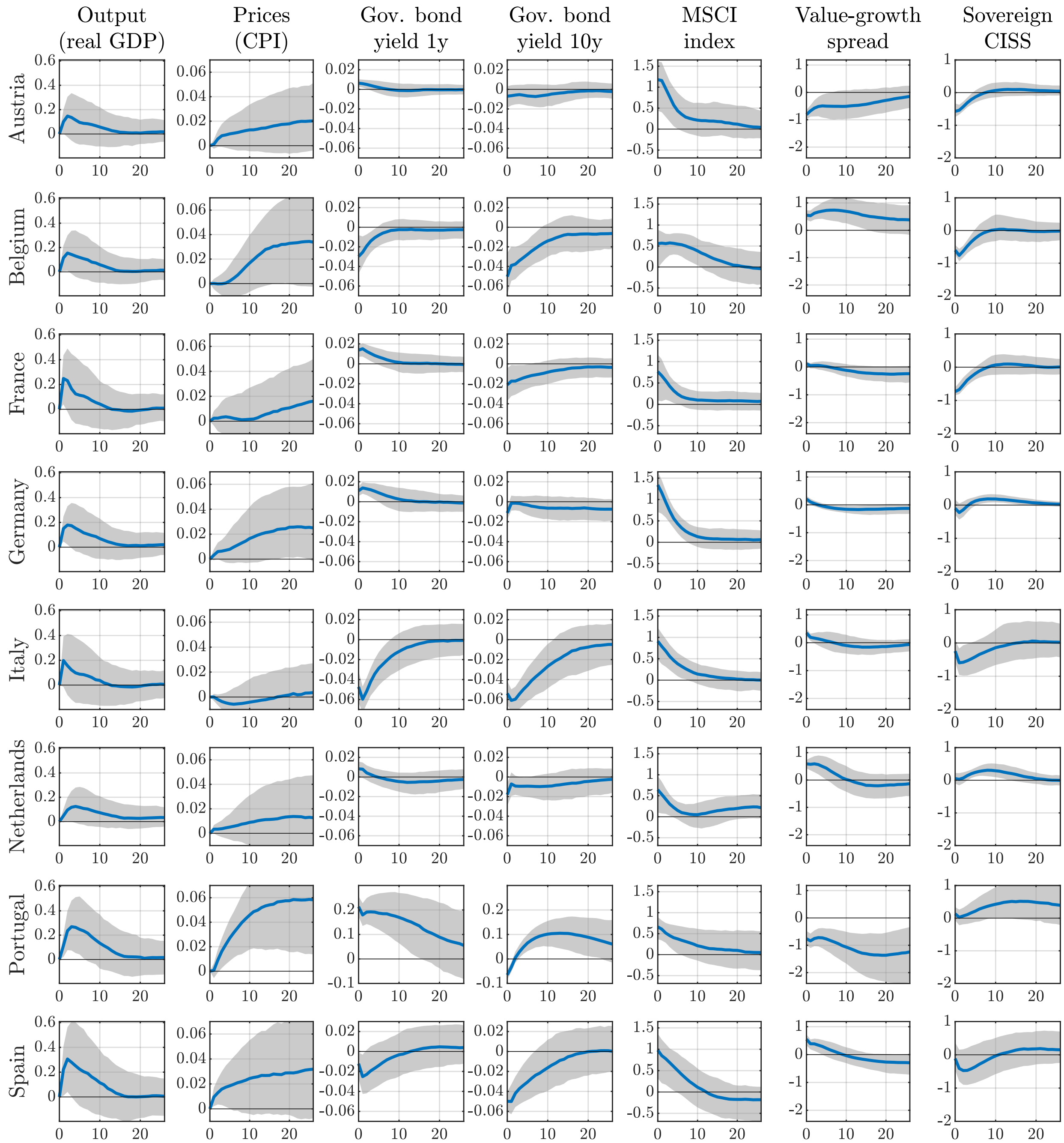
An asset purchase announcement seems to alleviate stress in sovereign debt markets for Southern European countries, as sovereign stress drops by roughly 0.5%. For the core countries this effect is insignificant or even positive, except for the Netherlands, which stress index initially drops 0.4% and later increases 0.4%. The reduction in stress in sovereign debt markets of Southern European countries is consistent with Eser and Schwaab (2016), who find that the securities market program indeed reduced their default risk premia.

A central bank information shock influences all economies quite similar in magnitude as shown in Figure 10. As in the Euro level baseline model, the effects are short-lived—in line with the nature of this shock. The impact on both output and price is in most cases positive and insignificant.

In our baseline model we find positive effect on both the 1- and 10-year government bond yields. However, we find different results when looking at countries separately. For Austria, France, Germany and the Netherlands 1-year government bonds slightly increase within the first year by 1 to 2 basis points. The Portuguese 1-year government bond increases by 20 basis points in response to a central bank information shock. This is likely a consequence of the sharp rise in Portuguese yields prior to the bail out at the beginning of 2011. However, for Belgium, Italy and Spain the effect on government bond yields seems to be negative. Next to that, the 10-year government bonds decrease for every country, with the most profound effect for Belgium, Italy, Portugal and Spain. This indicates that central bank information shocks only contain positive information about the short-term.

Stock indices increase by 0.5–1.3% for each country, and for the Southern European countries the effect on the value-growth spread is positive, except for Portugal, where the effect is negative and persistent. This could be due to the fact that the value index of Portugal consists of utility and energy stocks for a substantial part compared to other countries. These

Figure 10: Impulse responses to a central bank information shock



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

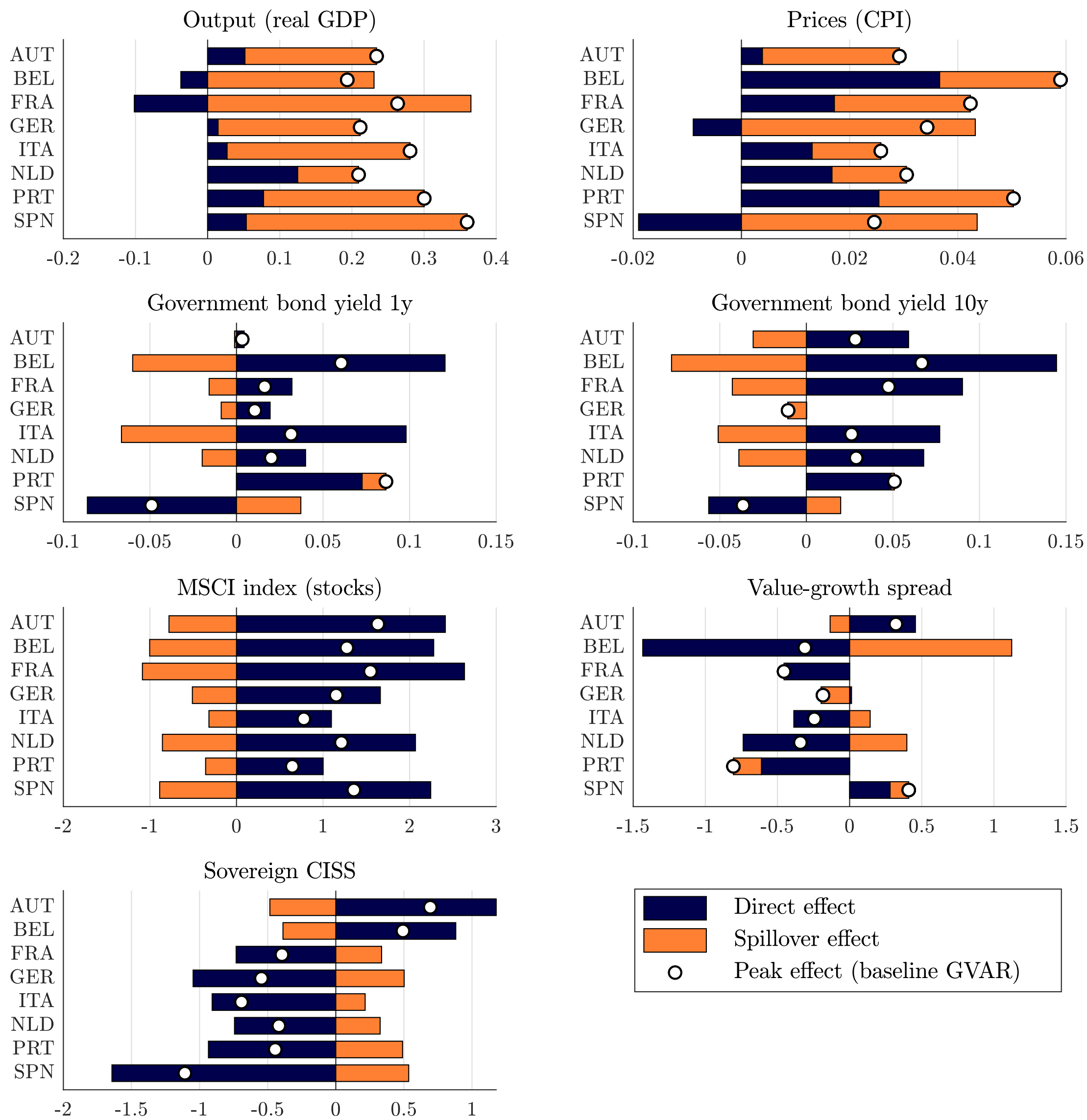
sectors are the least affected by a central bank information shock (see Figure 8). Further, a positive central bank information shock reduces stress on sovereign debt markets for Austria, Belgium, France and Italy. For other countries this effect is negligible.

As we document some heterogeneity in transmission of an AP shock across countries, we examine whether this heterogeneity originates from direct or spillover effects across countries as in Burriel and Galesi (2018). For each economy i, we estimate the direct effect by only considering the effect of the common factors and its own factors, i.e., by setting $\Lambda_{i,\ell}$ to zero in Equation (4). The spillover effects are then calculated as the difference between the estimated IRFs and the direct effects.

Figure 11 shows the direct and spillover median peak effects of an asset purchase shock. The median peak response is the maximum absolute effect for each variable over the horizon. For output and prices, the spillover effects amplify the positive effects. For financial markets—government bond yields and stock prices, direct and spillover effects generally offset each other. These financial products can be seen as substitutes. For example, German and Dutch yields are similar as they are neighboring countries with high credit ratings. As German yields increase, the spillover effect from the Netherlands relative to this increase is negative—dampening the net effect on domestic yields. Next to that, the spillover effect also dampens the positive effect on stock prices, indicating that investors also divert to neighboring countries in response to an AP shock. The direct and spillover effect on the value-growth spread even each other out, which becomes more clear considering the effects over time (see Figure IA.11 in Appendix D). Thus, spillover effects do play a role in heterogeneous transmission. Without taking into account spillover effects, the macroeconomic effects of an asset purchase shock would be underestimated, and the financial effects overestimated.

All in all, the effects of an asset purchase shock and a central bank information shock are somewhat heterogeneous. Especially in the transmission mechanisms of asset purchase shocks to financial markets, where the effect on government bond yields is the most heterogeneous.

Figure 11: Direct and spillover effects of an asset purchase shock



Note: Median peak responses to a one-standard deviation asset purchase shock. Peak response denotes the largest absolute effect over a 25 month horizon. The direct effects are calculated by setting the cross-country linkages in the domestic models to zero. The spillover effects are calculated as the difference in effects in the baseline GVAR model and the model with cross-country linkages set to zero. The peak effect corresponds to the largest absolute median effect in Figure 9.

6 Conclusion

This paper investigates the dynamic effects and transmission of the European Central Bank's asset programs conducted from July 2009 until March 2021 on the macroeconomy and financial markets. Using Bayesian structural VAR analysis, we identify an asset purchase shock by market movements around a monetary event window, and sign and zero restrictions motivated by economic theory. We distinguish between announcements containing monetary policy information and information regarding economic outlook. Using this novel identification approach, we find evidence of heterogeneous transmission of AP shocks across stocks and EMU countries.

We find that an asset purchase shock causes a temporary rise in output and in prices in Europe, where the rise in output is higher than the rise in prices. For Southern European countries this effect is more profound compared to other European countries. These effects are amplified by spillovers. Furthermore, European government bonds immediately decrease, where the 1-year maturity bonds decrease more than the 10-year maturities. The term spread does not seem to be affected. However, this is not the case when considering countries separately in a global VAR setting. An asset purchase shock decreases government bond yields of Spain, whereas it increases yields of Belgium, France and the Netherlands. A possible explanation is that the yields of the latter countries are close to zero in our sample period, making it difficult to decrease more. Next to that, some announcements were disappointing to market participants—driving higher credited yields up instead of down.

Stock prices tend to increase, but respond slower in response to an asset purchase shock. Spillovers reduce these effects. We also find that the spread ratio of the value and growth stocks increases for the Euro area—value stocks seem to rise more than growth stocks, indicating heterogeneous transmission of asset purchases. This effect is not found for central bank information shocks. The sector-specific stock analysis confirms the heterogeneous transmission as we document heterogeneous responses across sectors. Financial stocks are the most affected and this effect lasts over one year. Other stocks are also positively influenced by an asset purchase shock, such as the energy, industrial, consumer discretionary, information technology and the real estate sector.

The BBB spread and the sovereign stress index have a delayed decreasing response, implying that asset purchase programs have a stabilizing effect on corporate and sovereign debt markets. We also find that the nominal effective exchange rate depreciates in response to an asset purchase shock. This effect lasts over almost two years. Asset purchases do stimulate lending to corporations and households, as both lending rates decrease. All in all, the ECB's asset purchase programs do seem to stimulate the macroeconomy and the stock market, but these effects are heterogeneous across industry sectors and across European countries.

These findings provide empirical evidence for all three discussed transmission channels. The immediate reduction in 1-year government bond yield points towards the signaling channel. The asset purchase announcement signals to investors that the interest rate will stay low for longer time, therefore, expectations on the short-term rate decline. The portfolio rebalancing channel suggests that the demand for assets increase relative to the supply in response to an asset purchase shock, pushing prices up and government bond yields down, as our findings confirm. This mitigates risk for banks, such that banks lower their lending rates. This is confirmed by the lagged decreasing response of the lending rates. Finally, the lagged reduction in risk premium on high yields and the stress indices, is in line with the re-anchoring channel, as investors divert to more risky assets in search for yield.

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Appendix

Heterogeneous Macro and Financial Effects of ECB Asset Purchase Programs

Terri van der Zwan, Erik Kole, and Michel van der Wel

February 2022

Contents

A Asset Purchase Programs by the ECB

As a reaction to the financial crisis of 2007–2008, the ECB governing council adopted several conventional and unconventional measures to stimulate the market and support monetary policy transmission mechanisms. The ECB introduced two asset purchase programs—a two-fold covered bond purchase program (CBPP1 and CBPP2) and the securities market purchase program (SMP). The CBPP is aimed to stimulate activity in the covered bond market, which is the main source of funding for banks. Under the CBPP1 European covered bonds are directly purchased for an amount of 60 billion Euro over a twelve month period starting from July 2009 and CBPP2 took place from November 2011 until October 2012 for an amount of 40 billion Euro. SMP started in May 2010 and consists of the purchases of European government bonds with a par value 220 billion Euro. The aim of SMP was to add liquidity to the debt securities market and restore the monetary policy transmission mechanism. See Beirne et al. (2011) and Eser and Schwaab (2013) for a more detailed description of the CBPP and SMP, respectively.

On January 22, 2015, the ECB governing council announced the ECB's APP to promote price stability and to reduce deflation risk by easing financial conditions for both households and firms, as the interest rate approached the zero lower bound. This APP is yet the ECB's largest asset purchase program. The APP consists of four programs—a corporate sector purchase program (CSPP), public sector purchase program (PSPP), asset-backed securities purchase program (ABSPP) and the third covered bond purchase program (CBPP3). From October 2014 until December 2018, net purchases of securities from one or more of the above mentioned programs were conducted. For a more detailed description about the ECB's asset purchase programs, see e.g. Altavilla, Carboni, and Motto (2015) and Gambetti and Musso (2020). The program was re-calibrated a few times depending on the economic circumstances and stopped on December 2018. On September 12, 2019 the ECB announces to restart of security purchases under the APP for indefinite duration, e.g., as long it is necessary to stimulate its policy rates' impact. In the meantime, the ECB reinvested the money from maturing securities under the APP. On March 2020, a direct CSPP envelope of 120 billion Euro was announced.

Additionally, the ECB announced a new temporary asset purchase program named Pandemic Emergency Purchase Program (PEPP) to address serious risks to the monetary policy transmission mechanism after the COVID-19 outbreak in Europe. As the spread of the coronavirus required lockdown measures from March 2020 on, the economic future outlook was very uncertain. The initially announced envelope was 750 billion Euro, but was on June 2020 increased by 600 billion to a total of 1,350 billion Euro. All four categories eligible under the existing APP are also eligible under the PEPP. The PEPP will continue purchases under PEPP until the COVID-19 crisis is over, but not before June 2021. On December 2020 an additional envelope of 500 billion was announced, reaching a total of 1,850 billion Euro. The PEPP is extended to at least March 2022.

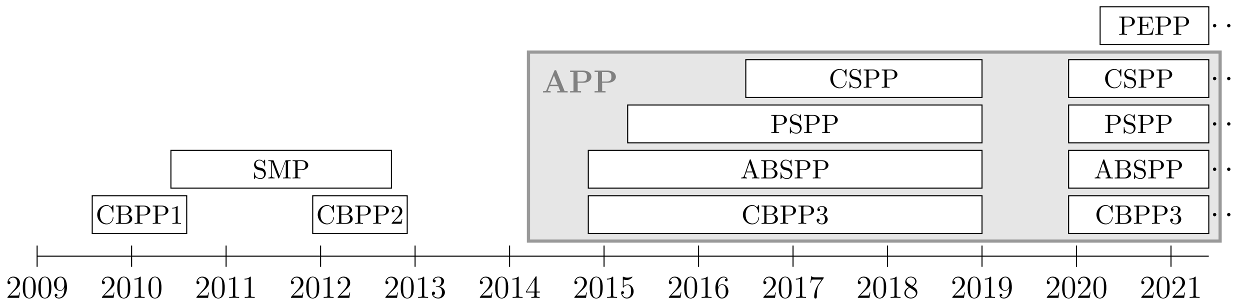
Table IA.1 contains details on these asset purchase programs—their announcement dates, implementation date and quantities purchased. Figure IA.1 shows the time line of the ECB's implemented asset purchase programs.

Table IA.1: ECB's asset purchase programs

Program	**Annc.**	**Start**	**Details program**
CBPP1	07/05/2009	Jul/09	One year program, purchases of €60 billion
SMP	10/05/2010	May/10	Purchases of bonds, €220 billion
CBPP2	06/10/2011	Nov/11	One year program, purchases of €16.4 billion
ABSPP, CBPP3	04/09/2014	Oct/14	Initial announcement, later part of APP
APP	22/01/2015	Mar/15	Start of purchases under APP (ABSPP and CBPP3), net asset purchases of €60 billion p.m.
PSPP	04/03/2015	Mar/15	Adds PSPP to the APP
APP recalibration	03/12/2015	Dec/15	APP extended to March 2017
CSPP	10/03/2016	Jun/16	Adds CSPP to the APP
APP recalibration	10/03/2016	Apr/16	Net asset purchases raised from €60 billion to €80 billion p.m.
APP recalibration	08/12/2016	Apr/17	APP extended to December 2017, net asset purchases reduced from €80 billion to €60 billion p.m.
APP recalibration	26/10/2017	Jan/18	APP extended to September 2018, net asset purchases reduced from €60 billion to €30 billion p.m.
APP recalibration	14/06/2018	Sep/18	APP extended to Dec 2018 net asset purchases reduced from €30 billion to €15 billion p.m.
APP restart	12/09/2019	Nov/19	Net asset purchases €20 billion p.m.
APP recalibration	12/03/2020	Mar/20	Adds a CSPP envelope of €120 billion
PEPP	18/03/2020	Mar/20	Start of purchases under PEPP until December 2020 with purchases in all four APP categories, and an additional envelope of €750 billion
PEPP recalibration	04/06/2020	Jun/20	PEPP extended to June 2021, and an additional envelope of €600 billion
PEPP recalibration	10/12/2020	Dec/20	PEPP extended to Mar 2022, and an additional envelope of €500 billion

Note: p.m. refers to per month, all amounts are in nominal value. For a complete overview of the ECB announcements, see `https://www.ecb.europa.eu/press/pr/html/index.en.html`.

Figure IA.1: Timeline of the ECB's purchase programs



B Data

Table IA.2 reports the data, transformation, source and corresponding identifier. In order to estimate the parameters a VAR model consistently, the variables need to be stationary. However, in our case the goal is to assess the relation between variables. Sims et al. (1990) and Toda and Yamamoto (1995) suggest estimating the VAR model in levels, since this preserves possible long-term relationships between variables. While imposing cointegration or taking first differences can lead to a gain in efficiency, it can also lead to misspecification. We therefore include variables such as output and prices in levels instead of (log) differences.

Table IA.2: Data description

Data	Description, transformation, source and identifier
Monetary policy data	
APP cumulative purchases	Log of total assets bought under the Asset Purchase Program (APP). Data on ECB's balance sheet, including CSPP, PSPP, ABSPP and CBPP3 available at the ECB's website, `https://www.ecb.europa.eu/`.
PEPP monthly purchases	Log of total assets bought under Pandemic Emergency Purchase Program, available at the ECB's website `https://www.ecb.europa.eu/`.
Price changes around monetary event	All price changes during the monetary event window are obtained from `https://www.ecb.europa.eu/pub/pdf/annex/Dataset_EA-MPD.xlsx`.
Macroeconomic data	
Industrial production	Seasonally adjusted industrial production of the Euro area, obtained from the ECB Statistical Data Warehouse, identifier: `STS.M.I8.Y.PROD.NS0020.4.000` (and country specific identifiers).
Real GDP Euro	Log of seasonally adjusted Euro GDP of 19 countries, interpolated using Chow-Lin interpolation with monthly industrial production as reference series. Obtained from the FRED data base, identifier: `CLVMEURSCAB1GQEA19` (and country specific identifiers).
Harmonized CPI	Log of seasonally adjusted Harmonized Index of Consumer Price of the Euro area, obtained from the ECB Statistical Data Warehouse, identifier: `ICP.M.U2.Y.000000.3.INX` (and country specific identifiers).
Financial data	
Government bond yield	Government bond yield with 1- and 10-year maturity, Euroland triple A rating. Obtained from Datastream, identifiers: `GVEA03(CM1),GVEA03(CM10)` (and country specific identifiers).
MSCI	Log of the MSCI performance index, end-of-the-month. Obtained from Datastream, identifier: `MSCI EUROPE E` (and country specific identifiers).
MSCI value	MSCI performance index European value firms. Obtained from Data stream, identifier: `MSCI EUROPE :V E` (and country specific identifiers).
MSCI growth	MSCI performance index European growth firms. Obtained from Data stream, identifier: `MSCI EUROPE :G E` (and country specific identifiers).
High yield spread	Option-Adjusted Spread of the ICE BofA Euro High Yield Index, triple B spread. Obtained from the FRED, identifier: `BAMLHE00EHYIOAS`.
Sovereign CISS	Composite Index of Sovereign Systemic Stress Hollo et al. (2012), ranging from 0 (no stress) to 1 (total stress). Measures stress in sovereign debt markets. Obtained from the ECB Statistical Data Warehouse, identifier: `CISS.M.U2.Z0Z.4F.EC.SOV_GDPW.IDX` (and country specific identifiers).

Table IA.2—*continued*

Data	Description, transformation, source and identifier
Additional European data	
GDP weights	Time series average GDP share based on real GDP.
Trade-based weights	Country-specific weights based on bilateral trade flows based on real GDP, year 2014. Source: World Input Output Database (WIOD).
Lending rates house purchase	Lending rates for households for house purchases, new loans. Obtained from the ECB Statistical Data Warehouse, identifier: `MIR.M.U2.B.A2C.AM.R.A.2250.EUR.N`.
Cost borrowing corporations	Cost of borrowing for non-financial corporations. Obtained from the ECB Statistical Data Warehouse, identifier: `MIR.M.U2.B.A2I.AM.R.A.2240.EUR.N`.
NEER	Nominal effective exchange rate, weighted average of nominal bilateral bilateral rates of the Euro against a basket of foreign currencies, based on EER–19 trading partners. Obtained from the ECB Statistical Data Warehouse identifier: `EXR.M.E5.EUR.EN00.A`.
Forward inflation-linked swap	Refinitiv Euro 5 years forward 5 years swap. Difference in market interest rates for a period of 5 years, starting 5 years in the future. Obtained from Datastream, identifier: `EU5YF5Y`.
Sub-CISS indices	All sub-stress indices are obtained from the ECB Statistical Data Warehouse, identifiers: `CISS.D.U2.Z0Z.4F.EC.SS_XX.CON`, where `XX` varies.
Sub-MSCI indices	All sector and industry-specific MSCI indices are obtained from Datastream, identifiers: `M1URITE`, `M1URHCE`, `M1URFNE`, `M1URCDE`, `M1URT1E`, `M1URIDE`, `M1URCSE`, `M1URE1E`, `M1URU1E`, `M2URR2E`, `M1URM1E`, `M2URB2E`, `M2URD2E`, `M2URI2E`, `M3URESE`, `M3UROGE`.

C Bayesian estimation procedure

C.1 Priors and posterior distributions

In this section we discuss the Bayesian estimation method we use to obtain the parameters of the reduced-form VAR of (1). We denote this model in matrix notation

$$\begin{pmatrix} Z & H & X \end{pmatrix} = \mathcal{X} \begin{pmatrix} B^z & 0 & B^x \end{pmatrix} + \begin{pmatrix} U^z & U^h & U^x \end{pmatrix}, \tag{IA.1}$$

where the left-hand side has dimensions $(T-p) \times N$, with $Z = \left(z_{p+1}, ..., z_T\right)'$, $H = \left(h_{p+1}, ..., h_T\right)'$, $X = \left(x_{p+1}, ..., x_T\right)'$. The right-hand side $\mathcal{X}$ contains all lags of the VAR and the constant. So a row of $\mathcal{X}$ at time t is $\left(z_{t-1}, h_{t-1}, x_{t-1}, ..., z_{t-p}, h_{t-p}, x_{t-p}, 1\right)$. The residuals are $U^l = \left(u^l_{p+1}, ..., u^l_T\right)'$ for $l = z, h, x$. In order to estimate the coefficient matrices in (IA.1)

$$B^z = \Big(B_1^{zz}, B_1^{zh}, B_1^{zx}, ..., B_p^{zz}, B_p^{zh}, B_p^{zx}, \mu_z\Big)', \tag{IA.2}$$

$$B^x = \Big(B_1^{xz}, B_1^{xh}, B_1^{xx}, ..., B_p^{xz}, B_p^{xh}, B_p^{xx}, \mu_x\Big)', \tag{IA.3}$$

we define $B = \Big(B^z, B^x\Big)$. Further, we partition the covariance matrix

$$\Sigma = \begin{pmatrix} \Sigma_{zz} & \Sigma_{hz} & \Sigma_{xz} \\ \Sigma_{zh} & \Sigma_{hh} & \Sigma_{xh} \\ \Sigma_{zx} & \Sigma_{hx} & \Sigma_{xx} \end{pmatrix} \text{ and its sub-matrix } \Sigma_{ZX} = \begin{pmatrix} \Sigma_{zz} & \Sigma_{xz} \\ \Sigma_{zx} & \Sigma_{xx} \end{pmatrix}. \tag{IA.4}$$

The prior on B and Σ is an independent normal-inverted Wishart prior, such that $p(B, \Sigma) = p(B)p(\Sigma)$, with

$$\Sigma \sim \mathcal{IW}(S_0, v_0) \propto |\Sigma|^{-v_0/2} \exp\Bigg(-\frac{1}{2}\text{tr}(S_0)\Sigma^{-1}\Bigg), \tag{IA.5}$$

and

$$\text{vec}(B) \sim \mathcal{N}(\text{vec}(B_0), V_0) \propto \exp\Bigg(-\frac{1}{2}\text{vec}(B - B_0)' V_0^{-1} \text{vec}(B - B_0)\Bigg). \tag{IA.6}$$

Here $\mathcal{IW}$ is the inverted-Wishart distribution and $\mathcal{N}$ is the normal distribution. The prior parameter $v_0 = N + 2$ and S_0 is a diagonal matrix with σ_i^2 on its diagonal, where σ_i denotes the standard error in a simple $AR(p)$ model of variable i. In B_0 we set the coefficient the diagonal element corresponding to the first lag to one if the corresponding variable is non-stationary, and zero otherwise. All remaining entries are zero. The matrix V_0 is a diagonal matrix, where each element corresponds to the implied standard deviation of lag ℓ of variable j in equation i, which is equal to $\lambda_1 \sigma_i / \sigma_j \ell^{-\lambda_2}$. We set $\lambda_1 = 0.2, \lambda_2 = 1$ as in Litterman (1986) and Jarociński and Karadi (2020). We also report results for looser ($\lambda_1 = 0.9, \lambda_2 = 0.5$) and tighter prior specifications ($\lambda_1 = 0.1, \lambda_2 = 1$) in Appendix D Figure IA.5.

The posterior distribution of Σ is

$$\begin{aligned} \Sigma | B, Z, H, X &\sim \mathcal{IW}(\overline{S}, \overline{v}), \\ \overline{S} &= S_0 + \Big(U^z \quad U^h \quad U^x\Big)' \Big(U^z \quad U^h \quad U^x\Big), \\ \overline{v} &= v_0 + T, \end{aligned} \tag{IA.7}$$

where the latter two equations are updating equations. The posterior distribution of B is

$$\begin{aligned}
&\operatorname{vec}(B)|\Sigma, Z, H, X \sim \mathcal{N}(\operatorname{vec}(\overline{B}), \overline{V}), \qquad \text{(IA.8)}\\
&\qquad \overline{V} = \left(V_0^{-1} + \Upsilon^{-1} \otimes \mathcal{X}'\mathcal{X}\right)^{-1},\\
&\operatorname{vec}(\overline{B}) = \overline{V}\Big(V_0^{-1}\operatorname{vec}(B_0) + \left(\Upsilon^{-1} \otimes \mathcal{X}'\right)\operatorname{vec}\Big(\begin{pmatrix} Z & X \end{pmatrix} + H\Sigma_{hh}^{-1}\begin{pmatrix} \Sigma_{hz} & \Sigma_{hx} \end{pmatrix}\Big)\Big),
\end{aligned}$$

using the partitioning in (IA.4) and with $\Upsilon = \Sigma_{ZX} - \begin{pmatrix} \Sigma_{zh} & \Sigma_{xh} \end{pmatrix}' \Sigma_{hh}^{-1} \begin{pmatrix} \Sigma_{hz} & \Sigma_{hx} \end{pmatrix}$, which is an invertible matrix. We use Gibbs sampling to compute the posterior distribution. To compute the complete posterior distribution, we sample in an iterative manner from (IA.7) and (IA.8) until the sampler converges.

All the VARX models combined in the GVAR are estimated country-per-country in a similar fashion as described here. As the country-specific VARs and the common VAR contains exogenous variables, we need to account for them as well in $\mathcal{X}$ of (IA.1), and therefore in (IA.6) and (IA.8). For B_0 we include the exogenous variables as well and set the first lag to one if the corresponding exogenous variable is non-stationary, and zero otherwise. We also need to include the exogenous variables in the diagonal matrix V_0, where we add rows with the diagonal element corresponds to the standard deviation of lag ℓ of exogenous variable l in equation i is equal to $\lambda_1 \sigma_i / \sigma_l \ell^{-\lambda_2}$. Proceed as described above.

C.2 Invertibility of the VAR

Even though we do not need invertibility to obtain valid impulse response functions in case our model coincides with the internal instrument approach of Plagborg-Møller and Wolf (2021), we still only select models based on their invertibility. Invertibility implies that that structural shocks can be recovered from past and current observations. In terms of our model, we need the VAR(p) model of (1) to be invertible into a infinite vector moving average. This is the case when all eigenvalues of the companion matrix lie inside the unit circle (see, e.g., Kilian and Lütkepohl, 2017). The companion matrix refers to the parameter matrix of the VAR(1) companion representation, where the companion representation refers to a VAR(p) model written as a VAR(1) model.

For our baseline setting, we find that our model is not identical to the internal instrument approach of Plagborg-Møller and Wolf (2021) as the surprises h_t (OIS 3m and STOXX 50) are not uncorrelated with z_t and x_t, and its own lags. Table IA.2 report these correlations. Although most of the correlations are insignificant, we do find moderate autocorrelation in the overnight interest rate swap surprises. Both the surprises in OIS and STOXX 50 are negatively correlated with the high yield spread and the sovereign stress index. It is therefore helpful to make sure the models are invertible. In our baseline setting, roughly 60% of our drawings are stable/invertible, meaning that 40% of our draws have one or more unit roots outside of the unit circle.

Table IA.2: Correlation variables

		z_t		x_t						
		Output	CPI	AP ann.	Gov. bond 1y	Gov. bond 10y	MSCI	Value-Growth	BBB spread	Sov. CISS
h_t	OIS 3m	0.09	0.20**	0.05	−0.16**	−0.21**	0.18**	−0.20**	−0.17**	−0.15*
	STX 50	0.11	0.02	−0.07	0.00	−0.02	0.16*	0.04	−0.27***	−0.23***
	Euro	0.02	0.02	0.04	−0.02	−0.02	0.03	−0.08	−0.02	−0.04
				Lag 1	Lag 2	Lag 3		OIS 3m	STX 50	Euro
h_t	OIS 3m			−0.17**	−0.19**	0.29***		1		
	STX50			0.01	0.01	−0.09		−0.22***	1	
	Euro			−0.15*	0.02	−0.11		0.45***	−0.33***	1

Note: ***, **, and * denote significant correlation at the 1%, 5%, and 10% level, respectively.

C.3 Algorithm

In order to obtain draws from the SVAR, we use the following algorithm.

Step 1. Draw reduced-form parameters Σ and B from its posterior distributions (IA.7) and (IA.8), respectively. We consider a burn-in period, and consider every third of the following draws. Check whether the selected model is stable (see Section C.2).

If the model is stable, proceed with *Step 2*.

Otherwise, consider a new draw until a stable model is found.

Step 2. Construct the rotation matrix Q as in (3), for which we draw a 2×2 orthogonal matrix Q_S obtained from a QR decomposition on matrix-valued Gaussian random variables as in Jarociński and Karadi (2020).

Step 3. Calculate the candidate $A_0^{-1} = PQ$, where $P = \text{chol}(\Sigma)$. Check whether the imposed sign restrictions are satisfied.

If the sign restrictions are satisfied, calculate the weights

$$\omega \propto \frac{\left|\det(A_0)\right|^{-(2N+Np+2)}}{\text{vol}_Z(A_0, A_1, ..., A_p)}, \tag{IA.9}$$

where $\text{vol}_Z(\cdot)$ denotes the volume element conditional on the zero restrictions defined as in Arias et al. (2018). Then proceed with *Step 4*.

Otherwise, go back to *Step 2.* If the maximum number of Q draws M_Q is reached, go back to *Step 1.*

Step 4. Repeat *Step 1* until *3* a total of M times until we obtain $\widetilde{M} \leq M$ draws meeting the sign restrictions.

Step 5. Calculate the normalized importance weights as

$$\widetilde{\omega}_j = \frac{\omega_j}{\sum_{j=1}^{\widetilde{M}} \omega_j}, \qquad \text{for } j = 1, ..., \widetilde{M}. \tag{IA.10}$$

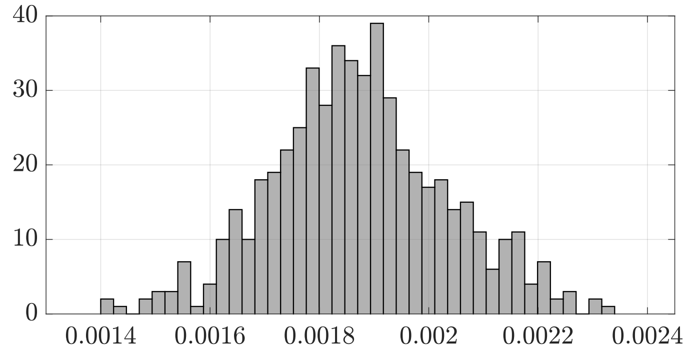
Step 6. Re-sample with replacement M^* times according to the specified importance weights $\widetilde{\omega}_j$ in *Step 5.* Based on Arias et al. (2018), we set

$$M^* = \left\lfloor \frac{1}{\sum_{j=1}^{\widetilde{M}} \omega_j^2} \right\rfloor.$$

Calculate the corresponding impulse response functions.

For *Step 1* we consider a burn-in period of 5,000 draws and select every third of the following draws until we have $M = 1,000$ stable models. We set the maximum number of draws of Q, $M_Q = 5,000$. In our baseline setting we find that $\widetilde{M} = 528$, which implies that over 50% of the drawn models satisfy the restrictions. The effective number of re-sampled reported responses is $M^* = 528$. We further consider the logarithm of the weights (as in Arias et al., 2018) to avoid scaling issues. Figure IA.2 shows the weights of (IA.10). The weights are quite uniformly distributed—with the highest weight being 0.0023 and the lowest 0.0014, about a 0.1 percent point difference. Hence, the influence of the re-sampling procedure is minimal.

Figure IA.2: Importance sampler rescaled weights



Note: The histogram shows the distribution of the rescaled weights $\widetilde{\omega}$ of our baseline setting. There are 528 weights, adding up to 1.

D Additional results and robustness checks

D.1 Model diagnostics

In this section we display some model diagnostics. Figure IA.3a shows the correlation and auto-correlations of the residuals of the baseline model, and Figure IA.3b shows the trade-based weights, eigenvalues and (auto-)correlations of the GVAR residuals. For the baseline setting we find that 80% of the residuals have a contemporaneous correlation lower than 0.4. The correlation is mainly between sovereign CISS residuals and BBB spread residuals. Further, there is mild autocorrelation in the residuals, which is within proportions.

Regarding the GVAR, the trade-based weights should be small and there should be cross-sectional weak dependence in the idiosyncratic shocks (Pesaran et al., 2004). The trade-based weights are on average low—only large for Austria importing from Germany (0.7). 90% of the residuals have a contemporaneous correlation of lower than 0.3. Next to that, the majority of the residuals are indeed weakly autocorrelated.

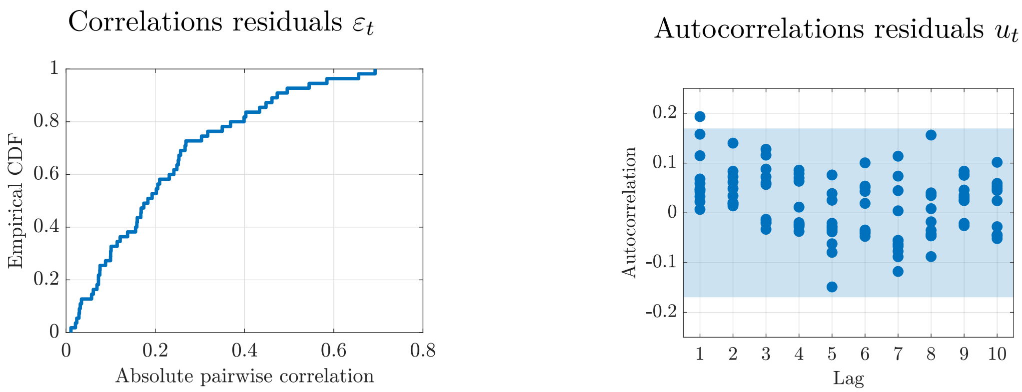
Further, we assume that the trade-based weights and GDP weights are constant over time. This is a reasonable assumption, as the relative trade relations and relative GDPs barely change in our sample.

D.2 Lag length

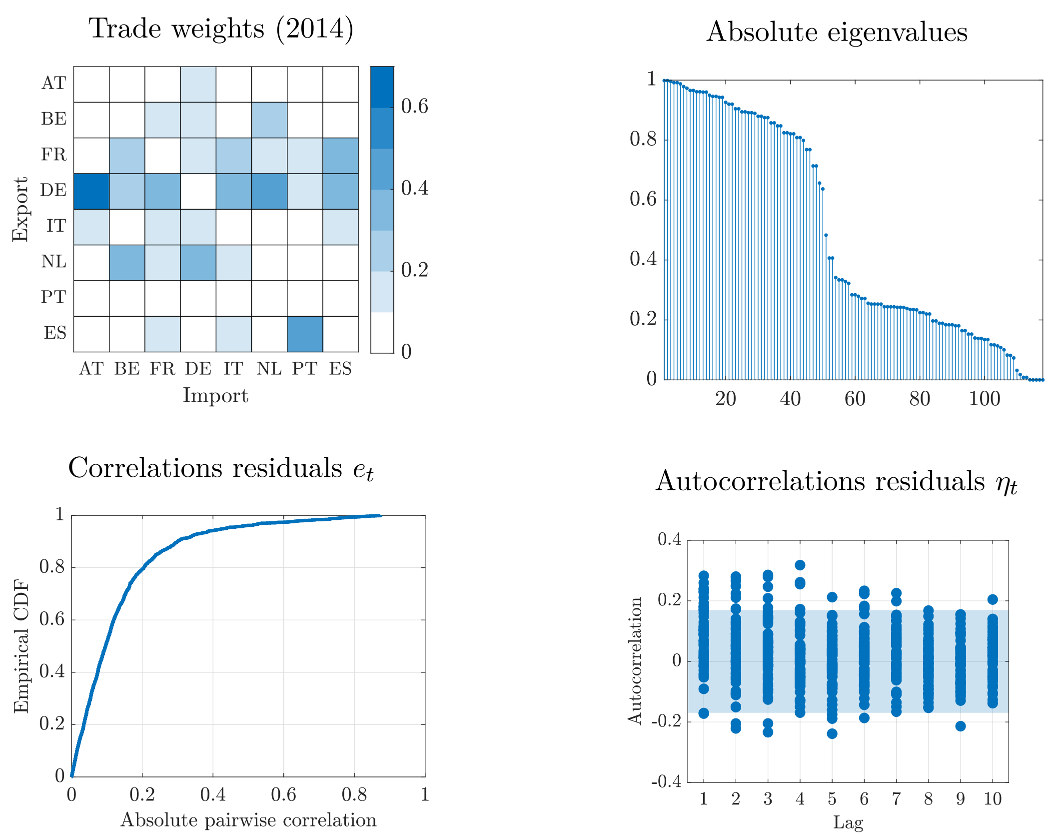
We consider multiple criteria to determine the lag length. Specifically, we consider the Akaike information criterion (AIC; Akaike, 1974), the Schwarz/Bayesian information cirterion (BIC; Schwarz, 1978) and the Hannan-Quinn criterion (HQC; Hannan and Quinn, 1979). The latter

Figure IA.3: Model diagnostics

(a) Baseline setting



(b) GVAR framework



Note: Figure IA.3b is based on Burriel and Galesi (2018). Trade weights are from 2014, import columns add up to 1. Eigenvalues, correlations and auto-correlations are reported of the median posterior draw.

two criterion penalize the number of parameters heavier compared to the AIC. Results for our baseline setting (estimated with OLS and using the surprises as exogeneous variables) are reported in Table IA.3. The model with the lowest criterion value has the best fit according to that criterion.

We do not want to include to many lags, as this might overfit the data, but we also do not want to little lags, as we might not capture the dynamics within the data. To keep the model parsimonious, we set $p = 2$ in our baseline setting, following the Hannan-Quinn criterion. A lag length of 2 provides a good compromise between model parsimony and in-sample fit. We do not consider 1 lag, as Dolado and Lütkepohl (1996) recommend including at least 2 autoregressive lags to exclude the possibility of spurious relations. This lag choice is appropriate, as the autocorrelation in the residuals is generally below 0.2 and the residuals are low to moderately correlated (Figure IA.3). In order to investigate the sensitivity of the results to the lag length, we report the IRFs of the macroeconomic and financial variables based on a VAR(6) model in Figure IA.4. These results are quantitatively similar to the baseline VAR(2) model.

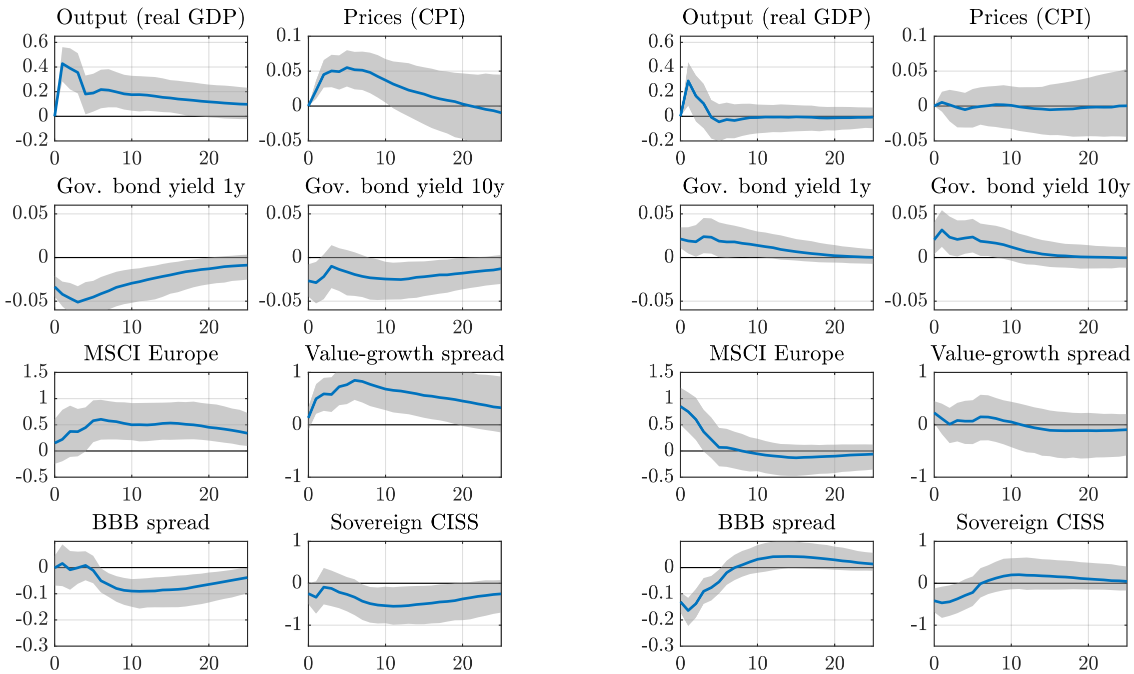
Table IA.3: VAR lag length selection criteria

Lags	**Log $\mathcal{L}$**	**AIC**	**BIC**	**HQC**
1	−1884.17	3948.35	4213.10*	4055.94
2	−1737.14	3816.28	4318.07	4020.20*
3	−1654.77	3813.54	4551.21	4113.31
4	−1576.54	3819.08	4791.43	4214.22
5	−1498.50	3825.01	5030.85	4315.03
6	−1399.43	3788.86	5226.97	4373.27
7	−1304.63	3761.27	5430.42	4439.56
8	−1190.02	3694.04	5593.00	4465.71
9	−1044.83	3565.66	5693.17	4430.19
10	−793.33	3224.66*	5579.45	4181.52

Note: * denotes the lag order selected by the criterion. Log $\mathcal{L}$ is the log likelihood, AIC denotes the Akaike information criterion, BIC the Schwarz/Bayesian information criterion and HQC the Hannan-Quinn information criterion.

Figure IA.4: Impulse response functions to an asset purchase shock (left) and a central bank information shock (right) for the baseline model with 6 lags

(a) Asset purchase shock **(b)** Central bank information shock



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

D.3 Prior sensitivity

In our baseline specification we consider the Minnesota type prior, i.e., the prior on B and Σ is an independent normal-inverted Wishart prior, following the large body of Bayesian VAR literature. Recall that the inverted Wishart prior on *Sigma* in Equation (IA.5) has two parameters, which are scale matrix S_0 and v_0 degrees of freedom. We set S_0 as a diagonal matrix with σ_i^2 on its diagonal, where σ_i denotes the standard error in a simple $AR(p)$ model of variable i, and $v_0 = N + 2$.

The normal distribution on B in Equation (IA.6) also has two parameters, the location parameter B_0 and covariance matrix V_0. In B_0 the entries are zero, and we set the coefficient the diagonal element corresponding to the first lag to one if the corresponding variable is non-stationary, and zero otherwise. The matrix V_0 is a diagonal matrix, where each element corresponds to the implied standard deviation of lag ℓ of variable j in equation i, which is equal to $\lambda_1 \sigma_i / \sigma_j \ell^{-\lambda_2}$.

Both λ_1 and λ_2 are hyperparameters and therefore chosen by the researcher. Here λ_1

is often referred to as the tightness parameter, and λ_2 the decay. When $\lambda_1 \to 0$, the prior becomes more tight as the data has little influence on the on the parameter estimates. In case $\lambda_1 \to \infty$, the prior is loose and the parameter estimates converge to the OLS estimates. The decay parameter λ_2 determines the prior variance in relation to the lag length. As we assume that more recent observations are more relevant than historical observations, we shrink the effect of larger lags. So when $\lambda_2 \to \infty$, we strongly shrink the effect of historical observations. As we consider only two lags in our baseline model, the effect of λ_2 is not very big.

In our baseline setting we set $\lambda_1 = 0.2$ and $\lambda_2 = 1$ as in Litterman (1986) and Jarociński and Karadi (2020). We also check the results using a looser prior, $\lambda_1 = 0.9$ and $\lambda_2 = 0.5$, and a tighter prior, $\lambda_1 = 0.1$ and $\lambda_2 = 2$. Figure IA.5 show the impulse responses for these prior specifications. Only the confidence intervals are affected—the loose (tight) prior specification has larger (smaller) confidence bounds. Therefore the results of our baseline setting are not affected by the hyperparameter choices.

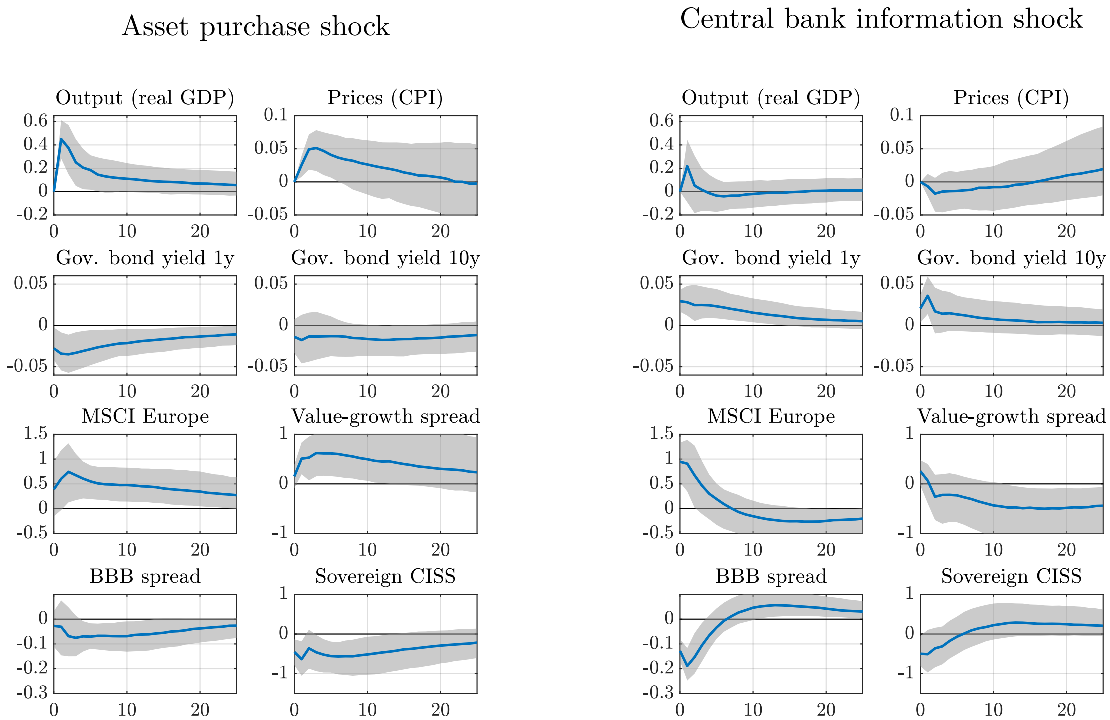
An alternative is to this independent specification is the more general specification, that is, a conditional prior distribution $p(B, \Sigma) = p(B|\Sigma)p(\Sigma)$, with

$$\Sigma \sim \mathcal{IW}(S_0, v_0) \qquad \text{and} \qquad \text{vec}(B)|\Sigma \sim \mathcal{N}(\text{vec}(B_0), \Sigma \otimes \Xi). \tag{IA.11}$$

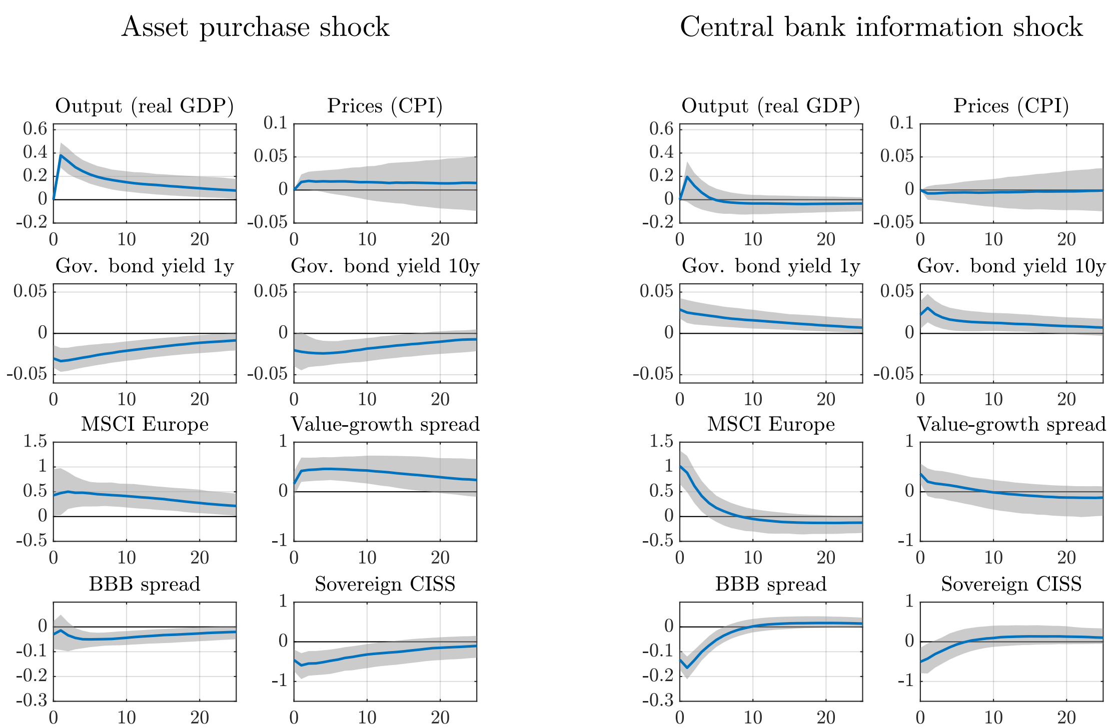
The hyperparameters for Σ, S_0, v_0 remain the same, as well as B_0. The difference is that V_0 now depends on draws of Σ, and hyperparameters Ξ. (Giannone et al., 2015) develops a method to optimally choose the tightness parameter. As their Figure 1 shows, as the size of the Bayesian VAR increases, it is more likely that the shrinkage is similar to the Minnesota prior specification. Next to that, Bańbura et al. (2010) shows that shrinkage is sufficient to Bayesian VARs with a large number of variables, provided that tightness of the hyperparameters on the prior is increased. Therefore, our choice $\lambda_1 = 0.2$ and $\lambda_2 = 1$ seems to be appropriate.

Figure IA.5: Impulse response functions alternative hyperparameter settings

(a) *Loose prior, with* $\lambda_1 = 0.9$ *and* $\lambda_2 = 0.5$



(b) *Tight prior, with* $\lambda_1 = 0.1$ *and* $\lambda_2 = 2$



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

D.4 Alternative identification strategies

Table IA.4 reports the impact responses of the surprises, for the baseline specification, the GVAR setting, and three alternative specifications: the specification without zero restrictions, adding the exchange rate and not considering a central bank information shock.

An AP shock in the baseline setting is characterized by a 2 basis point drop in the 3-month EONIA rate and a 29 basis point increase in EURO STOXX 50 in the monetary event window. A central bank information shock is characterized by a 1 basis point increase in the interest rate and a 62 basis point stock price increase. The asset purchase volume increases roughly 4%. The GVAR baseline identifies an asset purchase shock as a 2 basis point drop in the 3-month EONIA rate and a 49 basis point increase in EURO STOXX 50, and a 2.4% increase in the announced AP volume—which slightly differs from the baseline AP shock. The central bank information shock is compared to the baseline setting slightly higher. These results indicate that for each setting we analyze the same identified shocks.

We now consider alternative identification strategies. Adding the exchange rate of the Euro relative to other major currencies and restricting the response of the Euro to be negative does not affect the identified shock. Not disentangling a central bank information shock substantially decreases the response of the stock market. The impulse responses of alternative 1 and 2 from the macroeconomic and financial variables are very similar to the baseline setting reported in Figure 5.

Alternative 1: no zero restrictions on the macroeconomic variables
An AP shock is characterized by a larger increase in stock prices and announced AP volume (45 basis points and 5%), which is slightly different than the baseline setting. A central bank information shock is in virtually the same. Figure IA.6 reports the unrestricted responses of the monthly macroeconomic and financial variables. We do not impose zero restrictions on output and prices as in Weale and Wieladek (2016), and therefore order these variables after the financial market surprises. We estimate the posterior distributions following Rubio-Ramirez et al. (2010), which is appropriate in case of no zero restrictions (Arias et al., 2018).

The macroeconomic effects increase and remain positively significant for a year. These elevated responses of the macroeconomic variables can originate from supply and demand shocks, which are not excluded in this identification strategy. Other variables are not significantly influenced. Not restricting the responses of real GDP and CPI might therefore lead to overestimation of the macroeconomic effects of an asset purchase shock.

Table IA.4: Impulse responses identifying variables upon impact

		Asset purchase shock		Central bank information shock	
Specification	**Variable**	Median	18–84 perc.	Median	18–84 perc
Baseline	EONIA 3-month	−2.5	(−3.0, −1.6)	0.6	(0.1, 1.9)
	STOXX 50	29	(16, 60)	62	(34, 69)
	Ann. AP volume	3.7%	(0.6%, 11%)		
GVAR	EONIA 3-month	−2.1	(−2.4, −0.9)	1.2	(0.3, 2.3)
	STOXX 50	49	(23, 69)	50	(10, 66)
	Ann. AP volume	2.4%	(0.42%, 8.9%)		
Alternative 1: No zero restrictions	EONIA 3-month	−2.4	(−2.6, −1.5)	0.9	(0.2, 2.0)
	STOXX 50	45	(25, 70)	62	(29, 72)
	Ann. AP volume	5.2%	(1.1%, 15%)		
Alternative 2: Italian 2-year bond rate	Italy 2-year	−4.4	(−5.2, −3.6)	4.2	(2.5, 4.7)
	STOXX 50	68	(61, 73)	7.4	(0.8, 30)
	Ann. AP volume	1.8%	(2.4%, 49%)		
Alternative 3: Adding exchange rate surprises	EONIA 3-month	−2.3	(−2.6, −1.8)	0.6	(0.1, 1.7)
	STOXX 50	29	(16, 57)	62	(39, 69)
	Euro	−20	(−24, −17)		
	Ann. AP volume	4.5%	(0.8%, 12%)		

Note: Median and 16–84th percentiles (confidence intervals) of the posterior distribution. Surprises are reported in basis points, announced asset purchase volume increase (Ann. AP volume) in percentage.

Alternative 2: Italian bond rate surprises instead of European overnight swap surprises

An asset purchase shock is characterized by a larger decrease in Italian bond rate surprises and higher stock market surprises compared to the EONIA 3 month rate of the baseline model. A central bank information shock is also different; the bond rate responds more and stock prices less. Figure IA.6b reports the corresponding responses of the monthly macroeconomic and financial variables.

The impulse responses are similar to the baseline setting, except for the European yields, which do not respond in response to an AP shock. It seems that the identification strategy of our baseline setting is not limited by the zero lower bound.

Alternative 3: Adding exchange rate surprises

We also add the surprise in Euro against other major currencies to our baseline model and restrict this surprise to be negative in case of an asset purchase shock. This makes the set of identified impulse responses smaller. Figure IA.6c reports the corresponding responses of the monthly macroeconomic and financial variables. An asset purchase shock and central bank information shock are virtually the same. The median impulse responses of both shocks are not affected by this additional restriction, but the confidence bounds are smaller. This indicates that the AP shock identified by the baseline setting is already includes this depreciation of the Euro.

Figure IA.6: Impulse response functions alternative identification strategies

(a) *Alternative 1: no zero restrictions on the macroeconomic variables*

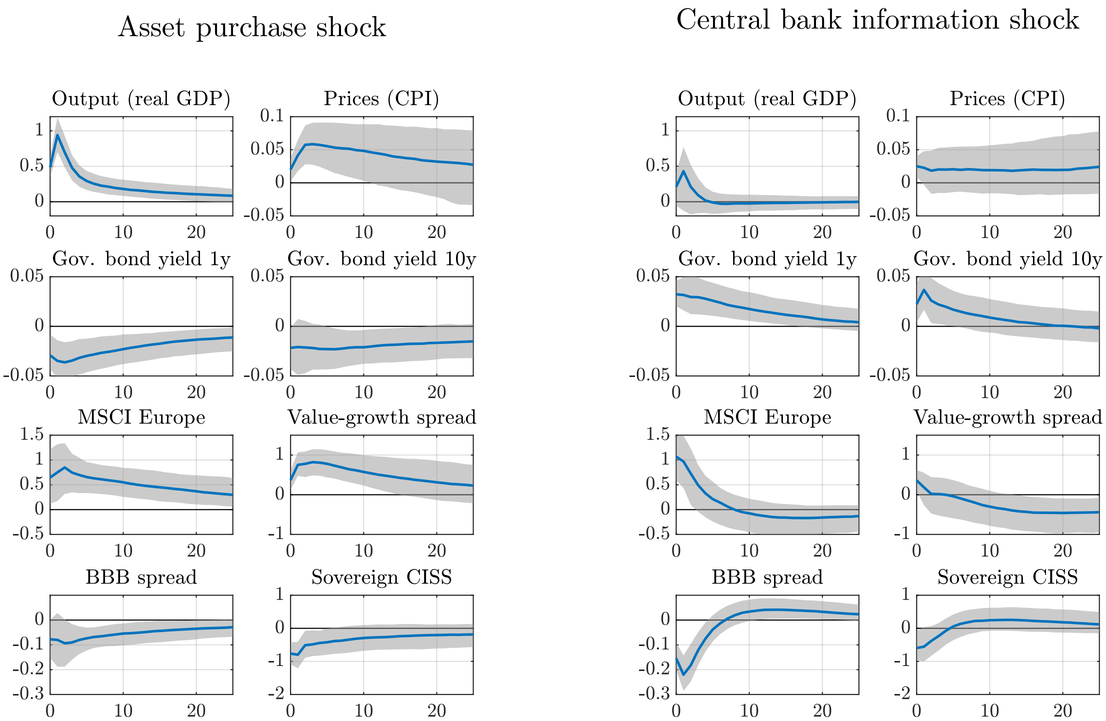
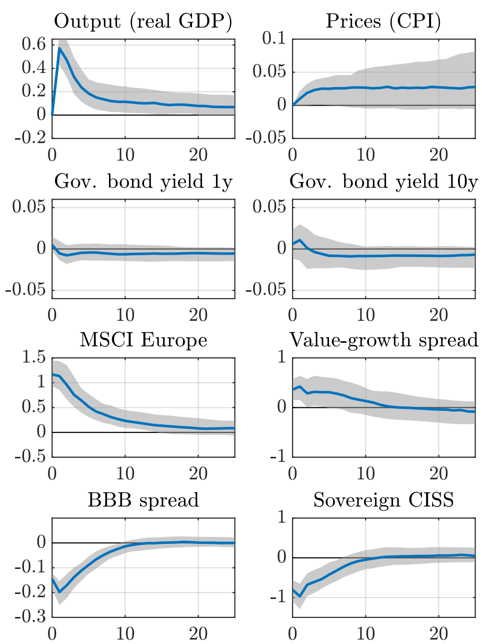


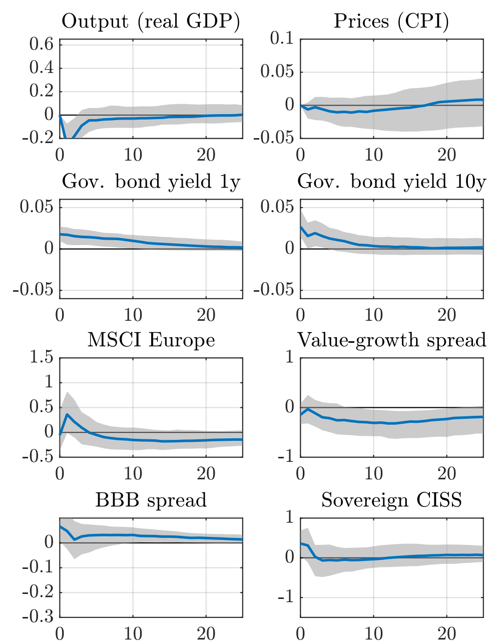
Figure IA.6—*continued*

(b) *Alternative 2: Italian bond rate surprises instead of 3 month EONIA surprises*

Asset purchase shock

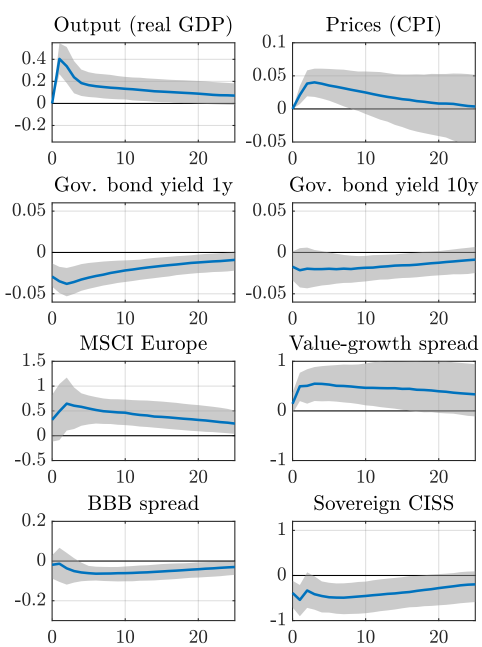


Central bank information shock

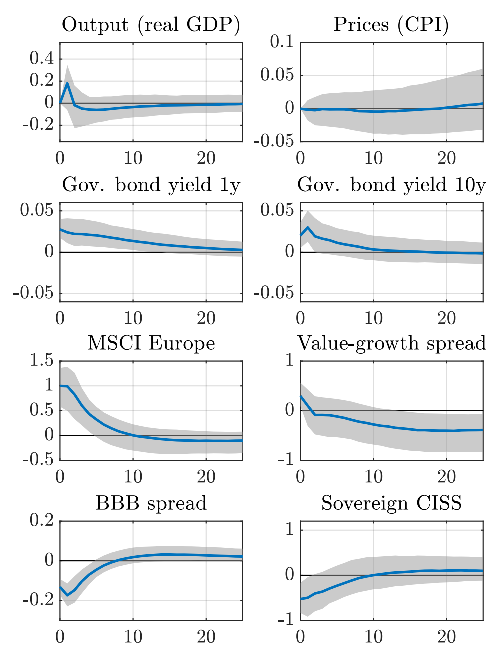


(c) *Alternative 3: Adding exchange rate surprises*

Asset purchase shock



Central bank information shock

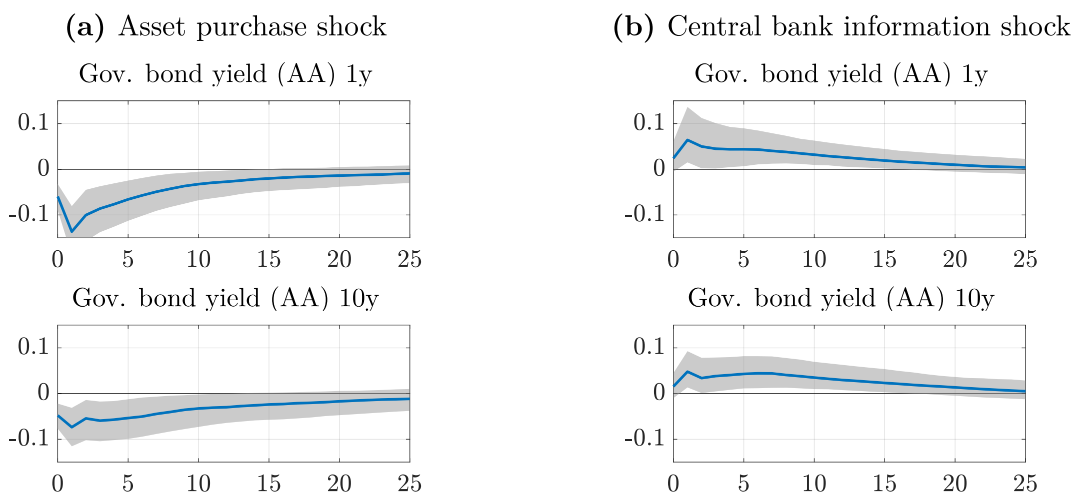


Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

D.5 Alternative European government bond yield

Figure IA.7 reports the impulse response functions for AA rated government bond yields, replacing the AAA government bond yields in our baseline setting. As this replacement does not affect the responses of other variables, we only report the AA European government bond yields for 1- and 10-year maturity for both shocks. The effects on AA European government bonds is more severe for an asset purchase shock compared to the AAA European government bonds in Figure 5, as the AA yields decrease by 13 and 7 basis points for 1- and 10-year maturity respectively. The effect of a central bank information shock is very similar on AA government bond yields.

Figure IA.7: Impulse response functions of alternative yields to an asset purchase shock (left) and a central bank information shock (right)



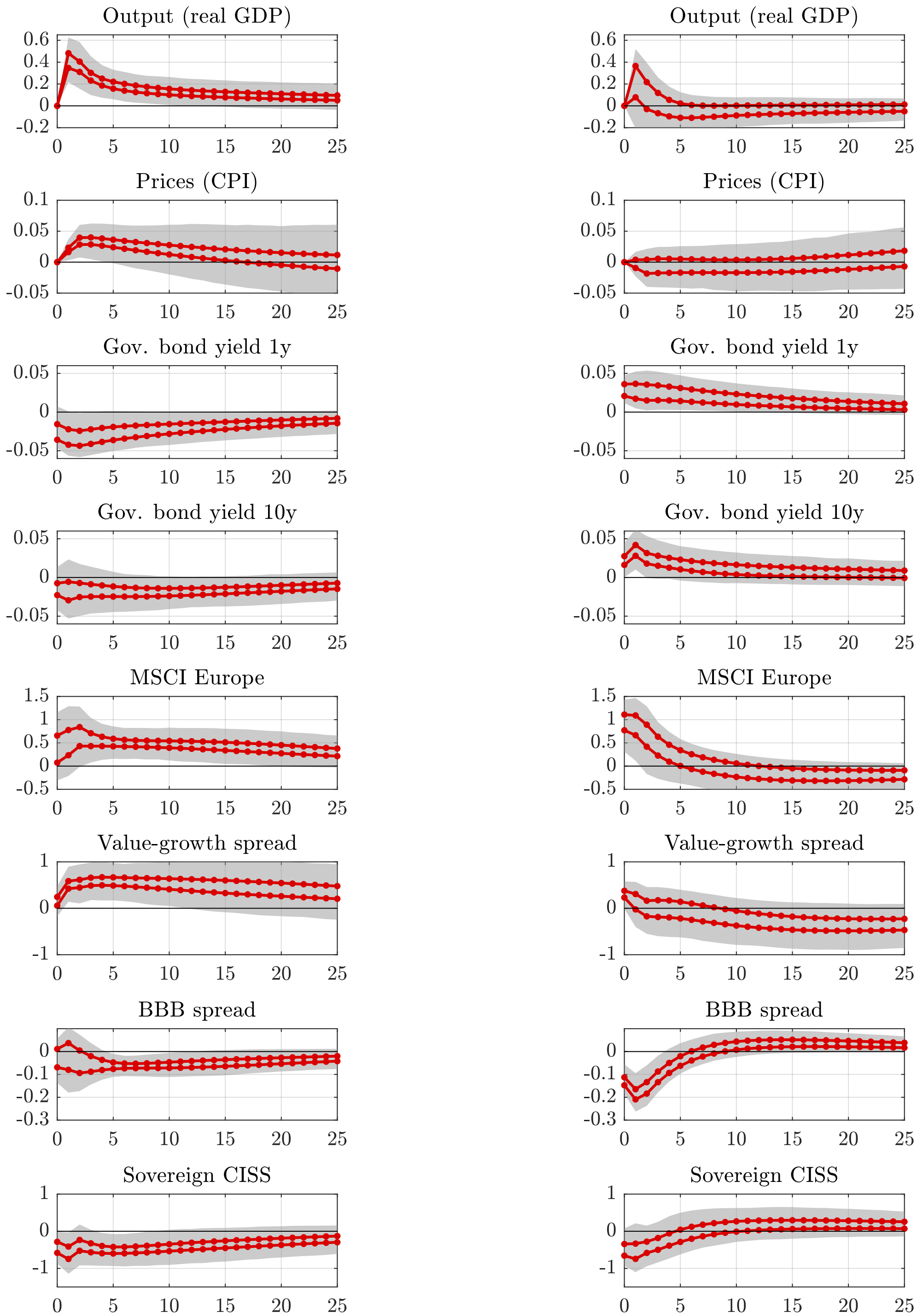
Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

D.6 Robust error bands

We show that our results are not sensitive to the prior of rotation matrix Q by adopting the approach of Giacomini and Kitagawa (2021). We report the posterior mean bounds and the robust credible regions in Figure IA.8. The red dotted lines correspond to the posterior mean bounds, and the shaded area corresponds to the 16th and 84th percentiles of the robust credible region. As Giacomini and Kitagawa (2021) state, the set of posterior means consistently estimates the true identified set, and the robust credible region corresponds to the frequentist asymptotic view of the true identified set.

Figure IA.8: Impulse response functions to an asset purchase shock (left) and a central bank information shock (right) for the baseline model with robust bounds

(a) Asset purchase shock **(b)** Central bank information shock



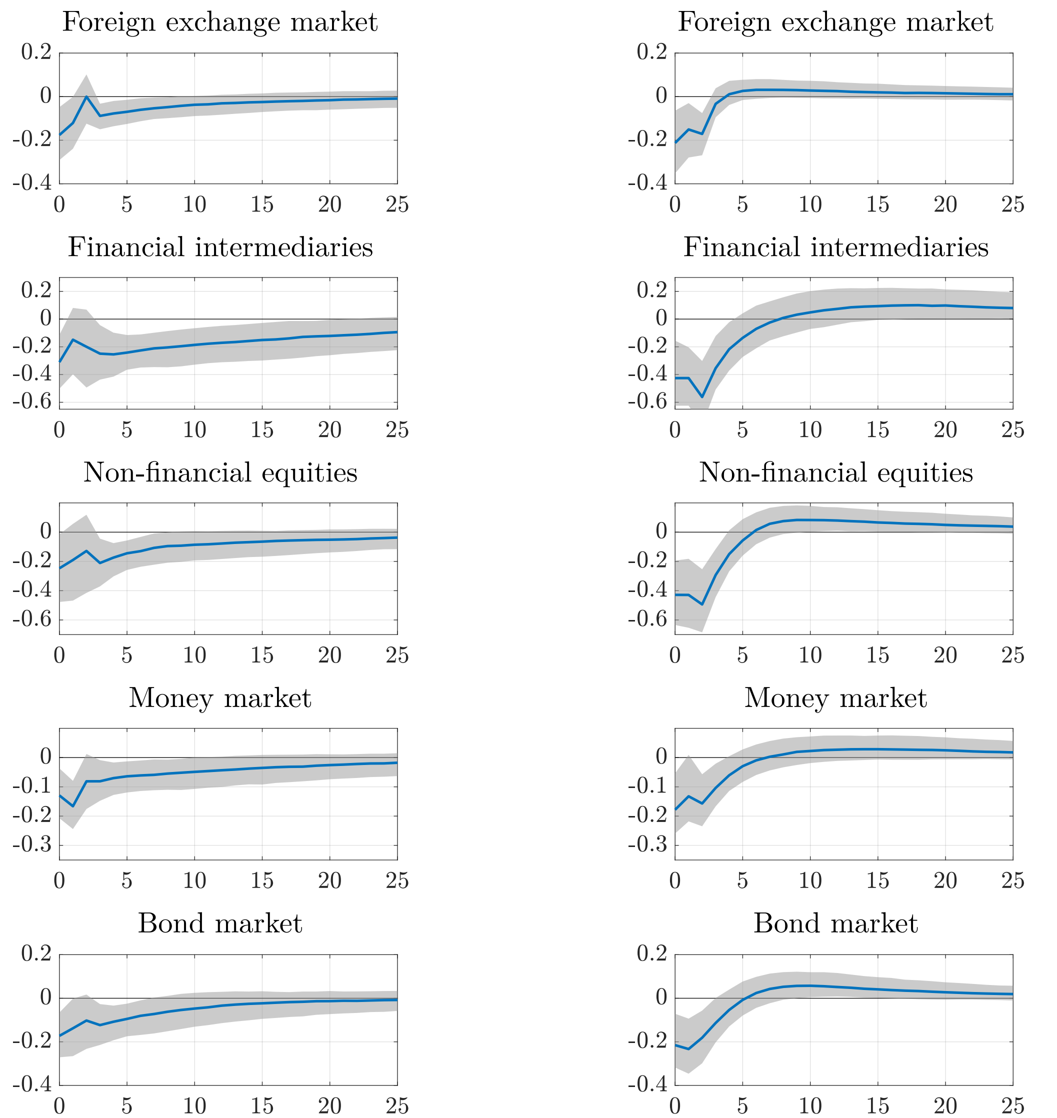
Note: Responses to one-standard deviation shocks. Posterior mean bounds (red dotted lines), 16–84th percentile robust credible region of Giacomini and Kitagawa (2021) (grey area).

D.7 Sub-indicators of the stress index CISS

In order to analyze the difference in markets, we add each sub-CISS index one by one to the baseline model. Figure IA.9 show the responses of the 5 sub-indicators. Both shocks lead to a reduction in stress in all markets. For asset purchase shocks this reduction in stress is homogeneous across markets, whereas for a central bank information shock containing information about for example economic outlooks, the equity market is mostly reassured.

Figure IA.9: Impulse response functions sub-indices CISS

(a) Asset purchase shock **(b)** Central bank information shock



Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

D.8 Sector-specific MSCI stock market indices

We analyze the sector heterogeneity within stocks by adding sector-specific MSCI indices one by one to the baseline model. Figure IA.10 show the responses for nine of the eleven major categories of the Global Industry Classification Standard (GICS). The sectors financials and utilities are shown in Figure 6. Health care is positively affected by an asset purchase shock after over a year. This can be attributed to the COVID-19 pandemic, as this effect disappears when we consider the sample until the end of 2019. The positive effect on the real estate sector is driven by REITs rather than a rise in management & development.

Figure IA.10: Impulse response functions MSCI sub-indices

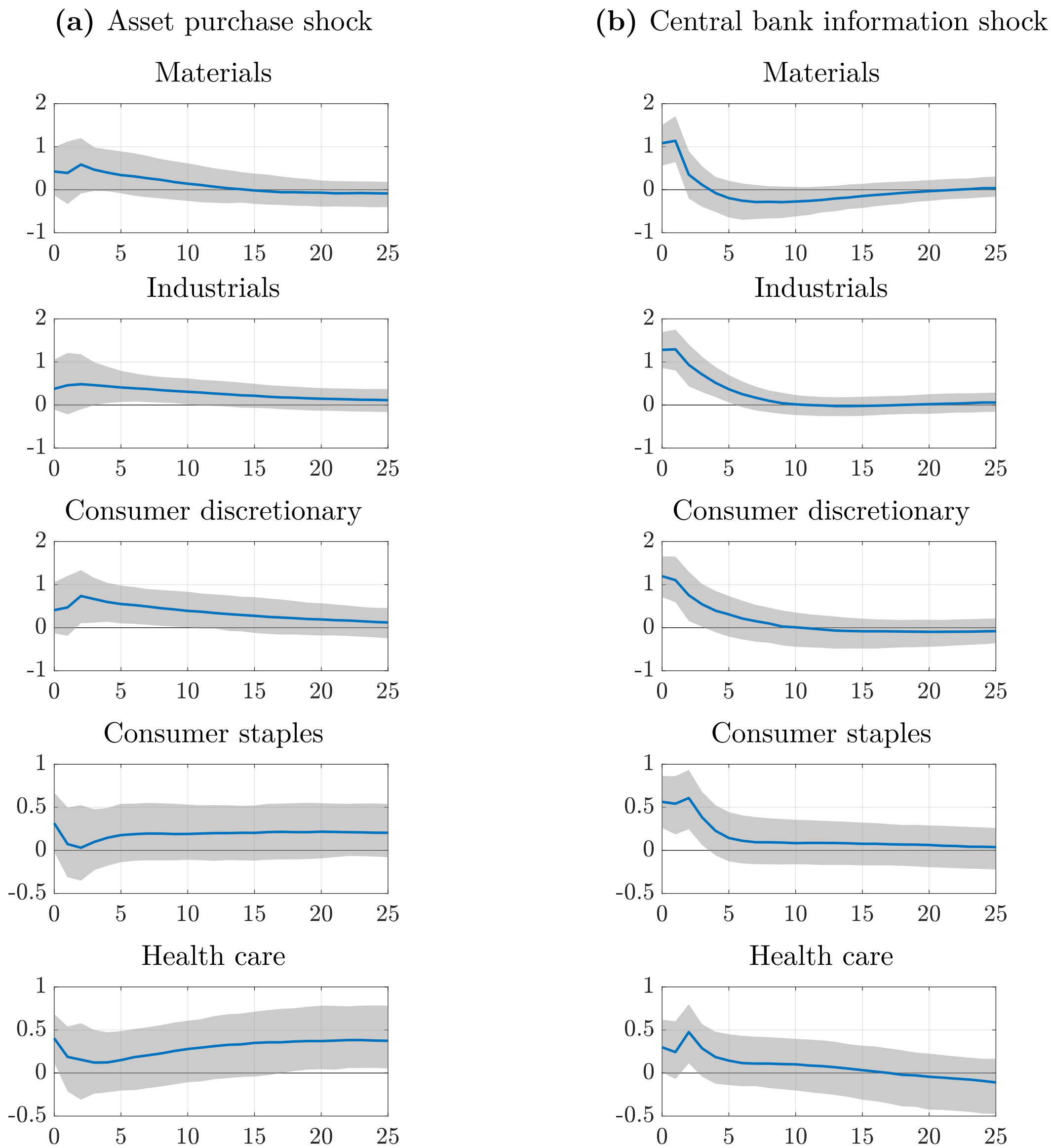
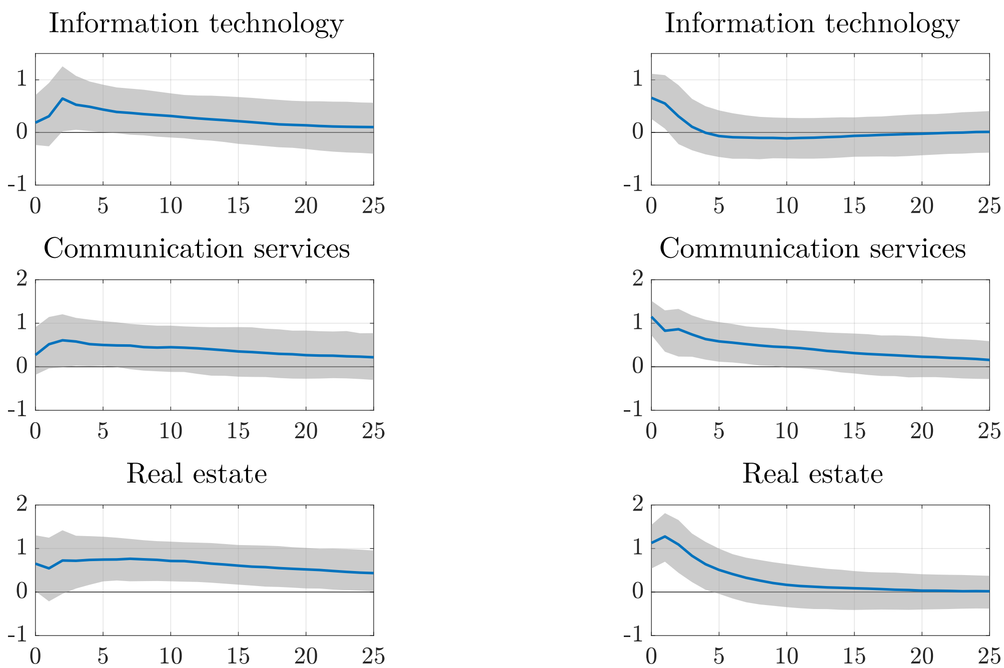


Figure IA.10—*continued*

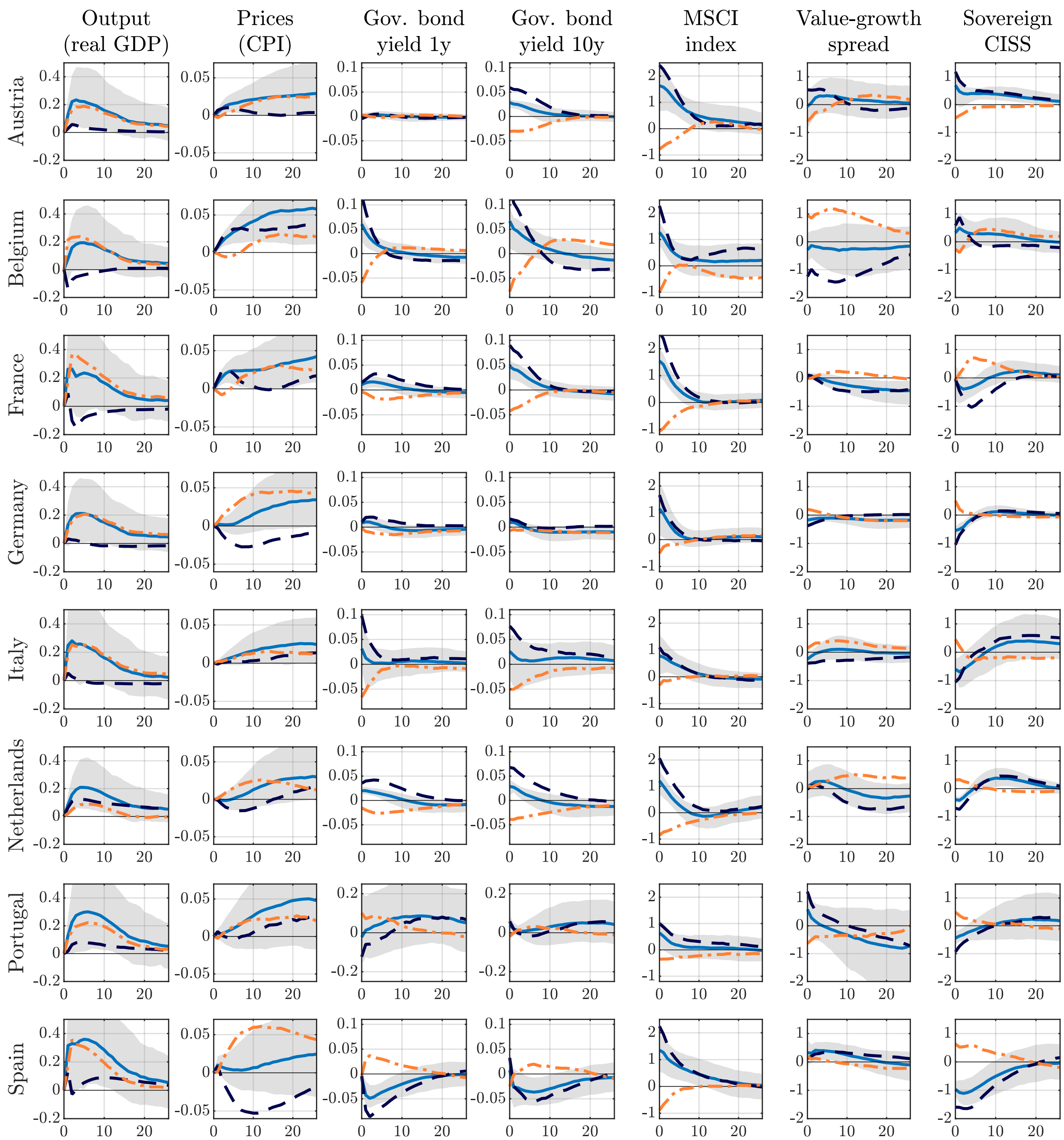


Note: Responses to one-standard deviation shocks. Median (solid line), 16–84th percentiles (grey area).

D.9 Country spillover effects

Figure IA.11 shows the direct and spillover effects over time (Figure IA.11 shows the median peak responses of the direct and spillover effects). We adjust the baseline GVAR model; for each economy i, we estimate the direct effect by only considering the effect of the common factors and its own factors, e.g., by setting $\Lambda_{i,\ell}$ to zero in (4) for every lag. The spillover effects are then the difference between the estimated IRFs and the direct effects.

Figure IA.11: Impulse responses direct effect and spillover effect of an asset purchase shock



Note: Responses to a one-standard deviation asset purchase shock, rescaled to the identified asset purchase shock in our baseline setting. Median effect (solid line) with corresponding 16–84th percentiles (grey area), median direct effect (dashed line), and median spillover effect (dash-dotted line).