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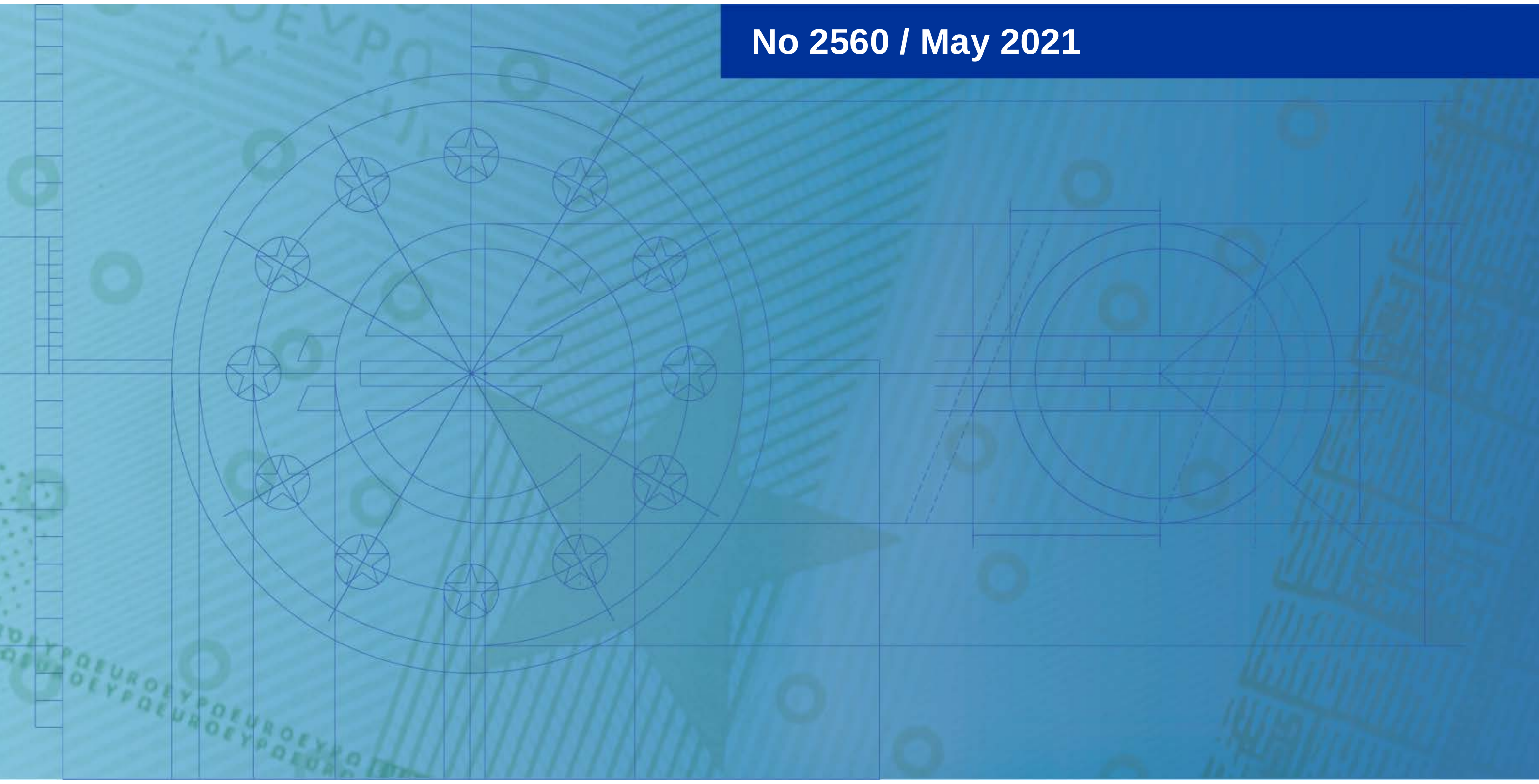
What drives euro area financial market developments? The role of US spillovers and global risk



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Abstract

Financial asset prices contain a rich set of real-time information on the economy. To extract this information, it is crucial to understand the driving factors behind financial market developments. In this paper, we exploit daily cross-asset price movements in a sign-restricted BVAR model to analyse the extent to which euro area and US yields, equity prices, and the euro-US dollar exchange rate are jointly driven by monetary policy, macro and global risk factors. A novelty is that we allow for cross-Atlantic spillovers while also accounting for the unique role of the US in the global financial system. Our results underline the importance of US spillovers and shifts in global risk sentiment for understanding the dynamics of euro area financial variables. Euro area shocks transmit much less to US financial markets in comparison, with global risk shocks being more important instead. Using the daily shocks as instruments in a Proxy-SVAR, we demonstrate that the transmission of financial market movements to the macroeconomy depends on the underlying driver, thereby illustrating why it matters to look into the driving factors in the first place.

JEL classification: C32, C54, E44, E52.

Keywords: International transmission, financial conditions, monetary policy, large-scale asset purchases, high-frequency identification.

Non-technical summary

Monetary policy makers closely monitor fluctuations in financial asset prices in search for signals on monetary policy transmission and the expected dynamics of the economy. It is well-established that asset prices contain a rich set of information; they react in real time to economic news as market participants price in their revised expectations and hint at the effects of these on growth and inflation going forward.

The difficulty in extracting information from asset prices in real time is that these are jointly determined by a multitude of factors. Economic shocks do not occur in isolation and often steer financial variables in different directions, hence blurring their signalling content. In addition, financial conditions are not only driven by domestic developments but also by foreign spill-overs, reflecting in particular the dominant role of the US economy in global financial markets. The safe haven status of US dollar-denominated assets implies that US asset prices are also susceptible to shifts in global risk sentiment, with the latter taking centre stage during periods of heightened market uncertainty such as observed during the COVID-19 pandemic. When extracting information from financial market developments, it is therefore crucial to allow for spillovers from the major financial centres, while also accounting for the unique role of US dollar-denominated assets in shaping global financial market dynamics.

Disentangling the drivers of financial asset prices can provide relevant insights into the interpretation of financial market developments, as the transmission of any given movement in financial variables to the economy might differ depending on its underlying driver. For example, a decline in long-term interest rates due to accommodative monetary policy can be associated with very different economic outcomes compared to when yields decline because of adverse macroeconomic news. The fact that shock dependence matters has been well documented in the literature on exchange rate passthrough, for example, but it applies to financial asset prices more generally.

The contribution of this paper is twofold. First, we propose an empirical framework to jointly decompose daily movements in euro area and US financial asset prices into several key underlying drivers – euro area and US monetary policy, euro area and US domestic macro risk, and global risk – based on an identification approach that exploits the information content of daily co-movements in asset prices. A novelty of our paper is that we explicitly allow for spillovers between the euro area and the US while at the same time accounting for the potential importance of global risk shocks. The main aim is to offer a high-frequency and comprehensive assessment of the drivers of financial conditions, which proves especially useful for policy makers to understand the underlying economic dynamics and the impact of their policies in "real time".

Our findings first show that both US spillovers and global risk shocks are indeed important drivers of euro area asset prices and need to be duly accounted for when assessing daily euro area financial market movements. In comparison, euro area shocks are found to be less relevant for US daily financial market movements. Instead, shifts in global risk sentiment determine an important part of the dynamics in US risk-free yields and the US dollar, consistent with its safe-haven status. We extensively test the performance of our model and find that our identified drivers have a clear economic interpretation, behave as expected following important narrative events and correlate strongly with alternative market-based measures commonly used by market participants to assess policy and risk factors.

Second, we show that the information extracted from the daily co-movement in financial asset prices carries over to macroeconomic aggregates at lower frequencies. In other words, daily financial markets developments are informative on the growth and inflation outlook. We find that, depending on the mix of drivers underlying financial market developments, the transmission to the macroeconomy can differ substantially – which underlines the importance of understanding what drives financial market developments in the first place.

1. Introduction

Monetary policy makers closely monitor fluctuations in financial asset prices such as bond yields, stock prices, and exchange rates in search for signals on the underlying expected dynamics of the economy. It is well-established that asset prices contain a rich set of information; they react in real time to economic news as market participants price in their revised expectations and hint at the effects of these on growth and inflation going forward.

The difficulty in extracting information from asset prices in real time is that these are jointly determined by a multitude of factors. Economic shocks do not occur in isolation and often steer asset prices in different directions, hence blurring their signalling content. In particular, yields, equity prices and the exchange rate are not only driven by domestic developments, but also by international factors that spill over to financial conditions at home. It is well documented that the US economy takes up a dominant role in global financial markets and its domestic developments can spill over significantly to other economies (Miranda-Agrippino and Rey, forthcoming). In addition, the safe haven status of US dollar-denominated assets implies that the US dollar and Treasury yields are particularly susceptible to shifts in global risk sentiment (Habib and Stracca, 2012; Fatum and Yamamoto, 2016). In periods of heightened market uncertainty, gyrations in global risk sentiment can take the centre stage in driving global financial markets, as observed since the outbreak of the COVID-19 pandemic. When extracting information from financial asset prices, it is therefore crucial to allow for spillovers from the major financial centres, while also accounting for the unique role of US dollar-denominated assets in shaping global financial market dynamics.

The reason why it is important to disentangle the drivers of financial asset prices is that the economic effects of any given movement in financial variables might differ depending on its underlying driver. For example, a decline in long-term interest rates due to accommodative monetary policy can be associated with very different economic outcomes compared to when yields decline because of adverse macroeconomic shocks. The fact that shock-dependence matters has been documented in the literature on exchange rate pass-through (Forbes, Hjortsoe and Nenova, 2018), but it applies to financial asset prices more generally.

The contribution of this paper is twofold. First, we propose an empirical framework to separate daily movements in euro area and US financial asset prices into their underlying drivers. We set up a Bayesian VAR model at daily frequency that identifies five different drivers of asset price fluctuations – euro area and US monetary policy, euro area and US domestic macro risk, and global risk – using an identification approach based on sign restrictions exploiting the information content of daily co-movements in risk-free yields, equity prices and the euro-US dollar exchange rate. A novelty of our paper is that we explicitly allow for spillovers between the euro area and the US and account for the potential importance of global risk shocks in driving financial markets on both sides of the Atlantic.[1]

As our results indicate, both US spillovers and global risk shocks are indeed important drivers of euro area asset prices and need to be duly accounted for when assessing daily financial market movements. In comparison, euro area shocks are found to be much less relevant for US financial markets. Instead, shifts in global risk sentiment determine an important part of the dynamics in US risk-free yields and the US dollar, consistent with its safe haven role. We extensively test the performance of our model by benchmarking its interpretation of daily financial market movements with narrative events and comparing the estimated shocks with changes in observables with which the shocks should be correlated.

Second, we show that the information extracted from the daily co-movement in financial assets carries over to macroeconomic aggregates at lower frequencies. In other words, daily financial markets developments are informative on the growth and inflation outlook. We demonstrate this in a proxy structural VAR model that includes a set of financial and macroeconomic variables and uses our set of daily shocks as econometric instruments. This analysis finds that, depending on the mix of drivers underlying financial market developments, the transmission to

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[1] Our paper comes close to the work of Ca’ Zorzi et al. (2020) who compare the international transmission of euro area and US monetary policy shocks in a unified framework, relying on “pure” monetary policy shocks which are identified in a narrow time window and purged for central bank information effects following of Jarociński and Karadi (2020). Our paper differs in two important aspects. First, we identify US and euro area monetary policy shocks for each trading day, which allows us to also capture policy decisions that are announced outside of the regularly planned meetings. Second, by simultaneously identifying macro, monetary policy and global risk shocks, we provide a more comprehensive picture of the relative importance of monetary policy shocks in driving financial markets.

the macroeconomy can differ substantially – which also underlines the importance of understanding what drives financial market developments in the first place.

The paper proceeds as follows. The next section explains the empirical setup of the daily Bayesian VAR model and the sign restriction identification scheme. **Section 3** documents the outcome of our identification approach, with the aim to test its validity, in particular as regards the economic interpretation of our identified drivers. **Section 4** reviews the main empirical results, focussing on the model decomposition of euro area asset prices over time and the assessment of cross-Atlantic spillovers and global risk shocks in specific episodes. It then evaluates the transmission of financial market developments to the real economy using a Proxy-SVAR model. **Section 5** concludes.

2. Methodology and estimation

2.1 Modelling approach

Our model is a two-country Bayesian VAR model (BVAR) for the euro area and the US, where the underlying drivers of daily changes in euro area and US asset prices are identified by way of sign restrictions exploiting cross-asset price movements. In our baseline, most parsimonious specification, we focus on several key drivers of asset price movements: euro area and US monetary policy, euro area and US domestic macro shocks, and a shock that we label a "global risk" shock, which aims to capture the growing importance of flight to safety or "risk-on/risk-off" episodes in driving daily market movements across the Atlantic.

More specifically, our modelling framework is a daily BVAR where shock identification is achieved following Arias et al. (2018). BVAR models with sign restrictions have become a standard tool in the empirical macroeconomic literature in recent years. Transposing it to high-frequency financial data offers a number of benefits to circumvent some of the well-documented limitations of working with low-frequency macroeconomic data. In particular, due to the rich data environment, the estimation can rely on rather minimalistic prior assumptions. The full econometric specification is laid out in Appendix 1 together with further robustness checks with respect to the sensitivity of our results to prior selection.

Our identification based on cross-asset price correlations reflects the intuition often portrayed in market commentary that co-movements between asset prices provide useful information for interpreting daily fluctuations in financial market indicators. For example, bond yields and stock prices typically co-move positively in response to news about the economy and negatively in response to news related to monetary policy. This intuition finds strong theoretical and empirical support and has been formalised in several papers that identify the contribution of monetary policy or growth shocks to yield and stock price reactions around monetary policy announcements. For example, Jarociński and Karadi (2020) use the high-frequency co-movement of interest rates and stock prices around policy announcements to disentangle monetary policy surprises from central bank information shocks. Andrade and Ferroni (2018) use co-movements between yields and inflation expectations to disentangle "Odyssean" monetary policy signals (in the sense of Campbell et al. 2012) from “Delphic” monetary policy surprises. Cieslak and Schrimpf (2018) use co-movements between stock prices and bond yields at different maturities to decompose asset price fluctuations into monetary policy surprises, information (or growth) surprises and risk shocks.

While – similarly to these studies – our approach also builds on high-frequency co-movements between asset prices, one important difference is that we use a more general set up that does not require to focus on a narrow time window around selected announcements. Instead, we extract information from asset prices in “continuous time”, reflecting the fact that news which may trigger a re-appraisal by market participants of the monetary policy stance or growth outlook flows virtually every day. In addition, this daily set up allows us to widen the approach to other important shock drivers such as growth and global risk shocks, for which the announcement window is less clear. Only then can the relative importance of different shock drivers be assessed.

The main aim of our model is to offer a high-frequency assessment of the drivers of financial conditions, which proves especially useful in “real time” as policy makers often glance at high-frequency financial market developments to understand the underlying economic dynamics and impact of their policies. In that sense, our approach is closer to Matheson and Stavrev (2014) who estimate a daily BVAR model for US yields and stock prices based on sign restrictions exploiting cross-asset prices movements. Compared to them, however, we extend the model to a two-country euro area-US framework including not only bond yields and equity prices but also the bilateral euro-US dollar exchange rate. Additionally, we build on the role of US dollar-denominated assets as safe haven assets for global investors to identify a new important source of daily market movements; the so-called “global risk” factor. As our results will show, both US spillovers and global risk are important determinants of euro area financial market variables, while global risk shocks are key to understand daily fluctuations in US financial markets. The remainder of this section provides more details on the data, identification and estimation.

2.2 Data

Our set of variables comprises daily changes in the 10-year euro area Overnight Index Swap (OIS), daily log-differences of the EURO STOXX price index, the US S&P500, and the bilateral euro-US dollar exchange rate, as well as daily changes in the spread between the 10-year euro OIS rate and 10-year US Treasury yield. We include the long-term rate for the following reasons. First, the 10-year euro area OIS rate and US Treasury yield are the main references for long-term risk-free rates in both jurisdictions.[2,3] Second, long-term rates capture not only conventional monetary policy – which mostly affects the yield curve at short to medium maturities – but also unconventional policy measures deployed by the Fed and the ECB over recent years. In particular, large-scale asset purchases have been found to exert their largest impact at longer maturities via reducing term premia.[4] Last, the use of risk-free rates is instrumental to identify the global risk shock, as flight to safety episodes primarily manifest themselves in increased investors' appetite for risk-free bonds against riskier assets. In that respect, the use of the 10-year Treasury yields is particularly important, as the US Treasury market is the largest provider of safe, US dollar-denominated assets globally.

While our baseline specification is rather parsimonious, it can easily be extended to capture additional drivers of euro area financial conditions, such as factors related to euro area sovereign or corporate credit risk.[5] While extending the model may enrich the interpretation, we find that the results regarding our key drivers remains largely unaffected. For our global risk shock, this implies that in essence, a simple framework that rests on two types of assets – risk-

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[2] The swap rate is the fixed rate which banks engaging in swap contracts agree to pay in exchange for receiving the average overnight interest rate for the duration of the swap. Unlike an unsecured interbank loan, in which the lender is exposed to the full credit risk of the borrower, a swap contract is settled in notional amounts, namely without involving a physical exchange of principals, and thus it is considered near-risk-free.

[3] An alternative would be to use the 10-year German Bund as a measure of the long-term risk-free rate. However, given that the 10-year OIS and 10-year German Bund are tightly correlated over time, estimating the model with the 10-year German Bund instead of the 10-year OIS leaves the results largely unaffected.

[4] The downward pressures on the term premium stem from the central bank extracting duration risk from the market, which is the well-documented duration channel of asset purchases. For an empirical assessment of the duration channel of ECB asset purchases based on a term structure model, see Eser et al. (2019).

[5] Additionally, one can consider yields at different maturities as a way to further disentangle the stance of monetary policy into specific instruments (negative interest rate vs. rate forward guidance vs. APP). In practice, empirically disentangling the monetary policy instruments in one single framework proves challenging. Rostagno et al. (2019) propose an approach that overcomes this challenge based on combining yield curve identification with a large macro BVAR. They also find that – while different instruments affect some parts of the yield curve more strongly than others – the directional impact is preserved across maturities: a contractionary shock causes yields to rise, an expansionary shock causes yields to fall. This supports our choice of a 10-year yield as the relevant risk-free rate.

free bonds and equity – in combination with a safe haven currency such as the US dollar seems sufficient to pin down the "flight-to-safety" component.

2.3 Shock identification and estimation

Table 1 summarises the structural shock identification scheme via sign restrictions on the contemporaneous impulse response function. A + and - denote an increase or decrease respectively in the variable following a specific shock, while empty fields leave that parameter unrestricted.[6] All restrictions are imposed on impact, reflecting the fact that markets typically react to news instantaneously or within the same day. For ease of comparison, all shocks in the table are normalised to lead to an increase in euro area long-term rates.

Table 1: Matrix of sign restrictions in the daily BVAR model

	Restrictive EA monetary policy	**Favourable EA macro news**	**Restrictive US monetary policy**	**Favourable US macro news**	**Favourable Global risk**
EA long-term yields	+	+	+	+	+
EA equity prices	-	+			+
US equity prices			-	+	+
USD/EUR exchange rate	+	+	-	-	+
EA-US long-term yield spread	+	+	-	-	-

Notes: Empty fields leave that parameter unrestricted, + and - denote an increase or a decrease in the respective variable on impact. A + (-) for the USD/EUR denotes an appreciation (a depreciation) of the euro vis-à-vis the US dollar.

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[6] Underlying our identification approach is the reasonable assumption that, while asset prices may react to news on monetary policy or the macroeconomy within the day, the reverse is not true: monetary policy does not respond to asset price changes within the same day, an assumption which is at the basis of the vast literature on high-frequency identification of monetary policy surprises (for an application to ECB monetary policy, see Altavilla et al. 2019).

Monetary policy versus macro news shocks

As discussed in **Section 2.1**, our identification is based on the co-movements between bond yields, stock prices and the exchange rate. We identify a contractionary monetary policy shock as driving up domestic yields while depressing equity prices and appreciating the exchange rate. On the other hand, a positive macro news shock is assumed to simultaneously increase domestic yields and equity prices and appreciate the domestic exchange rate. As we identify the macro shock based on high-frequency financial market data, this shock will also capture shifts in risk sentiment regarding the macroeconomic outlook as reflected in equity prices. While a global risk shock is characterised by a portfolio re-allocation between risky and risk-free assets (see below), news about the domestic macroeconomic outlook may also result in a re-allocation from domestic risky assets into risky assets in other jurisdictions. We allow for this re-allocation by leaving the effect of a domestic macro shock on foreign equity prices unrestricted.

Euro area and US spillovers

We allow for instantaneous spillovers between the euro area and the US, which poses the identification challenge that we need to properly control for the country origin of the shock. We address this issue via restricting the sign on the spread between euro area and US yields which in practice implies a magnitude restriction. That is, we differentiate a euro area from a US shock if it affects euro area yields more than US yields and vice versa. For example, an unexpected tightening of US monetary policy will put upward pressures on US and euro area yields, but as the spread of euro area over US rates is imposed to decline, US yields will react more strongly.

Global risk shock

Last, we identify a global risk shock which causes investors to re-allocate the share of relatively more risky assets in their holdings. For example, a deterioration of global risk sentiment will reduce equity prices and lower risk-free rates in both jurisdictions, reflecting reduced investors' appetite for risky assets. During episodes of heightened global risk, inflows into US dollar-denominated assets are assumed to be relatively stronger given their safe haven status, which implies that US risk-free rates will fall more strongly than euro area rates (causing the euro area-US rate spread to decline). In addition, the US dollar will appreciate vis-à-vis the euro exchange rate, reflecting the role of the US dollar as safe haven currency.

Estimation

The model is estimated over the period January 1999 – June 2020 including 4 lags of the dependent variables. While our main interest is on the most recent years starting after the global financial crisis, we include the pre-crisis sample as a way to benchmark post-crisis developments.

3. Model validation

3.1 Economic interpretation of the identified drivers

We start cross-checking our model performance by examining euro area and US monetary policy shocks. As it is key that our model is able to capture the impact of non-standard measures, we focus on the periods over which the ECB and the Fed have been most active in deploying unconventional policies: (i) 2014-2020 for the euro area, starting just before the adoption of negative interest rate policy (NIRP) and the Asset Purchase Programme (APP) announcement and covering the set of measures taken in response to the COVID-19 pandemic such as the Pandemic Emergency Purchase Programme (PEPP); and (ii) 2008-2012 for the US, during which the various Large-Scale Asset Purchase (LSAP) programmes were announced.

Looking at these two periods, the model results indicate that the largest realisations of our identified euro area and US monetary policy shocks coincide with the most important monetary policy announcements of non-standard measures (see **Figure 1**). In particular, the largest negative shock for the euro area is associated with the first APP announcement (22 January 2015), while for the US, the largest negative policy shock occurs on the day of the LSAP1 announcement (26 November 2008). Overall, this finding confirms that the model is successful at capturing important monetary policy announcements related to non-standard measures, including asset purchases but also other unconventional measures.[7]

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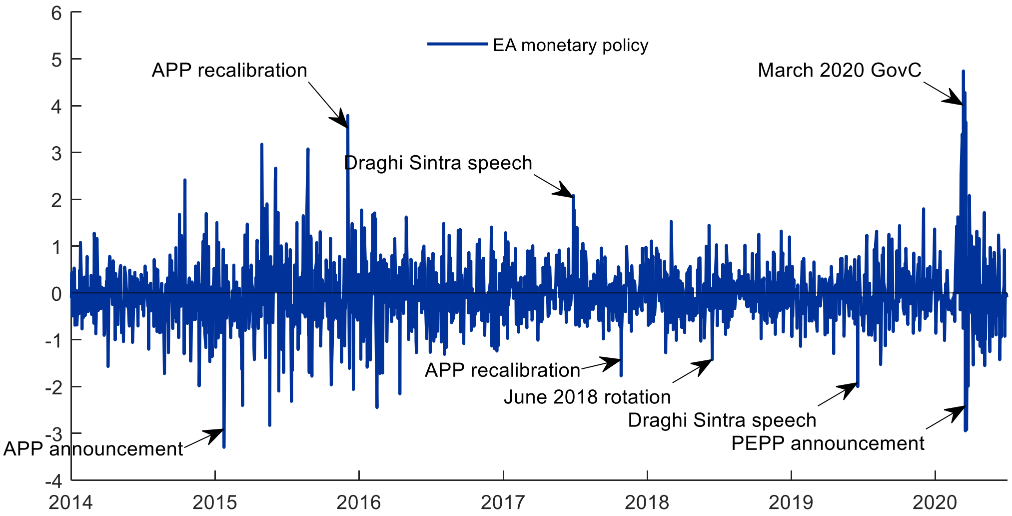
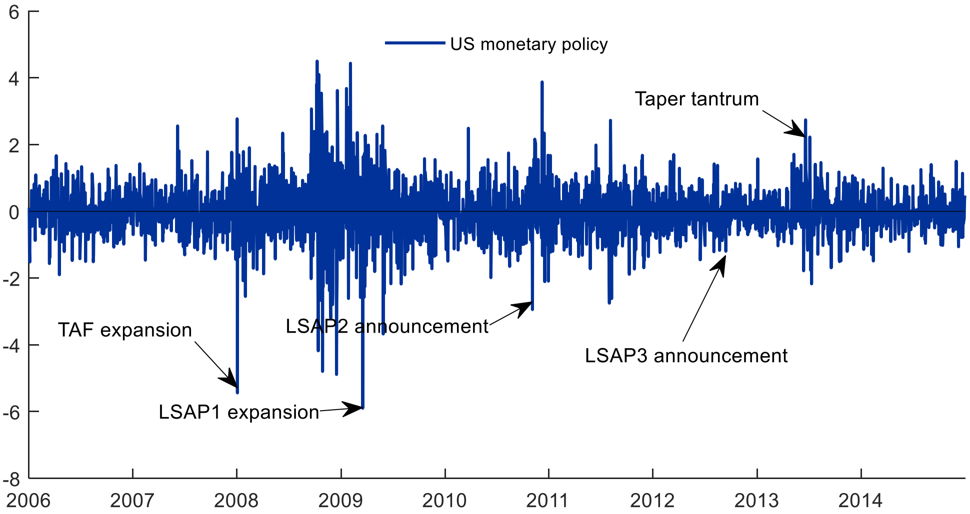
[7] These findings are consistent with the literature documenting a strong asset price reaction around large-scale asset purchase announcements. For the euro area, see Altavilla et al. (2015) and Andrade et al. (2016). For the US, see Krishnamurthy and Vissing-Jorgensen (2011) and Gagnon et al. (2011).

Figure 1: Euro area and US monetary policy shocks

A. Euro area: 01 January 2014 – 30 June 2020



B. United States: 01 January 2006 – 31 December 2014



At the same time, this cross-check highlights that monetary policy shocks do not only arise on days of monetary policy announcements – such as days where a monetary policy meeting of the ECB`s Governing Council or the FOMC takes place – but also on other days. Indeed, monetary policy announcements are associated with significant anticipation effects for example (see **Figure A.3.2** and **Figure A.3.3**).[8] These effects might arise from communication that hints at the future announcement (such as speeches), or alternatively to a re-appraisal by market participants of monetary policy expectations in response to news that is not strictly related to monetary policy communication, in particular macroeconomic data releases. This underlines the importance of also accounting for non-meetings days to fully capture the way in which policy makers convey news. Having said that, we find that realisations of monetary policy shocks tend to be larger – as much as twice as large – on policy meeting days than on non-meeting days (see **Figure A.3.1**).

To assess the performance of our identified global risk factor, we compare its developments to alternative risk measures commonly used by market analysts: the US and euro area indices of stock market volatility (VIX for the US and VSTOXX for the euro area) and the euro area CISS index of systemic stress (Kremer et al. 2012) as plotted in **Figure 2**. Overall, our global risk factor strongly co-moves with alternative risk measures, exhibiting similar spikes during episodes of market turmoil such as the 2008 Lehman collapse or at the start of the COVID-19 pandemic in early 2020. We also find evidence that the euro area sovereign debt crisis was accompanied by a surge in global risk aversion with investors moving out of euro-denominated assets into US-denominated assets in an attempt to reduce their exposure to redenomination risk.[9] In contrast to volatility-based risk measures, our global risk factor – being two-sided – tracks symmetrically both adverse and benign risk sentiment episodes, which is a useful feature for understanding financial market fluctuations over time.[10]

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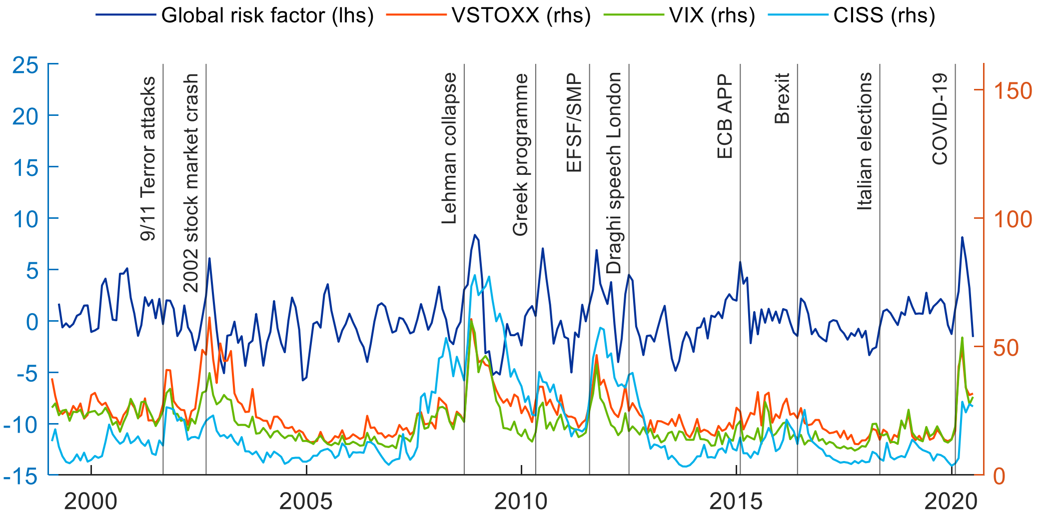
[8] In particular, our results suggest that, once accounting for anticipation effects, there is no evidence that the marginal impact of LSAP programmes on long-term interest rates has declined over time. This finding is in line with the evidence provided by Carlson et al. (2020), Cahill et al. (2013), and Foerster and Cao (2013). Cahill et al. (2013) show that, after controlling for pre-announcement market expectations, the yield impact of the Fed's asset purchases has not reduced over time. Foerster and Cao (2013) use surveys, newspaper articles and internet searches to show that announcements for various rounds of LSAPs were largely expected.

[9] This is consistent with evidence of investors' fears of a euro area breakdown, as captured by rising redenomination risk (De Santis 2018).

[10] For example, we find that when the euro area economy was on a recovery track, such as in the mid-2000s or over 2015-2018, the risk environment was especially favourable, which may have further supported the recovery.

Figure 2: Comparison of the global risk shock with alternative risk indicators
(index)



Notes: Global risk factor shows the rolling three-month sum of the global risk shock from the daily BVAR.

Finally, we examine the euro area and US domestic macro shocks by comparing them with the Citigroup Economic Surprise Index (CESI), which is a measure of macroeconomic surprises commonly used by market analysts.[11] Our measure of domestic macroeconomic risk strongly co-moves with the CESI over the estimated sample with an average correlation of about 60% for both the euro area and the US (see **Figure A.3.4**). At times, our macro factor disconnects from actual macro surprises with some persistence, which is consistent with the tendency of markets to over- or underreact to actual macro news in bouts of optimism or pessimism. The pandemic crisis is a case in point. While in the US our macro factor correlates strongly with actual macro news at the start of the pandemic, the euro area macro factor tends to disconnect which might be explained by the relative resilience of the euro area stock market in the initial phase of the pandemic – an indication that it took more time for markets to digest in full the negative implications of the pandemic for the euro area economy.

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[11] The CESI is defined as a weighted historical standard deviation of data surprises (actual releases versus the Bloomberg median survey) and is calculated daily in a rolling three-month window. The weights of the economic indicators are derived from relative high-frequency spot foreign exchange impacts of 1 standard deviation data surprises adjusted to include a time decay feature so as to replicate the limited memory of markets.

3.2 Event study evidence

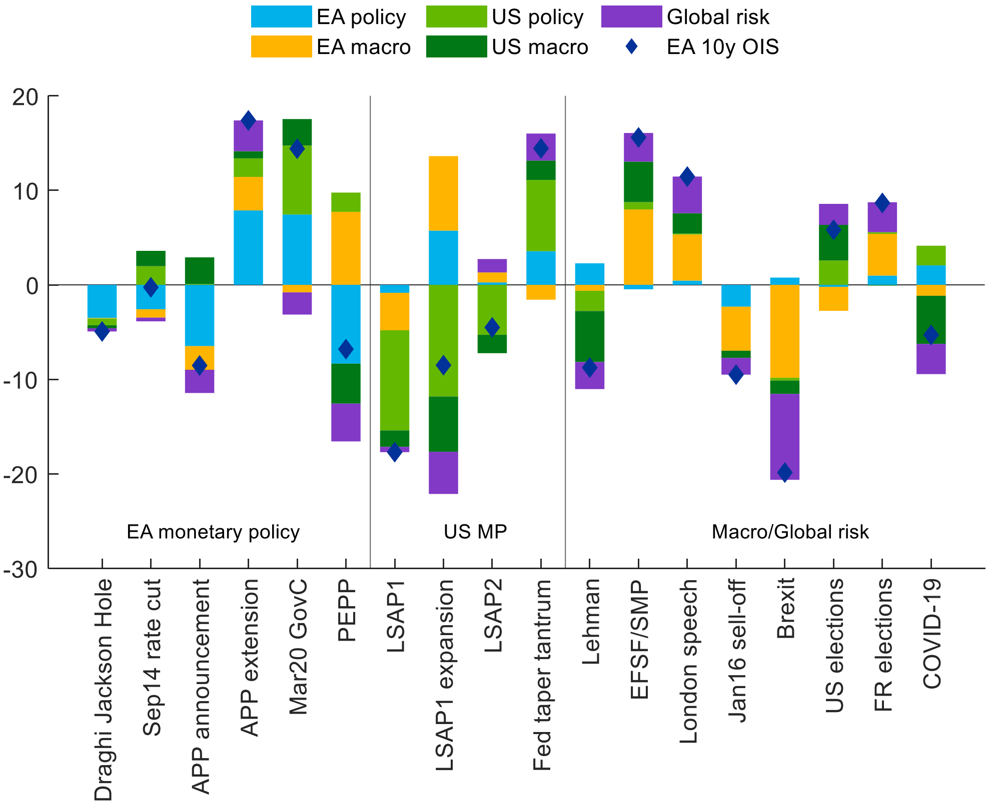
To cross-check the results in a more systematic way, we study the model predictions around a set of selected events. That is, we look at the reaction of long-term rates, stock prices and the exchange rate around significant events associated with euro area monetary policy (e.g. APP and NIRP announcements), US monetary policy (e.g. LSAP announcements) or important euro area or US macro events. **Table 2** lists all events that we consider.

Table 2: List of selected events

Date	**Announcement**	**Type**
16 September 2008	Lehman Brothers collapse	Global risk/macro
26 November 2008	LSAP1 announcement	US monetary policy
19 March 2009	LSAP1 expansion	US monetary policy
11 May 2010	Greek programme + EFSF + SMP announcement	EA monetary policy/macro
4 November 2010	LSAP2 announcement	US monetary policy
27 July 2012	Draghi London speech: “Whatever it takes”	EA monetary policy/risk
20 June 2013	FOMC meeting – Fed taper tantrum	US monetary policy
26 August 2014	Draghi Jackson Hole speech	EA monetary policy
5 September 2014	10bps DFR cut and ABSPP/CBPP announcement	EA monetary policy
23 January 2015	APP announcement	EA monetary policy
4 December 2015	10bps DFR cut and APP extension	EA monetary policy
5 January 2016	January 2016 stock market sell-off	EA macro/global risk
27 June 2016	Brexit referendum	EA macro/global risk
9 November 2016	US presidential elections	US macro/global risk
25 April 2017	French presidential elections	EA macro/global risk
25 February 2020	Intensification of COVID-19 crisis	Global risk/macro
13 March 2020	March 2020 Governing Council	EA monetary policy
20 March 2020	PEPP announcement	EA monetary policy

Our aim is twofold: first, to assess whether the model decomposition of the market reaction around those events matches the prior knowledge we have of each specific event, for example whether the monetary policy factor is the dominant driver around monetary policy-related events, and second, to dig deeper into the role of drivers that are not explicitly related to the content of the announcement itself, for example the role of non-monetary policy news in explaining the reaction of financial variables to monetary policy-related events. **Figure 3** plots the two-day reaction of euro area long-term rates for each of the selected events together with the contributions of the underlying drivers. The results for US yields, euro area stock prices and the exchange rate are reported in Appendix 3.

Figure 3: Drivers of the euro area 10-year OIS rate around selected events
(two-day change in basis points)



Two findings are worth highlighting. First, the model identification is successful at capturing prior knowledge of the specific nature of each event. For events that are associated with an important monetary policy announcement, the model tends to identify the monetary policy shock as the dominant driver of the change in euro area long-term rates over the two-day window around the event (see left panel in **Figure 3**). For example, the euro area monetary policy factor contributes 7 to the 10 basis points decline in the long-term yields around the January 2015 APP announcement. Similar conclusions apply to spillovers around US monetary policy events: we find that the US monetary policy shock tends to be the dominant driver of euro area long-term rates around these events (see middle panel in **Figure 3**). Finally, also global risk and macro events are well captured (see right panel in **Figure 3**). For example, the Brexit referendum is associated with a large decline in the 10-year OIS (-20 basis points), which is equally split between two factors – global risk and euro area macro. This decomposition sheds light on the market perception of the implications of Brexit: increased risk aversion leading to investment flows into safe dollar-denominated assets (as captured by the global risk factor), combined with a sudden re-appraisal of the euro area macro landscape through close trade and financial linkages with the UK (as captured by the euro area domestic macro shock).

Second, and interestingly, the exercise also illustrates again the benefit of our setup over alternative approaches such as event study or high-frequency identification, as the market reaction around any event reflects a mix of factors rather than a single type of news. This may reflect two elements. First, the fact that on any given day, there is typically a flow of news being released, some of which pertaining to monetary policy and others to macro information.[12] This might blur the signal associated with the specific event that one tries to assess in isolation. Second, the announcement may give rise to a re-appraisal along other dimensions that are not directly related to the specific signal conveyed. For example, we find that euro area monetary policy events tend to be associated not only with a monetary policy shock per se, but also with a re-appraisal of the euro area macro outlook. This result is consistent with the well-documented finding that ECB monetary policy events give rise to two types of monetary policy signals, namely a classic "Delphic" component (signal about a turn in the monetary policy stance) as well as an "Odyssean" component that conveys information on the central bank's assessment of the economic outlook (Andrade and Ferroni 2019; Jarociński and Karadi, 2020). Our approach allows us to effectively isolate the Delphic component of monetary news. At the same

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[12] For example, the Governing Council meetings tend to coincide with the release of important US macro news such as the preliminary release of US non-farm payroll data.

time, our results also suggest an important role of non-monetary news – macro and global risk – in explaining the reaction of asset prices around monetary policy events, which is consistent with the findings from the literature (Nakamura and Steinsson 2018).

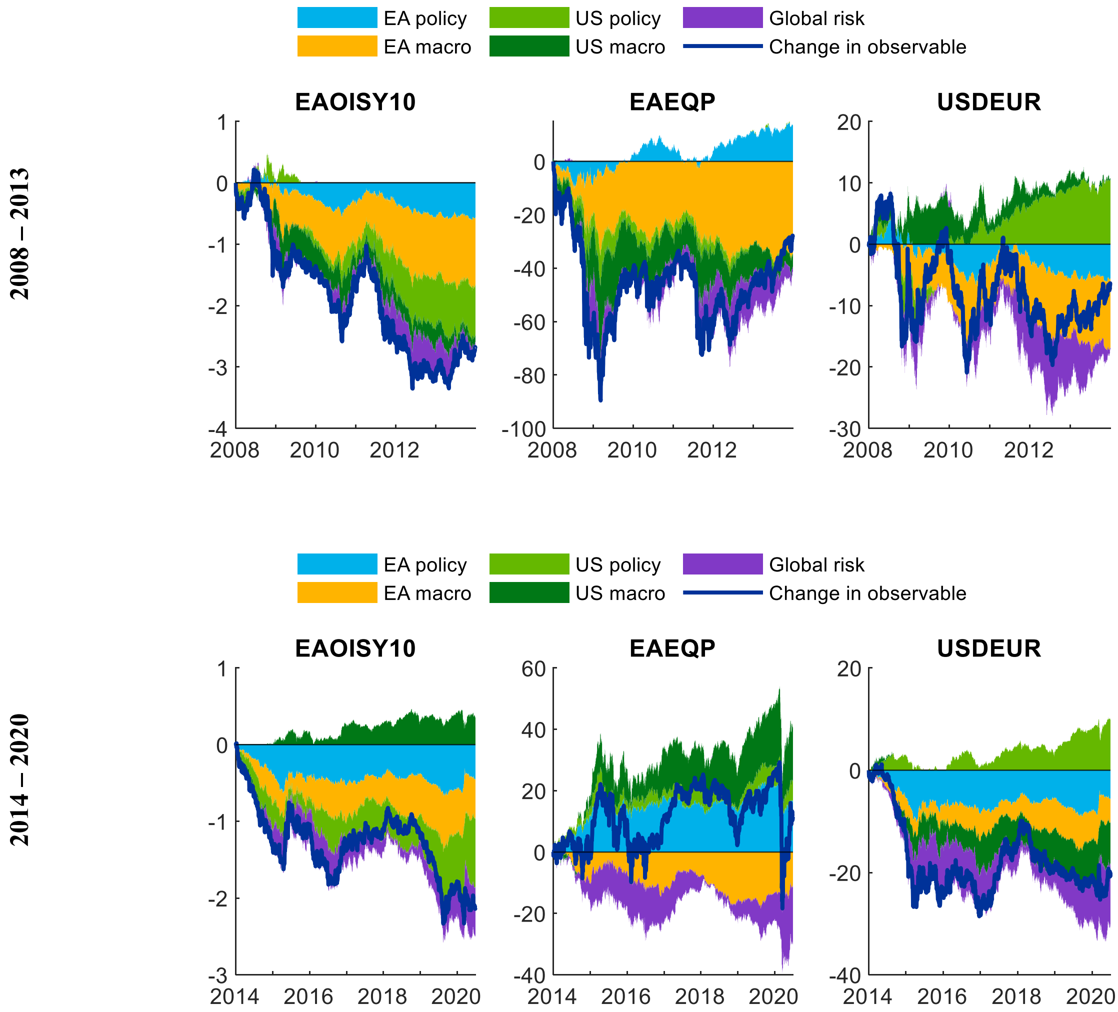
4. Empirical results

4.1 Drivers of financial assets

In order to get a broader overview of the drivers behind euro area financial assets, we show the historical decomposition of euro area long-term rates, equity prices and the euro- dollar exchange rate over two periods: (i) January 2008 – December 2013, dominated by the global financial and euro area sovereign debt crisis and (ii) January 2014 – June 2020, containing the shift of the ECB's policies into unconventional domain and the early phases of the COVID-19 pandemic. The corresponding results for the US are shown in the appendix (see **Figure A.3.9**).

First, during the global financial crisis and its recovery, a significant portion of euro area financial variables were driven by a deteriorating euro area macro outlook, explaining about half of the decline in euro area risk-free rates and causing about a 40% fall in euro area equity prices compared to early 2008, see top panel in **Figure 4**. The ECB's response to the crisis lowered long-term yields while supporting domestic equity markets. Concerning the exchange rate, the euro fell substantially against the US dollar in the first months of the crisis as the dollar strengthened noticeably following safe haven flows into dollar-denominated assets (captured by the global risk shock). As the macroeconomic outlook deteriorated on both sides of the Atlantic, macro shocks did not steer the bilateral exchange rate in a specific direction. That changed in the years thereafter, however, when the US economy recovered from the global financial crisis while the euro area entered a sovereign debt crisis. Adverse macro shocks continued to persistently weigh on financial markets in the euro area as the sovereign debt crisis intensified, lowering long-term yields and equity prices further. The euro exchange rate weakened substantially as investors questioned the robustness of the common currency (captured by a combination of euro area macro and global risk shocks), which more than offset upward pressures on the euro from the Fed's unconventional policy measures in 2011-2012 that depreciated the US dollar. The persistent drag of adverse macro risk shocks on the outlook for economic activity and inflation in the euro area triggered the ECB to resort to unconventional monetary policy in the months thereafter.

Figure 4: Historical decomposition of euro area asset prices
(yields in percent per annum, equity prices and USD/EUR in log-percentages)



Notes: Shock contributions are normalised to zero at the beginning of the review period.

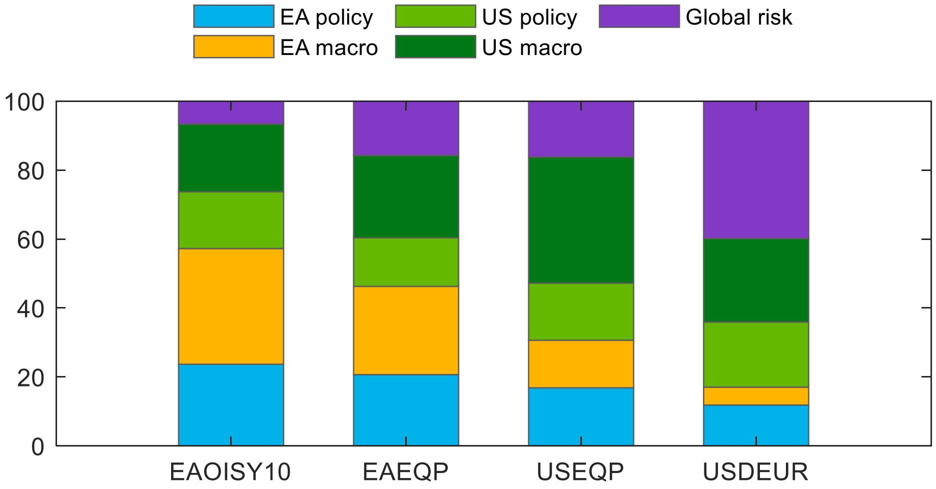
Second, over the period 2014 -2020, the ECB left a significant footprint on euro area financial assets as it widened its toolkit to include unconventional measures such as negative interest rates, rate forward guidance and asset purchases, which lowered euro area long-term yields, supported domestic equity markets and significantly depreciated the euro exchange rate against the US dollar throughout the review period, see the bottom panel in **Figure 4**. The outbreak of the COVID-19 pandemic in early 2020 affected euro area financial markets mainly through triggering inflows into safe assets (as captured by the global risk shock), lowering euro area long-term yields further, and explaining a substantial part of the fall in equity prices in the first months of 2020. Shifts in global risk sentiment were even more important for US financial asset prices – consistent with the safe haven status of the US dollar over this period – and explained a substantial share of the decline in US long-term rates and the US dollar appreciation in the direct aftermath of the pandemic (see **Figure A.3.9**).

4.2 Cross-Atlantic financial spillovers following different shocks

Beyond domestic factors, financial markets in the euro area and the US are also driven by cross-Atlantic spillovers. Our model framework shows that financial spillovers between the US and the euro area are indeed noticeable. The forecast error variance decomposition indicates that US shocks are found to explain close to 40% of variation in euro area yields and equity prices over the full sample, see **Figure 5**. Shocks originating in the euro area are relatively less important for US financial markets than vice versa, yet still account for about 30% of the dynamics in US equity prices on average while spillovers to US yields are much less pronounced, as we show below. Euro area financial markets are also affected by shifts in global risk sentiment, although these types of shocks play a larger role for US financial markets given the safe haven status of US dollar-denominated assets.

Interestingly, the extent to which foreign shocks drive euro area financial markets differs across assets. Foreign forces explain about half of euro area equity prices over our sample, while this share is smaller for euro area yields, possibly due to rate forward guidance which shields shorter-term rate expectations from foreign developments. For the euro-US dollar exchange rate, euro area-specific shocks only account for about 20% of the variation, with US shocks explaining about double that amount. Variation in global risk sentiment is however the dominant driver of the bilateral euro-US dollar pair, which is in line with the literature that underscores the importance of risk premia in driving exchange rates (Engel, 2014), while it also reflects the safe haven role of the US dollar.

Figure 5: Forecast error variance decomposition
(percent share of explained variation)

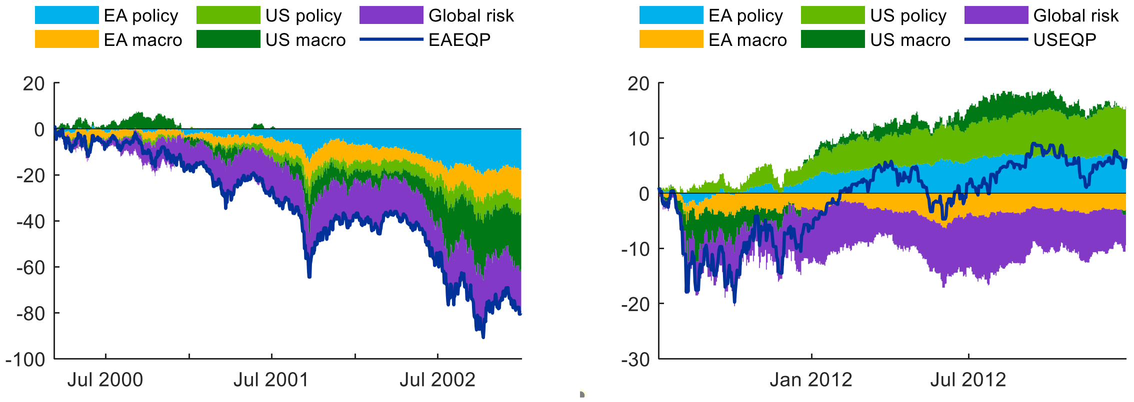


Notes: Chart shows the one step-ahead forecast error variance decomposition averaged over all draws from the daily BVAR.

To illustrate the importance of cross-Atlantic financial spillovers, it is useful to focus on periods that brought about major shifts in financial markets. As the extent of spillovers depends on the underlying shock, we show the spillovers following large shifts in macro risk and monetary policy in both economies: (i) US dot-com bubble (US macro shock), (ii) euro area sovereign debt crisis (euro area macro shock), (iii) the period since the first round of LSAP by the Fed (US monetary policy shocks), and (iv) the period since the ECB started using unconventional monetary policy (euro area monetary policy shocks). Below we only show the spillovers to selected financial market variables. For the historical decomposition of the domestic responses and the spillovers to other financial asset prices, see **Figure A.3.10**.

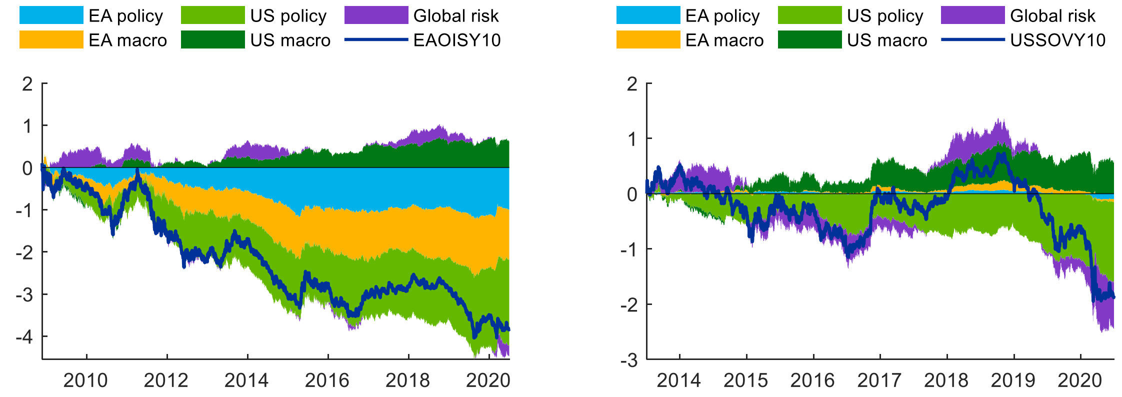
Concerning spillovers following macro-driven shocks, the US dot-com bubble period illustrates that these types of US-driven shocks can significantly steer euro area financial markets. After a prolonged period of optimistic macro prospects, the burst of the dot-com bubble in early March 2000 triggered a sharp sell-off in equity markets in the US that was to a significant degree transmitted to equity prices in the euro area (see panel A in **Figure 6**). Adverse US macro shocks caused euro area equity prices to decline by about 20% over a period of almost two years, which is close to the magnitude of the domestic US equity price reaction (see panel A in **Figure A.3.10**). The burst of the bubble also motivated investors to shift their portfolios from equities to bonds – as captured by the global risk shock – which further weighed on euro area equity prices. The negative US macro shock came at a time when the ECB was tightening its policy, causing the overall decline in equity prices in the euro area to be much more pronounced than the one observed in the US over that period.

Figure 6: Spillovers following different types of shocks
(yields in percent per annum, equity prices in log-percentages)



A. US dot-com bubble: spillovers to EA equity prices

B. EA sovereign debt crisis: spillovers to US equity prices



C. Fed unconventional policy: spillovers to EA long-term yields

D. ECB unconventional policy: spillovers to US long-term yields

Notes: Panel A shows cumulative changes in EA equity prices from 10 March 2000 to 31 December 2002 and panel B cumulative changes in US equity prices from 07 July 2011 to 31 December 2012. Panel C shows cumulative changes in EA 10y OIS from 24 November 2008 to 30 June 2020, and panel D cumulative changes in 10y US Treasury yields from 04 July 2013 to 30 June 2020. All shock contributions are normalised to zero at the beginning of the review period.

In comparison, the spillovers of euro area macro shocks to US financial markets are found to be noticeably smaller. Whereas the transmission following the US dot-com bubble across equity markets was close to full, only less than half of the drop in euro area equity prices caused by adverse macro shocks spilled over to US equity markets following the sovereign debt crisis (see panel B in **Figure 6** and **Figure A.3.10**). However, as the debt crisis also triggered flows into safer assets such as bonds, particularly dollar-denominated ones, US equity prices and long-term yields were importantly affected through the global risk channel instead.

Regarding monetary policy spillovers, it is also the case that US monetary policy shocks spill over more significantly to euro area financial markets than the other way around, which is in line with the literature that underlines the dominant role of US monetary policy in steering the global financial cycle (Miranda-Agrippino and Rey, forthcoming; Ca' Zorzi et al., 2020). Since the Fed embarked upon quantitative easing policies in late 2008, accommodative US monetary policy shocks are found to have considerably lowered euro area long-term yields (see panel C in **Figure 6**). Overall, as the ECB was loosening its policy stance as well over most of that period, the spillovers from the Fed supported domestic efforts to ease financial conditions. In contrast, the spillovers of the ECB's unconventional policies since mid-2013 – comprising forward guidance, negative short-term rates and asset purchases – are hardly registered in US long-term yields (see panel D in **Figure 6**). At that time, rates in the US were partly anchored by rate forward guidance which might have been a reason why euro area-to-US spillovers were smaller than those of the Fed's policies to euro area yields before 2013 when the ECB introduced rate forward guidance as well.

In sum, these results emphasise the importance of accounting for foreign shocks when analysing developments in financial markets. For the euro area, US monetary policy and macro shocks drive a noticeable part of yields, equity prices and, unsurprisingly, the euro-US dollar exchange rate. But also shifts to global risk sentiment move euro area financial assets as these shocks typically cause a rotation between equities and bonds, and between euro and US dollar-denominated assets, given the safe haven status of the latter. For this reason, global risk shocks are found to be an important driver of US financial markets. In contrast, euro area-specific shocks affect US financial markets to a much lesser extent.

4.3 Transmission to the macroeconomy: Proxy-SVAR analysis

It is important to assess the drivers of financial markets because the economic impact of financial market developments can differ substantially depending on the shock underlying these movements. In this section, we build upon the econometric framework used so far to demonstrate that the transmission of asset price changes to the macroeconomy is shock dependent. As our shocks are identified based on daily data, however, it is not obvious that their informational content carries over to macroeconomic aggregates at lower frequencies. In order to estimate the effect of changes in financial asset prices on the real economy we therefore employ a proxy structural VAR model (PSVAR) at monthly frequency that includes a set of financial and macroeconomic variables and uses the aggregated daily shocks as instruments.

Methodology

Generally, the literature has proposed various ways of using external instruments to help structural identification. The narrative approach, for example, relies on historical documents to construct a time series that is treated as exogenous (e.g. Hamilton 1985; Romer and Romer, 1989, 2010) and the literature employing high-frequency identification focusses on changes in financial variables in a narrow time window around a specific event (e.g. Altavilla et al. 2019, Gertler and Karadi 2015). The advantage of our approach – using daily structural shocks as instruments in a lower frequency VAR model – is that we employ structural shocks that have a clear economic interpretation and also capture anticipation effects contained in more informal pieces of information as we can identify shocks for each trading day. Our methodology also offers a set of instruments that allows us to jointly assess the economic effects of different types of shocks in a consistent framework. Regarding instrument validity, the first assumption that the instruments should be correlated with the shocks of interest is most likely fulfilled as the instruments are structural shocks from the daily BVAR model that carry the same economic interpretation attributed to the shocks in the PSVAR. The second assumption, which requires that the instruments are uncorrelated with all other structural shocks in the system, is supported by controlling for possible correlations between the instruments that appear when aggregating the daily shocks to monthly frequency.[13]

To estimate the impact of shocks on the real economy, we follow the PSVAR approach proposed by Stock and Watson (2012) and Mertens and Ravn (2013). Besides the financial asset prices included in the daily model, we include a set of macroeconomic variables available at monthly frequency: industrial production, inflation and the unemployment rate for both the euro area and the US. The aim is to identify the same set of shocks in the PSVAR as in the daily BVAR model in order to assess whether the information present in higher frequency movements in financial variables carries over to the real economy.

Connecting the PSVAR with our daily BVAR, the euro area 10-year OIS rate (US 10-year Treasury yield) is the target variable of the euro area (US) monetary policy shock, the EURO STOXX (S&P500) is the target variable for the euro area (US) macro shock, and the euro – US dollar exchange rate acts as a target variable for the global risk shock. As mentioned above, for each shock we will use the corresponding aggregated structural shock from our daily BVAR model as instrument. We use an uninformative prior over the reduced form, drawing from its posterior distribution using an adapted version of the method used in the daily BVAR model. Thus, the posterior is centred around the OLS estimator of the reduced form. The results show that the economic interpretation of the daily shocks carries over to the corresponding PSVAR shocks for which they serve as the instrument in the sense that the sign restrictions imposed to identify the daily shocks are preserved in the PSVAR (see **Figure A.3.11**). This underlines the validity of our approach and shows that shocks to financial variables are meaningful for the broader macroeconomy. More details on the empirical methodology are provided in Appendix 2.

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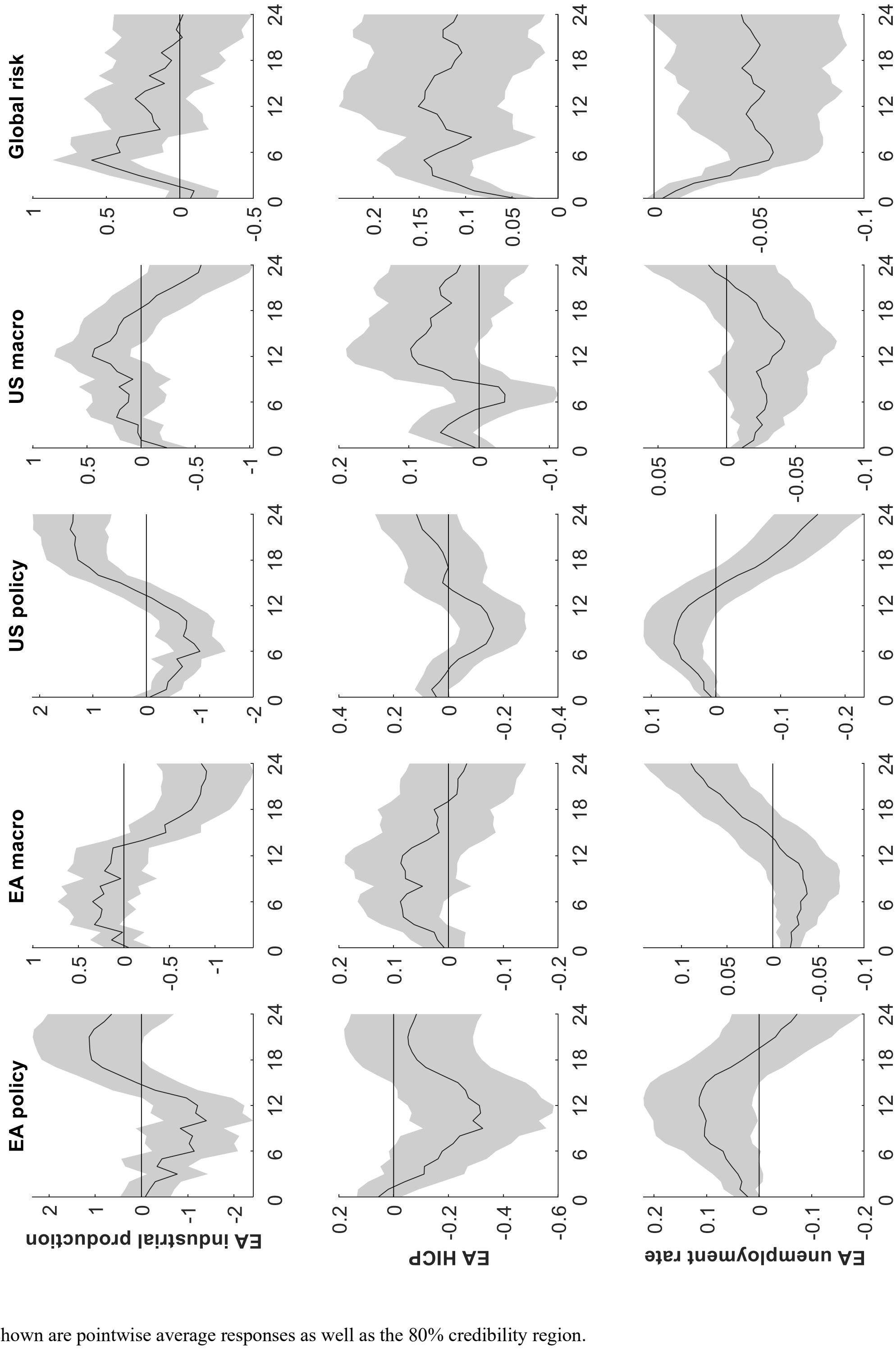
[13] To obtain the monthly instruments we aggregate the daily structural shock series from the BVAR model over the number of successful draws and over time, which introduces some correlation between the instruments in monthly frequency – despite shocks from each draw are uncorrelated at the daily frequency. To address this issue, we purge the instruments by sequentially regressing these on the other shock series in the order of endogeneity to ensure the shock instruments are uncorrelated.

Empirical results: shock dependence matters

Figure 7 shows the estimated macroeconomic effects of an impact increase in long-term rates in the euro area by 10 basis points depending on the shock causing higher yields: (i) a euro area monetary policy shock, (ii) a US monetary policy shock, (iii) a euro area macro shock, (iv) a US macro shock or a (v) global risk shock. Here we focus on different shocks to euro area yields but the implications are the same when the results are normalised on a specific change in another endogenous variable of the model, like the exchange rate.

The results show that indeed, the implications for euro area industrial production, inflation and unemployment differ markedly depending on the driver of higher yields. When euro area risk-free yields are higher because of a domestic monetary policy tightening, euro area industrial production and inflation decline, unemployment increases and the euro exchange rate depreciates against the US dollar. In case the increase in euro area yields originates from tighter monetary policy in the US, industrial production in the euro area will still fall while inflation declines by less given the depreciation of the euro against a strengthening US dollar. In contrast, when long-term euro area yields are higher because the domestic macroeconomic outlook is improving, industrial production and inflation in the euro area will be generally supported by the pick-up in demand, rather than being pulled down by higher yields and an appreciating euro. In this case, rising yields and a stronger euro exchange rate reflect expectations of higher economic growth that the negative impact of higher yields and a stronger currency, ceteris paribus, is not able to offset. Industrial production and inflation in the euro area are also supported when euro area long-term yields increase because of favourable US macro developments that spill over to the euro area. Finally, when euro area risk-free rates are higher because of improving global risk sentiment – in the recovery phase from the global financial crisis or the COVID-19 pandemic for example – higher yields will also be associated with strengthening growth and rising inflationary pressures. Overall, these results emphasise that when information is extracted from daily financial market developments, it is essential to account for the underlying drivers to better interpret the signals they transmit for lower frequency economic dynamics.

Figure 7: PSVAR impulse response functions for euro area macro variables
(Industrial production and HICP in percent over baseline, unemployment in percentage points, horizon in months)



Notes: Shown are pointwise average responses as well as the 80% credibility region.

5. Conclusions

In this paper we provide a novel approach to jointly assess the drivers of euro area and US financial market developments by exploiting the information content provided by asset price co-movements at daily frequency. We find that US factors and global risk are important drivers of euro area asset prices. In comparison, euro area factors are less relevant in explaining US financial market movements, with global risk shocks playing a much larger role consistent with the safe haven status of US dollar-denominated assets. Our approach delivers an economically plausible identification strategy and can be extended to account for additional drivers. We also show that the information extracted from the daily co-movements in financial asset prices carries over to macroeconomic aggregates at lower frequencies. Depending on the mix of drivers underlying financial market developments, the transmission to the macroeconomy can differ substantially. Overall, these results illustrate the importance of accounting for the underlying drivers of financial conditions in order to draw the correct inferences from daily movements in euro area and US asset prices.

6. References

Altavilla, C., G. Carboni and R. Motto (2015), "Asset purchase programmes and financial markets: lessons from the euro area", *ECB Working Paper Series*, No. 1864.

Altavilla, C., L. Brugnolini, R. S. Gürkaynak, R. Motto, G. and Ragusa (2019), "Measuring euro area monetary policy", *Journal of Monetary Economics*, Vol. 108, pp. 162-179.

Andrade, P., J. Breckenfelder, F. De Fiore, P. Karadi, and O. Tristani (2016), "The ECB's asset purchase programme: an early assessment", *ECB Working Paper Series*, No. 1956.

Andrade, P. and F. Ferroni (2018), "Delphic and Odyssean monetary policy shocks: Evidence from the euro area", *Federal Reserve Bank of Chicago Working Papers*, No. 2018-12.

Arias, J. E., J. F. Rubio-Ramirez, and D. F. Waggoner (2018), "Inference Based on Structural Vector Autoregressions Identified With Sign and Zero Restrictions: Theory and Applications", *Econometrica*, Vol. 86(2), pp. 685-720.

Boeckx, J., M. Dossche, A. Galesi, B. Hofman, and G. Peersman (2019), "Do SVARs with sign restrictions not identify unconventional monetary policy shocks?", *BIS Working Paper*, No. 788.

Ca' Zorzi, M., Dedola L., Georgiadis G., Jarociński M., Stracca L. and G. Strasser (2020), "Monetary policy and its transmission in a globalised world", *ECB Working Paper Series*, No 2407.

Cahill, M., S. D'Amico, L. Canlin, and J. Sears (2013), "Duration Risk versus Local Supply Channel in Treasury Yield: Evidence from the Federal Reserve's Asset Purchase Announcements", *Finance and Economics Discussion Series,* No. 2013-35. Board of Governors of the Federal Reserve System.

Campbell, J. R., C. L. Evans, J. D. Fisher, and A. Justiniano (2012), "Macroeconomic Effects of Federal Reserve Forward Guidance", *Brookings Papers on Economic Activity*, No. 44-1.

Carlson, M., S. D'Amico, C. Fuentes-Albero, B. Schlusche, and P. Wood (2020), "Issues in the Use of the Balance Sheet Tool", *Finance and Economics Discussion Series,* No. 2020-071, Board of Governors of the Federal Reserve System.

Cieslak, A. and A. Schrimpf (2019), "Non-monetary news in central bank communication", *Journal of International Economics*, Vol. 118, pp. 293-315.

De Santis, R. (2019), "Redenomination risk", *Journal of Money, Credit and Banking*, Vol. 51(8), pp. 2173-2206.

Elbourne A. and K. Ji (2019), "Do zero and sign restricted SVARs identify unconventional monetary policy shocks in the euro area?" *CPB Discussion Paper*, No. 391.

Engel, C. (2014) "Chapter 8 – Exchange rates and interest party", *Handbook of International Economics*, Vol. 4, pp 453-522.

Eser, F., W. Lemke, L. Nyholm, S. Radde, and A. Vladu (2019), "Tracing the impact of the ECB's asset purchase programme on the yield curve", *ECB Working Paper Series*, No. 2293.

Fatum, R. and Y. Yamamoto (2016), "Intra-safe haven currency behavior during the global financial crisis", *Journal of International Money and Finance*, Vol. 66, September 2016, pp 49-64.

Foerster, A. and G. Cao (2013), "Expectations of large-scale asset purchases", *Federal Reserve Bank of Kansas City Review*, Second Quarter 2013, pp. 5-29.

Forbes, K., Hjortsoe, I. and T. Nenova (2018), "The shocks matter: Improving our estimates of exchange rate pass-through", *Journal of International Economics*, Vol. 114, September 2018, pp 255-275.

Gagnon J. E., M. Raskin, J. Remache, and B. P. Sack (2011), "Large-scale asset purchases by the Federal Reserve: did they work?", *Economic Policy Review*, Federal Reserve Bank of New York, May, pp. 41-59.

Gertler, M. and P. Karadi (2015), "Monetary Policy Surprises, Credit Costs, and Economic Activity". *American Economic Journal: Macroeconomics*, Vol. 7(1), pp. 44-76.

Habib, M. and L. Stracca (2012), "Getting beyond carry trade: What makes a safe haven currency?", *Journal of International Economics*, Vol. 87, pp 50-64.

Hamilton, J. D. (1985), "Historical Causes of Postwar Oil Shocks and Recessions", *The Energy Journal*, Vol. 6(1), pp. 97-116.

Jarociński, M. and P. Karadi (2020), “Deconstructing monetary policy surprises: The role of information shocks”, *American Economic Journal: Macroeconomics*, Vol. 12, No 2, April 2020.

Kremer, M., M. Lo Duca, D. Holló (2012), “CISS - a composite indicator of systemic stress in the financial system”, *ECB Working Paper Series*, No. 1426.

Krishnamurthy, A. and A. Vissing-Jorgensen (2011), “The Effects of Quantitative Easing on Interest Rates”, *Brooking Papers on Economic Activity*, Vol. 42(2), pp. 215-287.

Matheson, T. and E. Stavrev (2014), “News and monetary shocks at a high frequency: a simple approach”, *Economics Letters*, Vol. 125(2), pp. 282-286.

Mertens, K., M. O. Ravn (2013). “The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States”, *American Economic Review*, Vol. 103(4), pp. 1212-1247.

Miranda-Agrippino, S. and H. Rey (forthcoming), “US Monetary Policy and The Global Financial Cycle”, *Review of Economic Studies*, forthcoming

Nakamura, E., and J. Steinsson (2018), “High-frequency identification of monetary non-neutrality: the information effect”, *Quarterly Journal of Economics*, Vol. 133(3), pp. 1283-1330.

Romer, C. D., D. H. Romer (1989), “Does Monetary Policy Matter? A New Test in the Spirit of Friedman and Schwartz”, *NBER Macroeconomic Annual 1989*, Vol. 4, pp. 121-184.

Romer, C. D., D. H. Romer (2010), “The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks”, *American Economic Review*, Vol. 100(3), pp. 763-801.

Rostagno, M., C. Altavilla, G. Carboni, W. Lemke, R. Motto, A. Saint-Guilhem, and J. Yiangou (2019), “A tale of two decades: the ECB’s monetary policy at 20”, *ECB Working Paper Series*, No. 2346.

Rubio-Ramirez, J. F., D. F. Waggoner, and T. Zha (2010), “Structural Vector Autoregressions: Theory of Identification and Algorithms for Inference”, *Review of Economic Studies*, Vol. 77(2), pp. 665-696.

Stock, J. H. and M. W. Watson (2012), "Disentangling the channels of the 2007–09 recession", *Brookings Papers on Economic Activity*, Vol. 43(1), pp. 81-135.

7. Appendix

Appendix 1: Structural Bayesian VAR at daily frequency

Inference with sign restrictions

Following the notation of Rubio-Ramirez et al. (2010), consider the general VAR model in structural form where y is an $n \times 1$ vector of endogenous variables. With a vector of exogenous variables z possibly containing a constant term, we have for $1 \leq t \leq T$:

$$y_t' A_0 = y_{t-1}' A_1 + y_{t-2}' A_2 + \cdots + y_{t-p} A_p + z_t{}' C + \varepsilon_t' \tag{1}$$

Conditional on past information and pre-sample initial conditions $y_{1-p}, \dots, y_0$, the structural shocks ε_t are assumed to be i.i.d. normally distributed with zero mean and unit variance such that their covariance matrix is the $n \times n$ identity matrix. Stacking the parameter matrices of the right-hand side allows us to express the model compactly as the sum of one predetermined and one stochastic term – conditional on information available at time t:

$$y_t' A_0 = x_t' A_+ + \varepsilon_t' \tag{2}$$

With m exogenous variables, the matrix of parameters A_+ is $(np + m) \times n$. As is well-known, the structural model characterised by (A_0, A_+) is not uniquely identified. Instead, write the reduced form of equation (2) as:

$$y_t' = x_t' B + u_t' \tag{3}$$

Here, $\mathrm{B} = A_+ A_0^{-1}$ and $u_t = \varepsilon_t' A_0^{-1}$ with $E[u_t u_t'] = \Sigma = A_0 A_0^{-1}$. Thus, for every (A_0, A_+) there exists an observationally equivalent $(A_0 Q, A_+ Q)$ with Q being any $n \times n$ orthogonal matrix. Since the set of orthogonal matrices is infinite, there exists an infinite number of structural models that give rise to the same observable data. However, given a specific Q, there exists a one-to-one mapping between reduced and structural form. Given the Cholesky-factorization[14] of the covariance matrix of the residuals, we can write the reduced form in terms of the underlying structural shocks:

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[14] Or any other decomposition h for which it holds that $h(\Sigma)' h(\Sigma) = \Sigma$ (Arias et al. 2018).

$$y_t' = x_t'B + \varepsilon_t'Q'chol(\Sigma) \tag{4}$$

Since B and Σ are exactly identified and Q uniquely links these to a valid structural model, we use the rotation matrix as a parsimonious way to carry theoretical restrictions on the structural parameters that are independent of the reduced form. In our Bayesian framework, these restrictions are expressed as a prior over Q that assigns zero probability mass to parts of the parameter space where the restrictions do not hold.

Note that since the reduced form model is unaffected by our choice of restrictions, we only add information via the prior over Q. Specifically, we adopt the conjugate prior choice of Arias et al. (2018) and use a normal-inverse-Wishart prior over the reduced form parameters as well as a uniform prior over the rotation matrix. Together with a normal likelihood, this parameterisation gives rise to a so-called normal-generalised-normal posterior distribution over the structural parameters (A_0, A_+) conditional on the restrictions imposed.

In our empirical application, we do not directly restrict the set of (A_0, A_+) itself but the contemporaneous impulse response function which can be derived from the moving-average representation of the VAR. If the model is invertible, any realisation of endogenous variables y can be expressed as a weighted sum of past and present structural shocks with weights approaching zero as $k \to \infty$:

$$y_t' = \varepsilon_t'L_0 + \varepsilon_{t-1}'L_1 + \varepsilon_{t-2}'L_2 + \ldots + \varepsilon_{t-k}'L_k + \cdots \tag{5}$$

Given a set of structural parameters (A_0, A_+), the sequence of $\{L_0, L_1, \ldots, L_k\}$ can be computed recursively as follows (where p is the number of lags in the model):

$$\begin{aligned} L_0 &= (A_0^{-1})' \\ L_0 &= \sum_{\ell=1}^{k} (A_\ell A_0^{-1})' L_{k-\ell} \quad \forall\, k \le p \\ L_0 &= \sum_{\ell=1}^{p} (A_\ell A_0^{-1})' L_{k-\ell} \quad \forall\, k > p \end{aligned} \tag{6}$$

Since the mapping between structural parameters and impulse response function is strictly bijective (one-to-one and onto), it is sufficient to specify restrictions on L without making explicit the restrictions on (A_0, A_+).

Here, we only restrict the behaviour of the shocks on impact, i.e., the $n \times n$ matrix L_0. Note that it holds that $L(A_0 Q, A_+ Q) = L(A_0, A_+)Q$. Thus, we start with a naïve candidate for $L(A_0, A_+)$, the Cholesky-factorisation of Σ, which we repeatedly rotate with draws of Q. If the rotated impulse response function conforms to our sign restrictions, we retain the draw, otherwise we discard it. In practice, we implement Algorithm 1 of Arias et al. (2018) which yields i.i.d. draws from the normal-generalised-normal posterior conditional on the set of sign restrictions.

Historical decomposition

For visualisation and counterfactual analysis, our main object of interest is the historical decomposition of the time series in the model. We would like to see how much of a change in asset prices on any given day can be attributed to the identified underlying factors. From equation (4), derive the structural shocks as a function of reduced form quantities:

$$\begin{aligned} \varepsilon_t' Q' chol(\Sigma) &= y_t' - x_t' B \\ \varepsilon_t' Q' chol(\Sigma) &= u_t' \\ \varepsilon_t' &= u_t' chol(\Sigma)^{-1} Q \end{aligned} \tag{7}$$

Together with the impulse response function as computed in equation (6), we calculate the marginal contribution of the j'th shock to changes in the $\imath$'th variable as follows:

$$H(A_0, A_+)_{i,j,t} = \sum_{\ell=0}^{t-1} \mathbb{I}_i' L_\ell(A_0, A_+) \mathbb{I}_j \cdot \mathbb{I}_j' \varepsilon_{t-\ell} \tag{8}$$

Here, let $\mathbb{I}_j$ denote an indicator column vector that is unity at j and zero everywhere else such that the first term on the right-hand side selects the (i, j) element in the structural MA coefficient matrix at lag ℓ. It is then scaled by the corresponding structural shock.

This decomposition allows us to assess the relative importance of different shocks in the development of a variable over time or construct counterfactual scenarios.

Robustness of daily BVAR estimates

In order to explore the informational content of our data we conduct a robustness test using random data. Since daily changes in financial asset prices are statistically nearly indistinguishable from white noise there is some legitimate worry that we are not actually identifying any economically meaningful behaviour. Instead, the VAR would simply reproduce the behaviour implied by the chosen prior.[15] Since our identification scheme and modelling approach relies on cross-asset movements by investors, we depend heavily on correctly estimating the conditional covariances in the system.

Due to the low persistence of the variables in the VAR, our objects of interest are mostly determined by the on-impact response to the structural shocks. Therefore, we focus on the posterior distribution of L_0 to evaluate the informativeness of our data. Through our identification scheme, we tightly restrict the permissible parameter space of L_0. Our goal in this exercise is to ascertain whether the behaviour of the estimated VAR truly reflects some informational content of the data or is driven by the restrictions imposed by us.

For this purpose, we construct a dataset of five uncorrelated variables that match some distributional properties of the data in our euro area - US benchmark model. In practice, we fit a Generalised Student's t-distribution to each variable and draw from it. We thereby aim to reproduce the univariate properties of each of the variables while "switching off" the cross-variable behaviour which we rely on for identification.

We then estimate the on-impact impulse response of these constructed variables applying the same sign restrictions and prior assumptions as in the benchmark. **Figure A.3.12** in Appendix 3 plots the empirical CDFs of the marginal posterior distributions of L_0 generated by the simulated data (orange) and the benchmark model (blue). We can see that while the support of

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[15] Recently, some suspicion has arisen in the literature that sign-restricted VARs are in danger of being dominated by prior information. See Elbourne and Ji (2019) for the initial critique and Boeckx et al. (2019) for a subsequent rebuttal.

the marginal posteriors is roughly the same across elements of L_0, both the shape and central tendency in general differ markedly.

To formalise the notion of differently shaped marginal posteriors, we conduct Kolmogorov-Smirnov tests for equality between the two posteriors for each parameter (see **Figure A.3.13**). For the vast majority of marginal posterior we can soundly reject equality between the simulated and the benchmark model at the 5%-level thereby corroborating the validity of our approach.

Appendix 2: Proxy SVAR

For the readers convenience, we formally re-state the PSVAR framework, where the derivations largely follow Stock and Watson (2012), Mertens and Ravn (2013), and Gertler and Karadi (2015). Let the structural VAR be given by

$$AY_t = C + \sum_{j=1}^{p} B_j Y_{t-1} + \varepsilon_t, \tag{9}$$

where ε_t denotes the vector of structural shocks and C denotes a vector of constants. Correspondingly, the reduced form VAR can be expressed as

$$Y_t = \bar{C} + \sum_{j=1}^{p} \bar{B}_j Y_{t-1} + u_t \tag{10}$$

where $\bar{C}$ is given by $A^{-1}C, \bar{B}_j$ is given by $A^{-1}B_j$, and u_t denotes the vector of reduced form residuals, where $u_t = A^{-1}\varepsilon_t$. The reduced form residuals' variance-covariance matrix, Σ, is thus equal to

$$E[u_t u_t'] = E[B_0 \varepsilon_t \varepsilon_t' B_0'] = E[B_0 B_0'] = \Sigma, \tag{11}$$

where we define the impact matrix, $B_0 = A^{-1}$, for notational convenience. In addition, the procedure requires the researcher to specify a target or policy variable, Y_t^p, that is among the variables in the VAR. The policy variable is the variable corresponding to the structural policy shock, ε_t^p, that one wishes to instrument with outside information. All other variables and shocks are denoted by Y_t^q and ε_t^q, respectively (see Gertler and Karadi 2015, Stock and Watson

2012, and Mertens and Ravn 2013). In the section on empirical results, the EA 10-year OIS rate (US 10-year Treasury yield) is the policy variable corresponding to the EA (US) monetary policy shock, the EURO STOXX (S&P500) price index is the policy variable for the EA (US) macro shock, and the USD-EUR exchange rate acts as a target variable for the global risk shock. Each instrument, Z_t – the structural shock from our daily VAR – needs to fulfil two crucial assumptions.

$$E\left[Z_t \varepsilon_t^{p'}\right] = \theta \tag{12}$$

$$E\left[Z_t \varepsilon_t^{q'}\right] = 0 \tag{13}$$

Assumption (12) requires that the instrument is correlated with the policy shock of interest, ε_t^p. As stated above, the instruments extracted in the daily VAR are defined in such a way that they have exactly the economic interpretation that we also attribute to ε_t^p itself through the lens of the financial markets. As such, they are essentially the shock we attempt to measure also in terms of their impact on macroeconomic aggregates. In addition, assumption (13) requires the instrument to be orthogonal to the other structural shocks, ε_t^q, in the monthly VAR. Given that our instruments stem from the same daily VAR, they are already orthogonal to one another at daily frequency. Identification is now achieved using two stage least squares (2SLS). First, u_t^p, the reduced form residual associated with the policy variable, is regressed on the instrument u_t to obtain the fitted value $\widehat{u_t^p}$. This first stage regression thus isolates the variation of the reduced form residual that can be explained by the policy instrument. In a second stage regression, the other reduced form residuals, u_t^q, are now regressed on $\widehat{u_t^p}$. Following Gertler and Karadi (2015), this yields

$$u_t^q = \frac{b_0^q}{b_0^p} \widehat{u_t^p} + \xi_t \tag{14}$$

with $\frac{b_0^q}{b_0^p}$ being consistently estimated as per assumption (13). Given that we are only interested in impulse response functions, it suffices to focus on the column in matrix B_0 that corresponds to the shock ε_t^p and will be denoted by B_0^p in the following. Estimates of b_0^p, the element of the impact matrix that corresponds to the impact of the structural shock, ε_t^p, onto the policy variable, Y_t^p, and b_0^q, the elements in this column of the impact matrix that do not correspond to the policy variable, can then be backed-out from the reduced form residuals' variance-covariance matrix, Σ.

Following Gertler and Karadi (2015), let u_t be partitioned such that $u_t = \left[u_t^p, u_t^q\right]'$. The impact matrix B_0 can then be we written such that:

$$B_0 = \left[B_0^p \quad B_0^q\right] = \begin{bmatrix} b_{0,11} & b_{0,12} \\ b_{0,21} & b_{0,22} \end{bmatrix} \tag{15}$$

The reduced form variance-covariance matrix, Σ, can similarly be expressed as

$$\Sigma = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix} \tag{16}$$

Further, let

$$Q = \frac{b_{0,21}}{b_{0,11}} \Sigma_{11} \frac{b'_{0,21}}{b_{0,11}} - \left(\Sigma_{21} \frac{b'_{0,21}}{b_{0,11}} + \frac{b'_{0,21}}{b_{0,11}} \Sigma'_{21}\right) + \Sigma_{22} \tag{17}$$

and

$$b_{0,12} b'_{0,12} = \left(\Sigma_{21} - \frac{b_{0,21}}{b_{0,11}} \Sigma_{11}\right)' Q^{-1} \left(\Sigma_{21} - \frac{b_{0,21}}{b_{0,11}} \Sigma_{11}\right)' \tag{18}$$

b_0^p is then identified up to a sign rotation and given by

$$\left(b_0^p\right)^2 = b_{0,11}^2 = \Sigma_{11} - b_{0,12} b'_{0,12} \tag{19}$$

b_0^q can then simply be backed out from the regression coefficients in (14).

Appendix 3: Additional figures

Figure A.3.1: Variability of monetary policy shocks on meeting days versus non-meeting days

A. Euro area B. United States

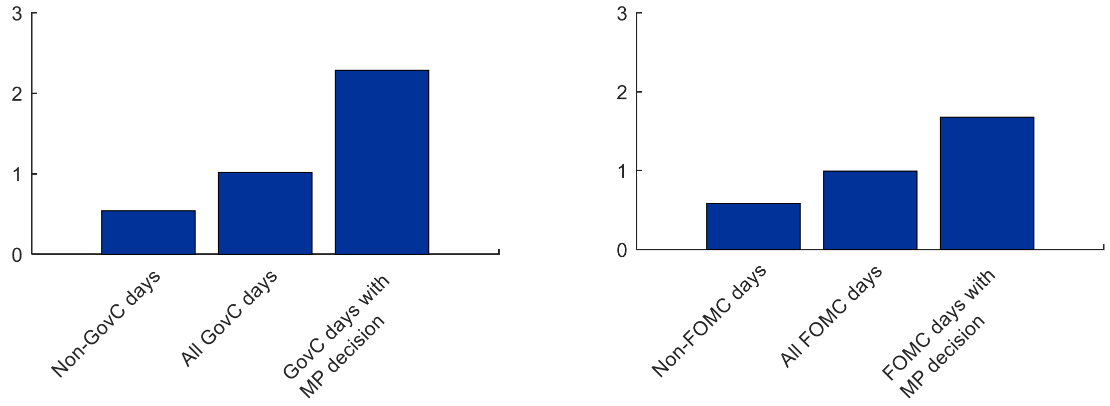
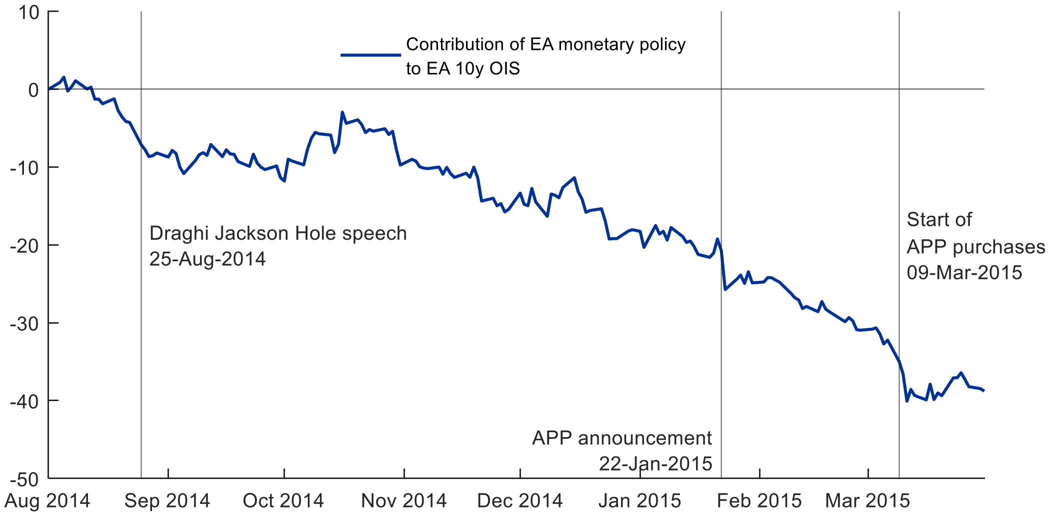
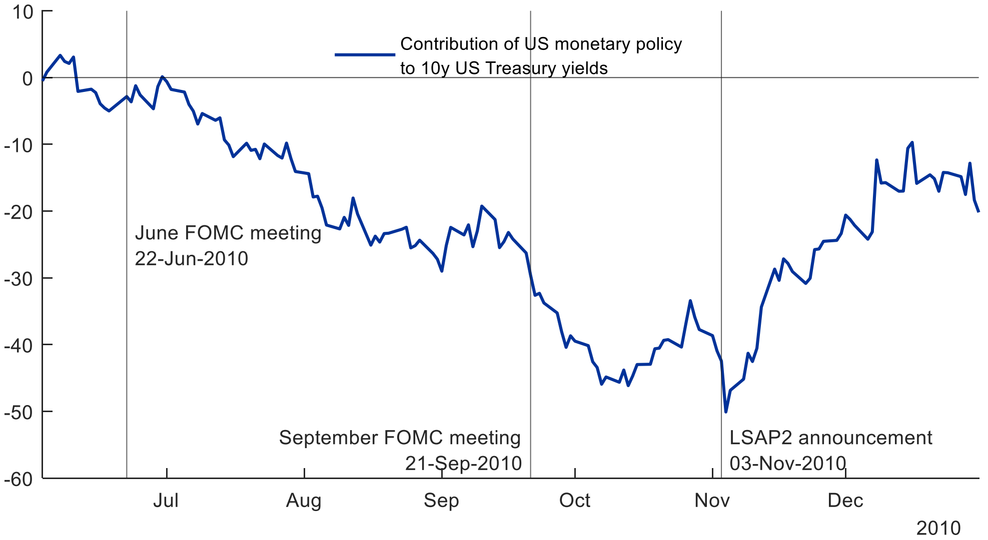


Figure A.3.2: Anticipation of a monetary policy announcement in the euro area
(basis points)



Notes: Chart shows the cumulative contribution of the euro area monetary policy shock to changes in the euro area 10y OIS rate from 01 August 2014 to 31 March 2015.

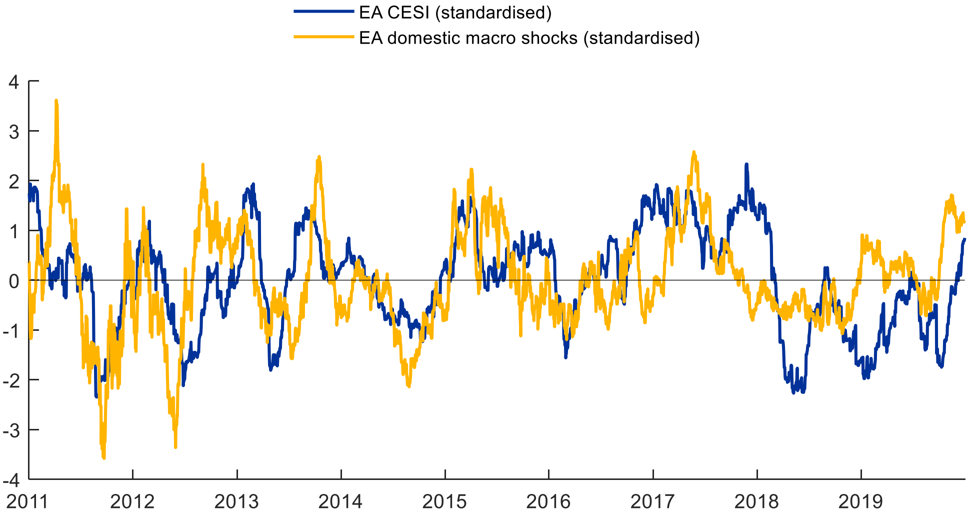
Figure A.3.3: Anticipation of a monetary policy announcement in the US
(basis points)



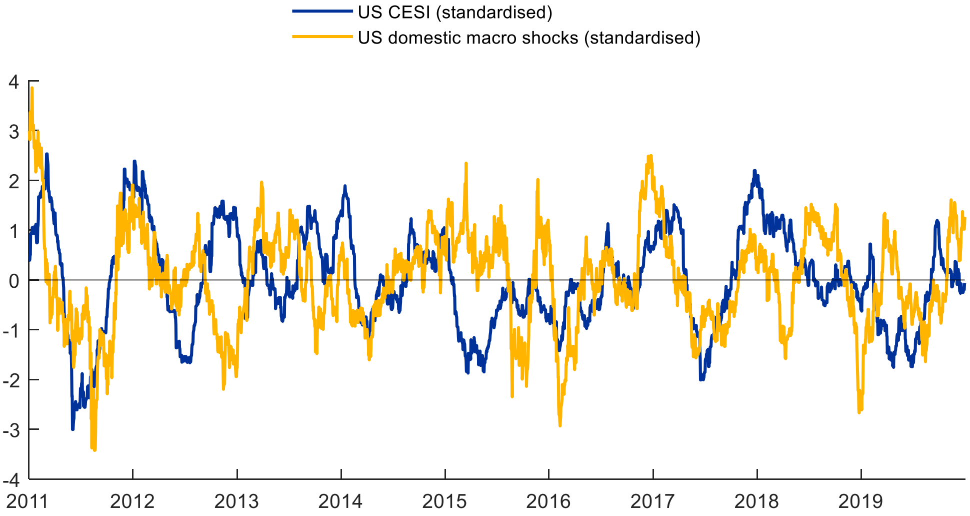
Notes: Chart shows the cumulative contribution of the US monetary policy shock to changes in the 10y US Treasury yield from 01 June 2010 to 31 December 2010.

Figure A.3.4: Comparison of estimated macro shocks with the Citigroup Economic Surprise Index

A. Euro area



B. United States



Notes: Shock series in both charts show the standardised rolling three-month sum of the corresponding shock from the daily BVAR.

Figure A.3.5: Drivers of EURO STOXX equity prices around selected events
(two-day change in percent)

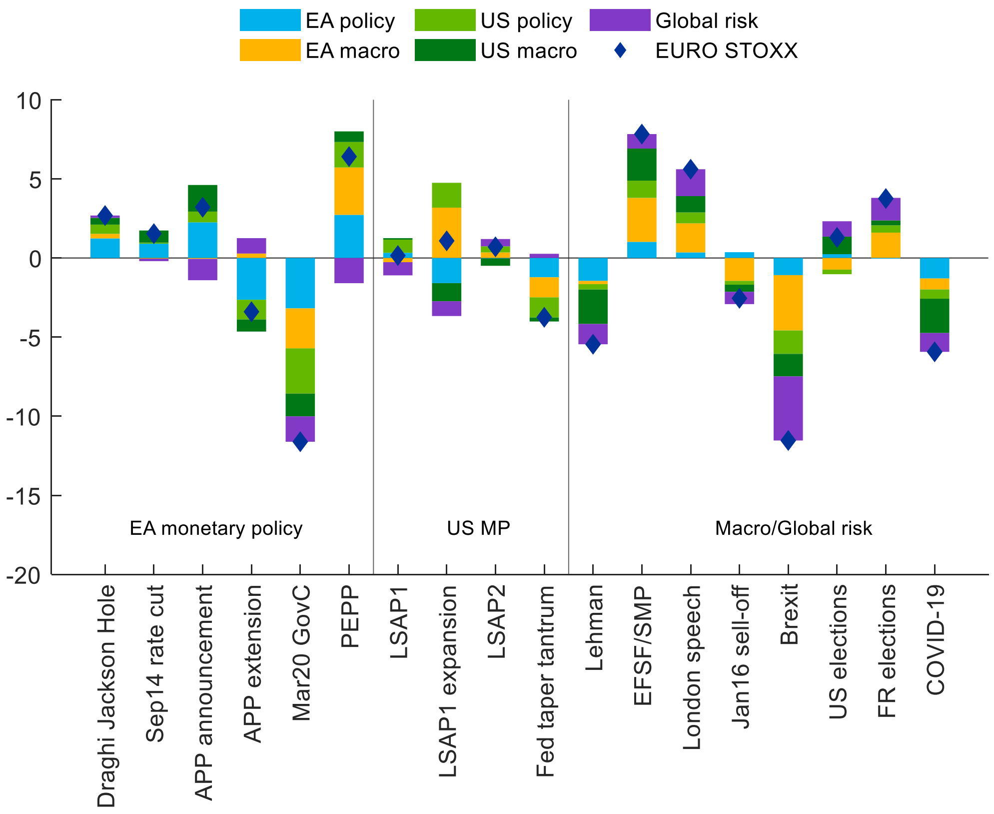


Figure A.3.6: Drivers of the USD/EUR exchange rate around selected events
(two-day change in percent)

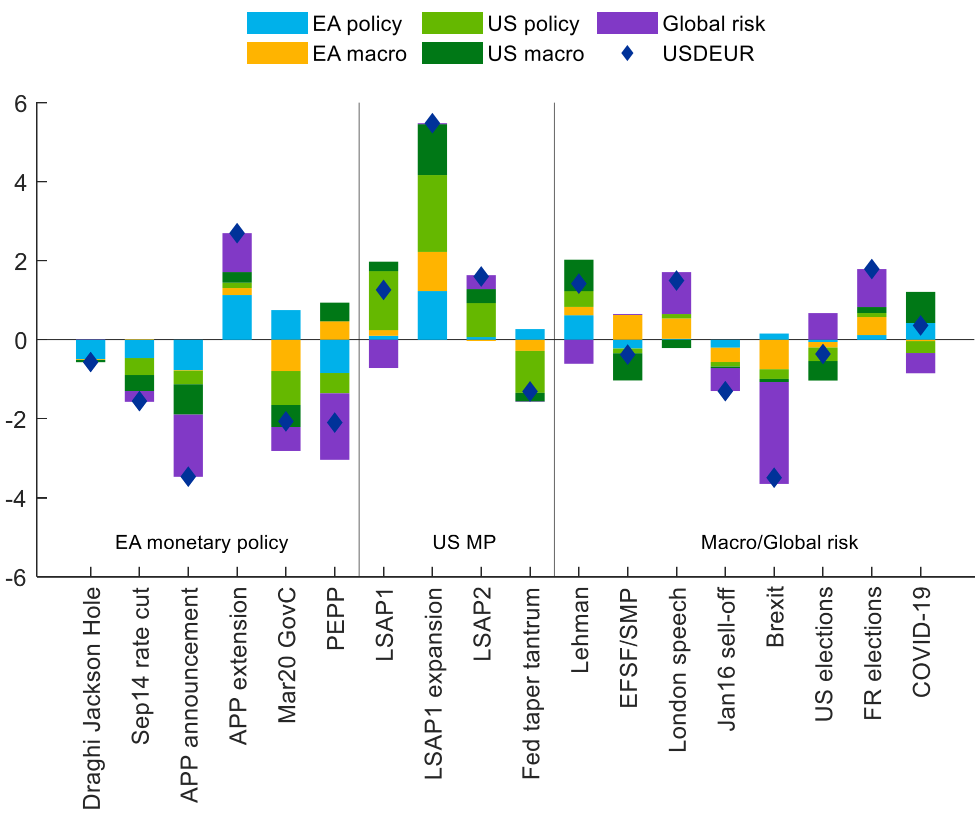


Figure A.3.7: Drivers of the 10-year US Treasury yield around selected events
(two-day change in basis points)

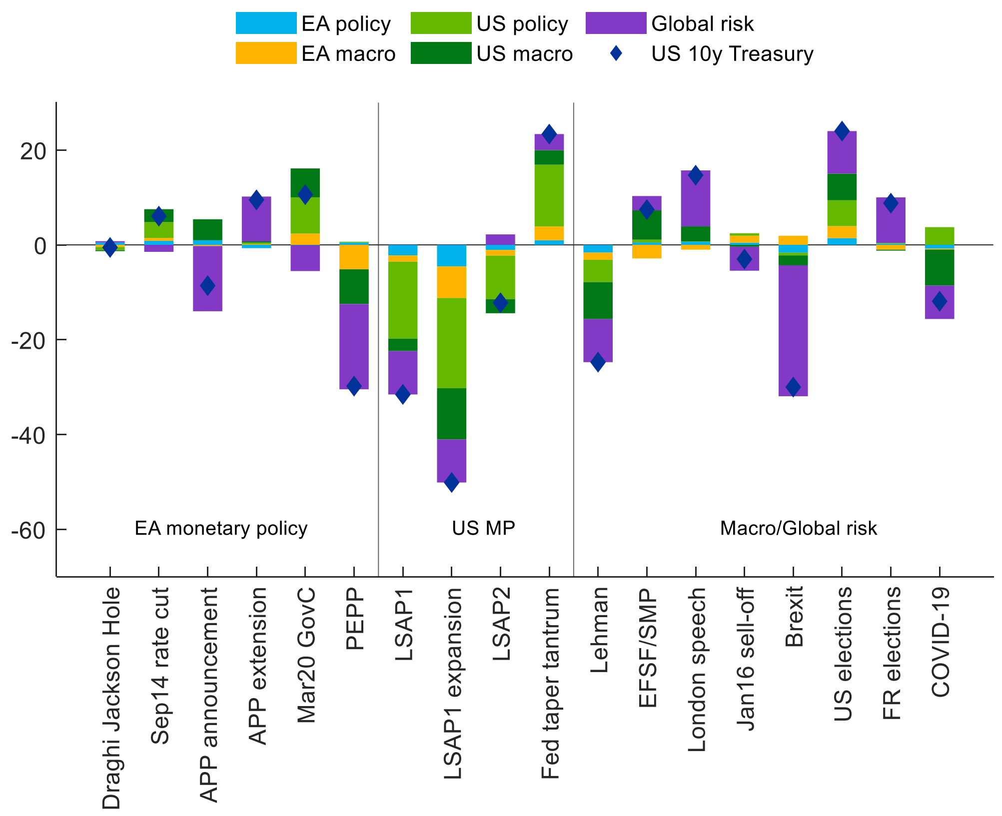


Figure A.3.8: Drivers of US S&P500 equity prices around selected events
(two-day change in percent)

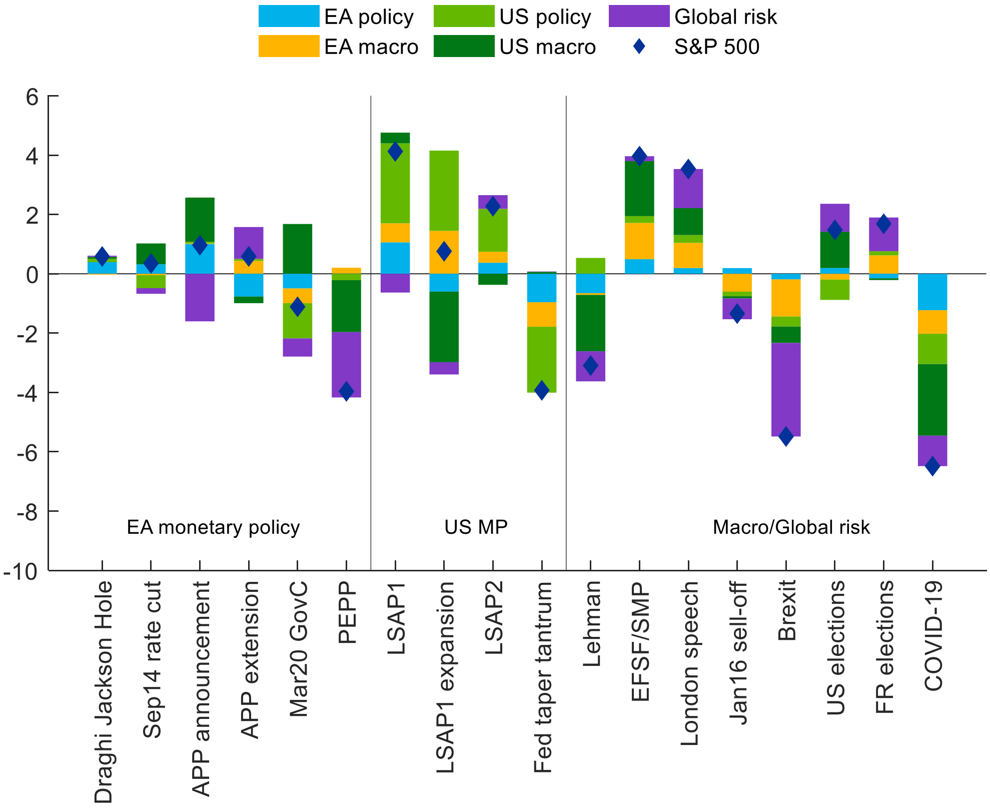
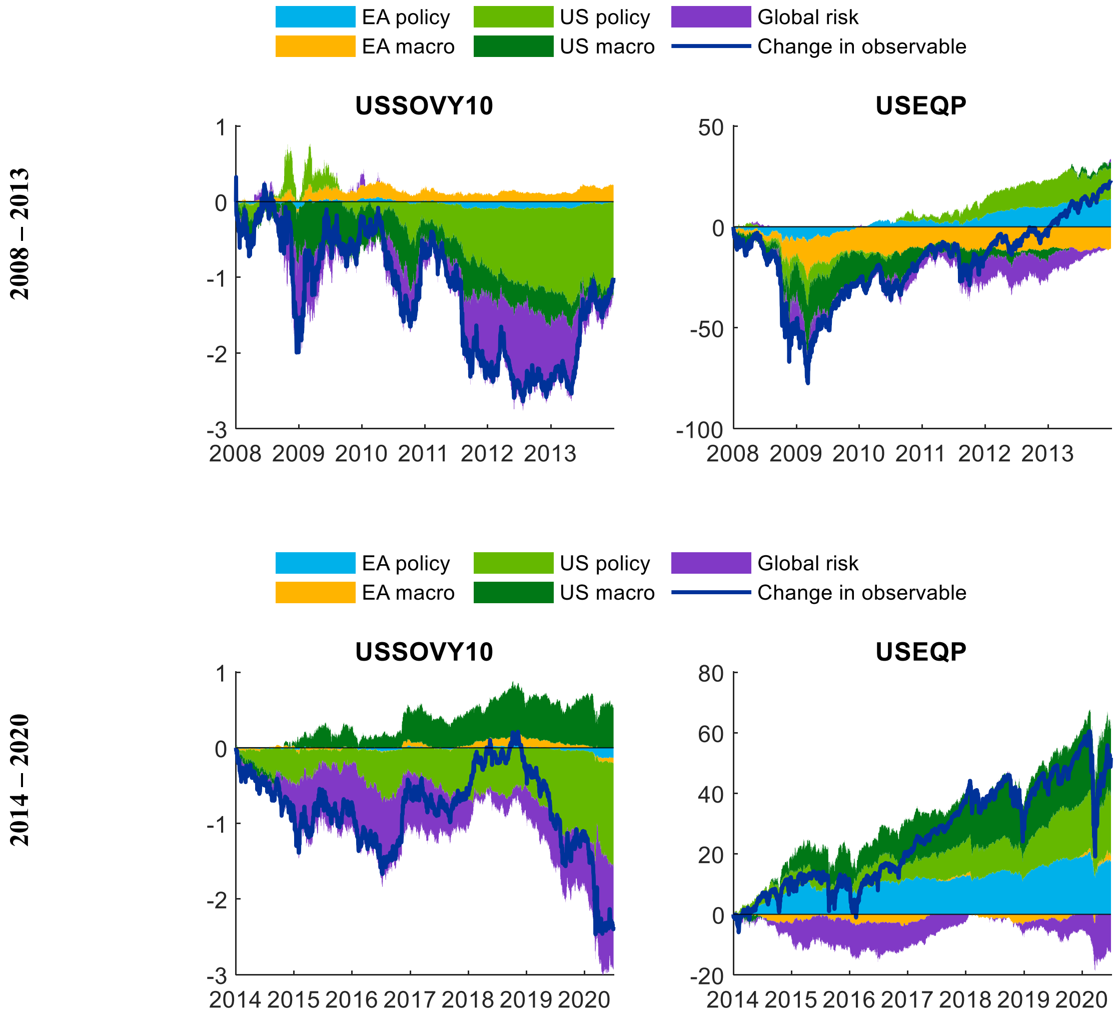


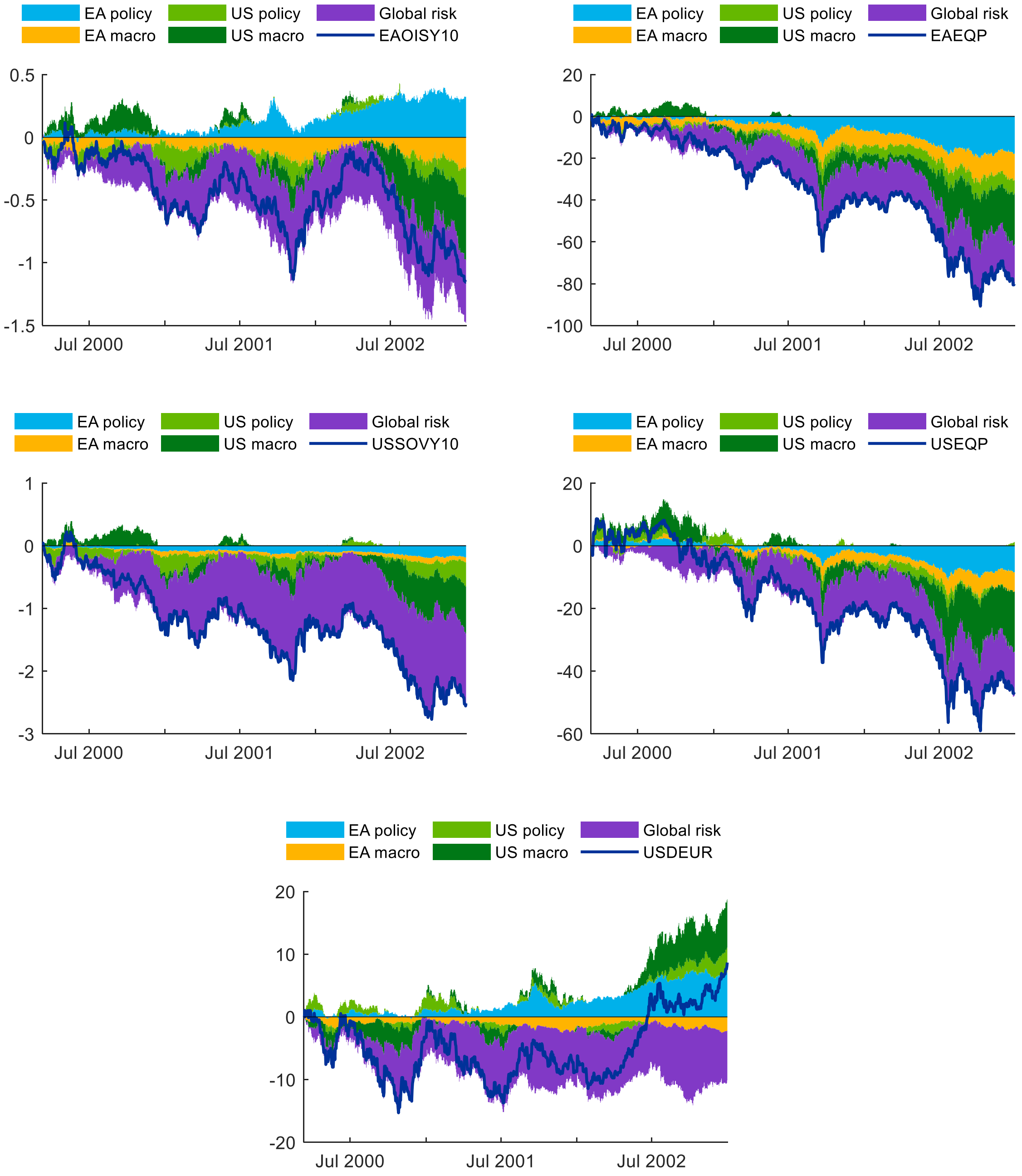
Figure A.3.9: Historical decomposition of US asset prices
(yields in percent per annum, equity prices in log-percentages)



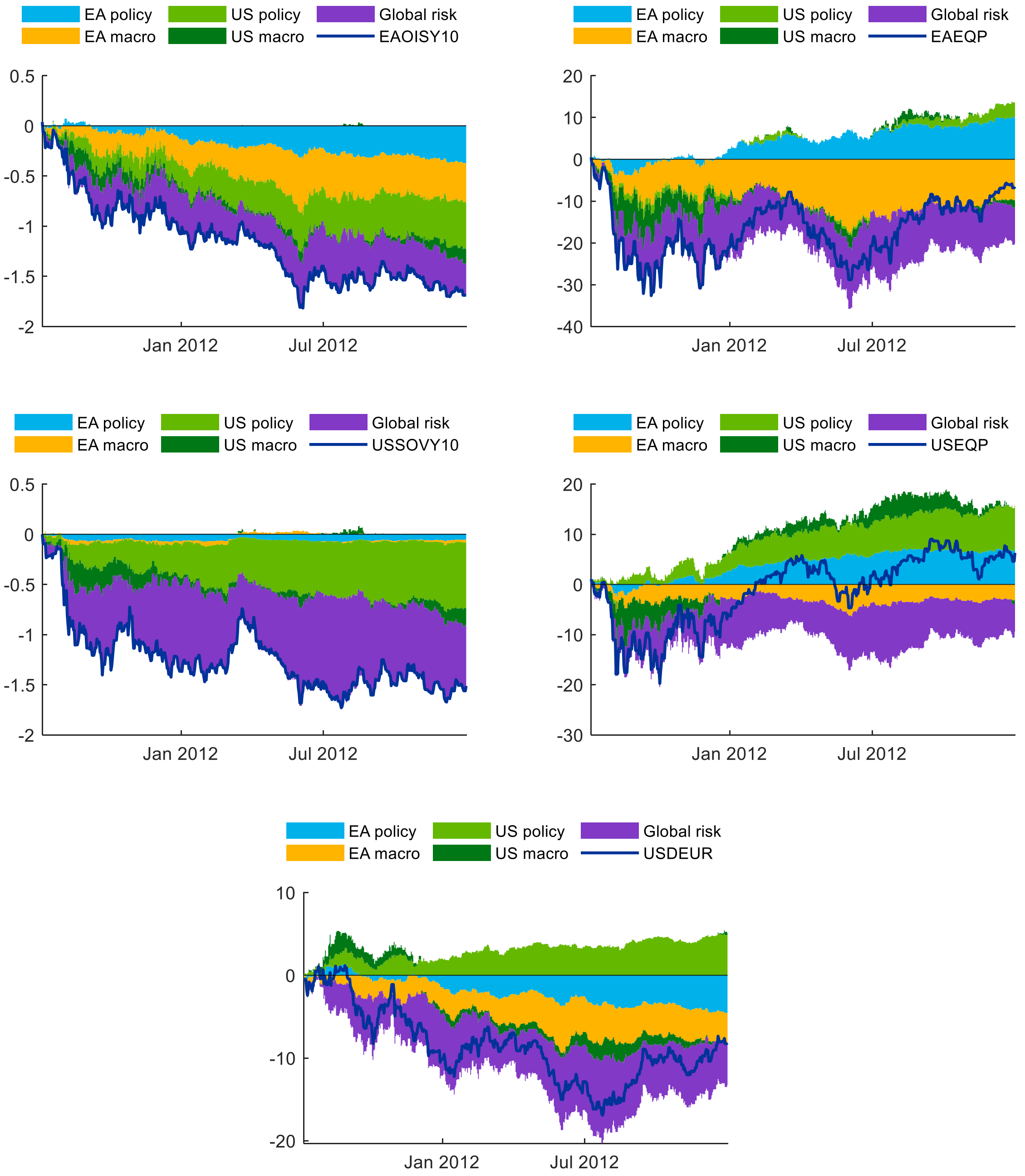
Notes: Shock contributions are normalised to zero at the beginning of the review period.

Figure A.3.10: Spillovers following different types of shocks
(yields in percent per annum, equity prices and exchange rate in log-percentages)

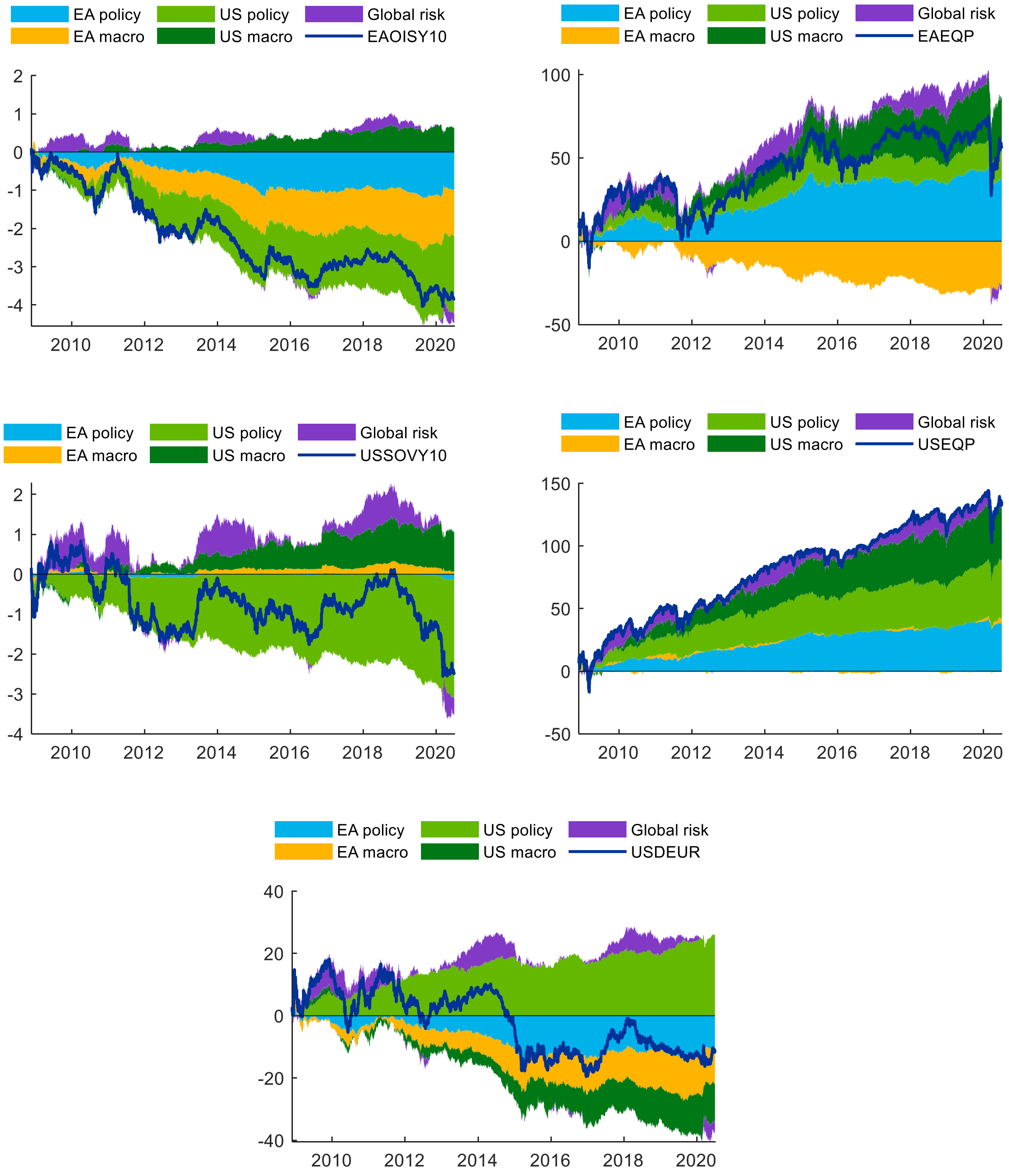
A. US dot-com bubble:
10 March 2000 – 31 December 2002



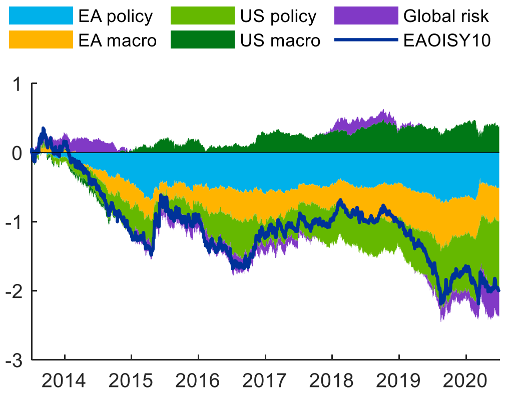
B. EA sovereign debt crisis:
07 July 2011 – 31 December 2012

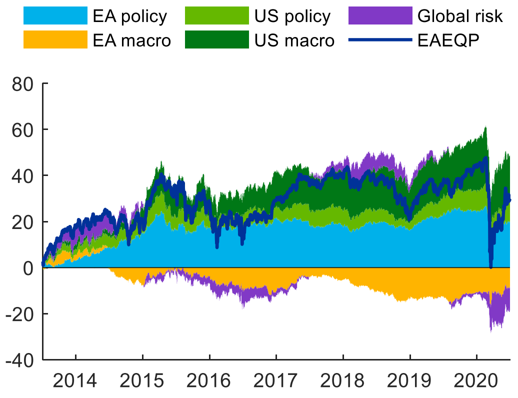


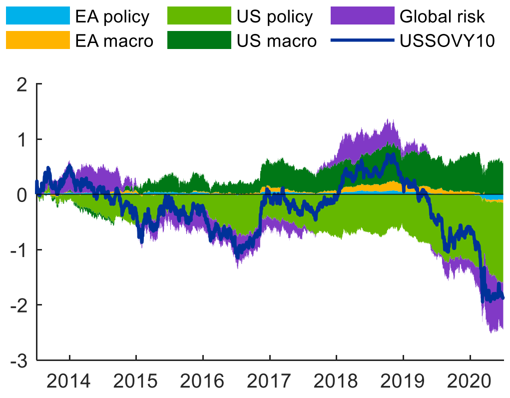
C. Fed unconventional policy:
24 November 2008 – 30 June 2020

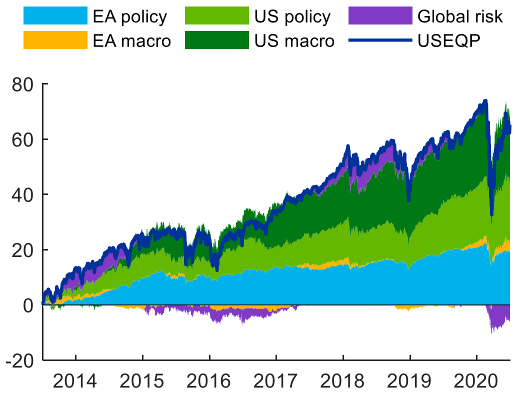


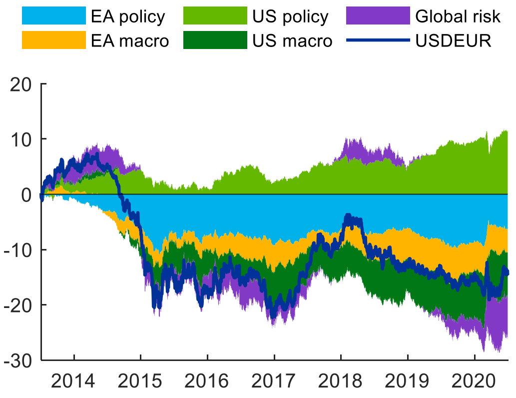
D. ECB unconventional policy:
04 July 2013 – 30 June 2020











Notes: All shock contributions are normalised to zero at the beginning of the review period.

Figure A.3.11: Posterior of on-impact response of financial variables

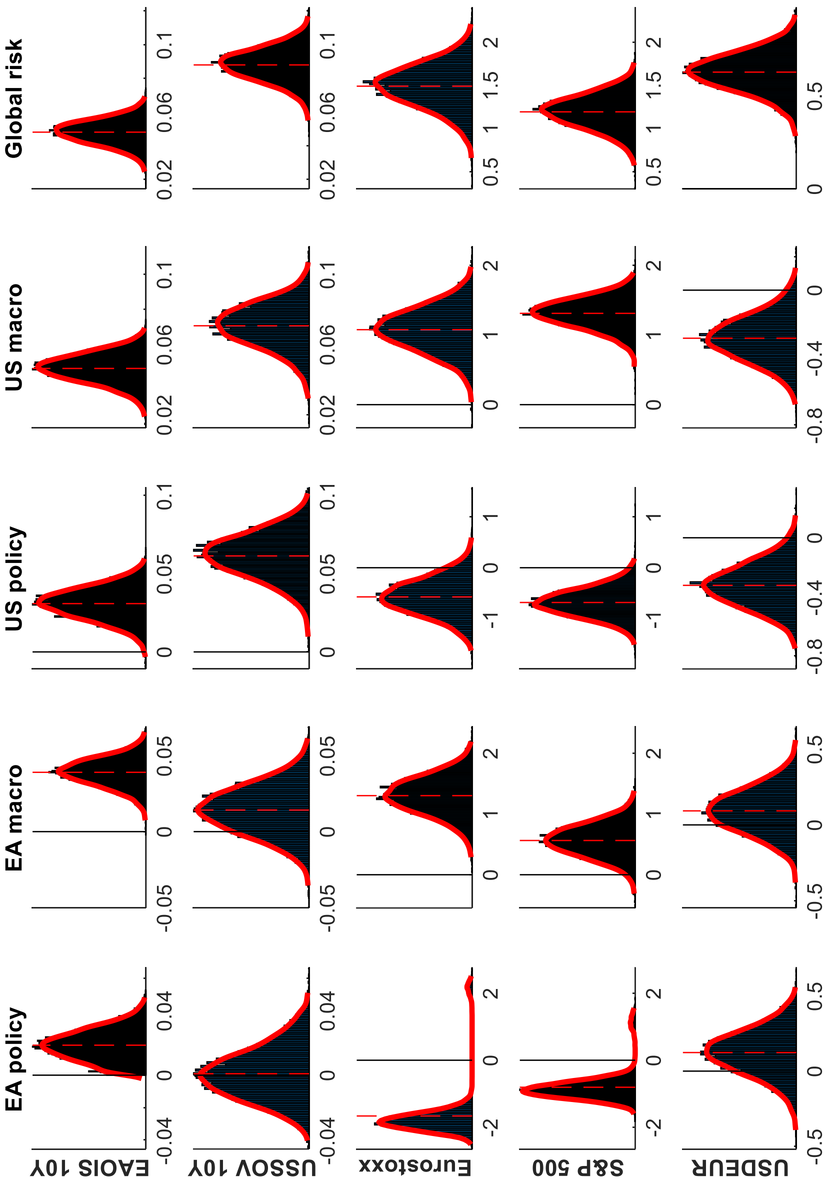


Figure A.3.12: Posterior CDF of L_0 based on simulated data and the benchmark model

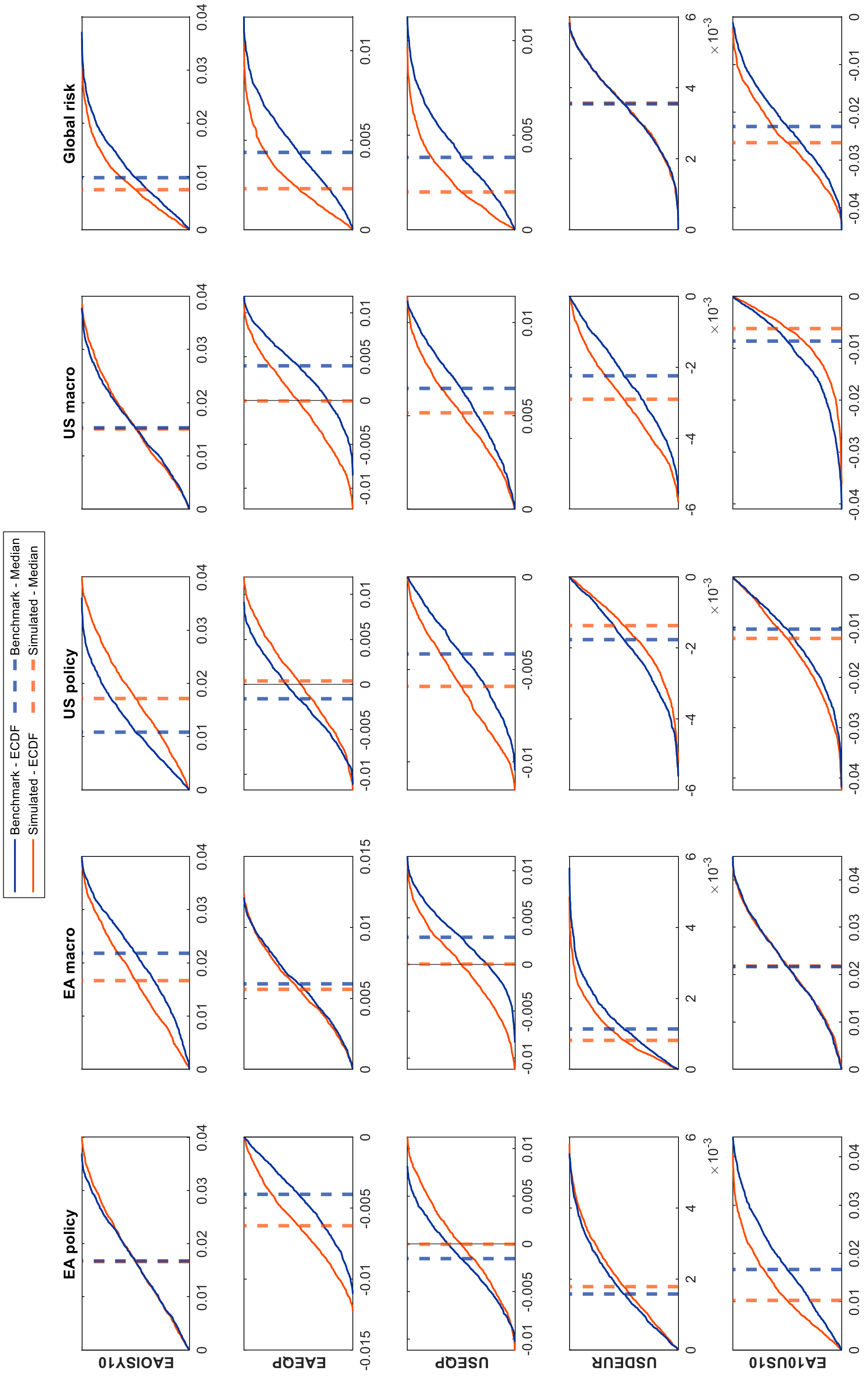
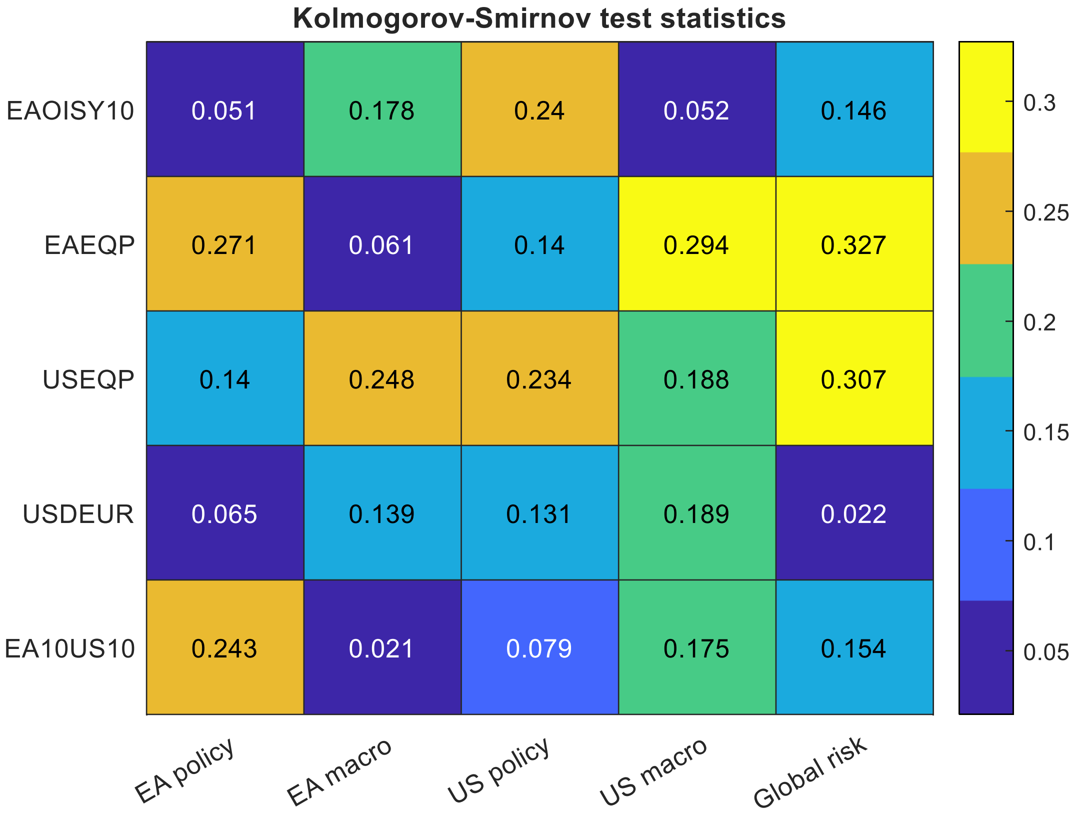


Figure A.3.13: Kolmogorov-Smirnov test statistics for equality between distributions in **Figure A.3.12**



Kolmogorov-Smirnov test statistics

	EA policy	EA macro	US policy	US macro	Global risk
EAOISY10	0.051	0.178	0.24	0.052	0.146
EAEQP	0.271	0.061	0.14	0.294	0.327
USEQP	0.14	0.248	0.234	0.188	0.307
USDEUR	0.065	0.139	0.131	0.189	0.022
EA10US10	0.243	0.021	0.079	0.175	0.154

Notes: Critical value for rejection of equality at the 5% level is 0.06.

Acknowledgements

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