Interest Rates and Foreign Spillovers*

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Abstract

We show that medium-term interest rates in the euro area, Japan, UK and US are affected by domestic and foreign shocks. We find that US rates are the main source of spillovers globally and are less exposed to foreign shocks. Foreign spillovers to European rates were negligible only during the sovereign debt crisis and the introduction of more aggressive monetary policies by the ECB. We identify causal relations among asset prices through structural vector autoregressions (SVAR) and magnitude restrictions. We use preliminary regressions on event days to estimate key parameters employed to constrain the structural parameter space of the SVAR.

JEL Classification: C3, F3, G1

Keywords: Money market rates, Spillovers, Event-study, Magnitude restrictions, SVAR.

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1 Introduction

Asset price spillovers are an important subject with a long history in the macro-finance literature. They can cause financial stability problems, public debt management issues and have important implications for economies' output gap through the real interest rate and its influence on the financing conditions of households and enterprises. Foreign shocks, which tighten (loosen) the domestic financing conditions, are particularly important when the domestic inflation rate is below (above) its target. If, for example, the inflation rate of a country is relatively low, an increase in foreign interest rates even due to positive demand or supply shocks, which spills over to the domestic financing conditions, might be perceived as unacceptable by the domestic policymaker.

The FED taper tantrum in May 2013, the elections of the US president Trump in November 2016, the US tax cut bill in December 2017 and market expectations about FED policy tightening in 2017 and 2018 have all caused a drastic increase in bond yields domestically and abroad, which was not necessarily welcome overseas. These developments are very relevant because we find that US rates are the main source of spillovers globally and foreign spillovers to European rates were negligible only during the sovereign debt crisis and the introduction of more aggressive monetary policies by the ECB. Moreover, consistently with other inferences, we find that US rates are less exposed to foreign shocks, but these outcomes are endogenously determined.

Identifying the country source of spillovers is a challenge, because asset prices highly comove. In this paper, we suggest a novel approach to identify a causal relation among asset prices. Our method combines the appeal of the event-study analysis and magnitude restrictions with the advantages of structural vector autoregressions (SVARs). We show that this approach is particularly suitable to address the source of spillovers and their dynamics across asset prices.

We study the importance of foreign spillovers in the dynamics of the 2-year risk free rate (Overnight Index Swap (OIS) rates) of the G4 economies,[1] the euro area, Japan, the United Kingdom (UK) and the United States (US), because medium-term money

[1]An OIS is a fixed-floating interest rate swap, a financial contract between two counterparties to exchange a fixed interest rate against a geometric average of uncollateralised overnight interest rates over the contractual life of the swap. The appeal of interest rate swaps is that the user can easily manage interest rate risk. An important distinction from bonds is that swaps are non-investible, i.e. they do not serve as a store of value. Therefore, there is no initial payment and, on interest payment dates, the value of the swap only deviates from zero if the interest rate for the remaining time to maturity differs from the agreed fixed swap rate. Because there is no exchange of principal and only the net difference in interest rates is paid at maturity, OISs have little credit risk exposure.

market rates are key reference rates to finance economic activity, these flexible exchange rate economies are fully integrated into the global economy, their shocks can affect asset prices globally, their business cycles can distinctly diverge and their central banks influence expectations of future medium-term interest rates and - through this forward guidance channel - the maturity spectrum of interest rates over the medium-term horizon. Addressing the relative importance of foreign shocks is more challenging after central bank reference rates were perceived by the markets to have reached the lower bound, because of their very low volatility. Yet our approach still provides useful information in line with a sequence of events, which are uncontroversial.

One key result of the paper is that we capture very well the dynamics of the spillovers after commonly recognised shocks and we can investigate the role of spillovers also in periods without key events. For example, after the election of Trump as US president on 8 November 2016, OIS rates in the US increased only by 3 basis points on the same day, 7 basis points after two days and surged by 40 basis points by the end of the year to their highest levels in months in anticipation of a fiscal stimulus. Owing to the US shocks by the end of 2016, we estimate that the 2-year OIS rates increased by about 30 basis points in the US, 10 basis points in the UK, and 5 basis points in the euro area and Japan. These dynamics in asset prices cannot be evaluated with event-study analysis, which typically use a 1-day or maximum a 2-day window to identify the source of shocks and quantify the spillover, because there are relatively few events.[2]

By investigating the dynamic developments of the spillovers, we can suggest that 2-year money market rates in the euro area, Japan, UK and US are affected by domestic and foreign shocks, but their contributions change over time. The US is less exposed to foreign shocks and is the main source of spillover globally. The US money market rates are mainly driven by domestic shocks, as the own shock explained more than 80% of the variance of the US rates over almost the entire sample period. Moreover, we find that euro area medium-term interest rates are highly influenced by developments in the US. Only during the hikes of the euro area sovereign debt crisis in 2011 and 2012 and after the European Central Bank (ECB) reference rates reached zero and introduced unconventional monetary policies, euro area rates were mainly driven by domestic shocks. The UK money market rates are also affected by developments in the US. Finally, global money market rates are more immune if shocks originate in Japan.

[2]Asset price spillovers are typically identified in the literature using event study analyses through interest rate or macroeconomic news. Event-study analysis is particularly used to assess the impact of events in security prices, because the latter react immediately (see MacKinlay (1997) for a survey).

Many authors have constructed measures of structural shocks from historical events and used them as the "true" structural shocks (Hamilton (1985), Romer and Romer (1989), Ramey and Shapiro (1998), Romer and Romer (2004), Kilian (2008), Romer and Romer (2010), Ramey (2011)) or as an external instrument of the targeted structural shocks (Stock and Watson (2012), Montiel Olea et al. (2016), Mertens and Ravn (2013), Gertler and Karadi (2015), Caldara and Herbst (2016)). The crucial difference is that we use the events to run preliminary univariate regressions that assess the relationship among variables, and then use the estimates to impose the restrictions on the SVAR's parameter space. Once lower and upper bounds of impact parameters are defined, we can investigate the spillovers also in periods without key events and this is not possible with external instruments SVARs.

Inspired by (i) the narrative restriction identification, where structural shocks are constrained around key historical events (Antolín-Diaz and Rubio-Ramírez (2018), Caldara et al. (2016)), (ii) the magnitude restriction identification, where structural shocks are constraint within bounds (Kilian and Murphy (2012), Kilian and Murphy (2014), De Santis and Zimic (2018)); and (iii) the use of priors on structural parameters (Baumeister and Hamilton (2015)); we combine the appeal of event studies that isolate exogenous variations in asset prices with the advantage of a magnitude restriction SVAR that allows us to study and describe the dynamic behavior of the time series after the realization of the shock.

More generally, our paper contributes to the research studying the spillovers from the US, which are found to be economically important across developed countries and emerging markets (see for example Ehrmann and Fratzscher (2005), Miniane and Rogers (2007), Faust et al. (2007), Craine and Martin (2008), Hausman and Wongswan (2011), Passari and Rey (2015), Chen et al. (2017)),[3] and investigating the US role as a key driver of the global financial cycle (see Miranda-Agrippino and Rey (2015); Rey (2016); Jorda et al. (2017)).[4]

The remaining sections of the paper are structured as follows. Section 2 describes

[3]The spillover occurs because foreign shocks on the domestic macroeconomy are not fully neutralised by the exchange rate (see Kamin (2010) for a survey of the literature). In the Mundell-Fleming flexible exchange rate regime, the exchange rate plays the role of a foreign shock absorber. Accordingly, there is empirical evidence pointing out that the correlation between countries' medium-term rates vis-à-vis the rate of the reference base country is lower for economies with a flexible than a fixed exchange rate (Shambaugh (2004); Obstfeld et al. (2005); Canova (2005); Hausman and Wongswan (2011); Goldberg (2013); Klein and Shambaugh (2015); and Obstfeld (2015)).

[4]Using term structure models, another branch of the literature has shown that global factors are economically important accounting for a significant fraction of variation in country bond yields also at shorter maturity (Diebold et al. (2008) and Jotikasthira et al. (2015)).

the methodology. Section 3 identifies the key events. Section 4 presents the data and the empirical model. Section 5 discusses the results. Section 6 provides the robustness checks. Section 7 concludes.

2 Econometric methodology

2.1 SVAR setup

A structural vector autoregression model (SVAR) can be written as:

$$A_0 y_t = A_1 y_{t-1} + A_2 y_{t-2} + ... + A_K y_{t-K} + B\varepsilon_t, \tag{2.1}$$

where y_t is the $N \times 1$ vector of endogenous variables, K is a finite number of lags, and the structural shocks ε_t are assumed to be white noise, $\mathcal{N}(0, I_N)$. A_0 describes the contemporaneous relations between the variables, while matrices A_k, $k \in [1, 2, \ldots, K]$, describe the dynamic relationships. The diagonal matrix B contains the standard deviation of the structural shocks.[5]

The system (2.1) implies a following structural moving average representation, $y_t = B(L)\varepsilon_t$, where $B(L)$ is a polynomial in the lag operator. The system in (2.1) is estimated in its reduced form:

$$y_t = A_1^* y_{t-1} + A_2^* y_{t-2} + ... + A_P^* y_{t-K} + u_t, \tag{2.2}$$

where $u_t = A_0^{-1} B\varepsilon_t$ and $A_k^* = A_0^{-1} A_k$.

The moving average representation of (2.2) is $y_t = C(L)u_t$. Therefore, the reduced form response function, $C(L)$, is related to the structural impulse response function by $B(L) = C(L)A_0^{-1}B$. In other words, to identify the structural shocks and obtain the structural impulse responses, $A_0^{-1}B$ ought to be identified.

Given $S = A_0^{-1}B$, A_0 is such that $\Sigma_u = SS'$, where Σ_u is the variance-covariance matrix of the reduced form errors. The decomposition $\Sigma_u = SS'$ is not unique. For any H such that $HH' = I$, the matrix SH also satisfies this condition. In this case, $SH(SH)' = SHH'S' = SS' = \Sigma_u$. Therefore, starting from any arbitrary $\tilde{S}$, such that $\Sigma_u = \tilde{S}\tilde{S}'$ (i.e. a Cholesky decomposition of Σ_u), alternative decompositions can be found

[5]From a notational point of view, we distinguish matrix A from matrix B, because we use a rolling window estimation, which allows us to separate the changes in the contemporaneous relations between yields from the changes in the variance of structural shocks.

by post-multiplying by any H. The entire set of permissible impact matrices is infinite and the impact matrix cannot be identified uniquely from data.

2.2 Identification: The event-study magnitude restriction

Prior assumptions are required to achieve identification. We impose restrictions at impact on the size of overall contemporaneous spillover effects measured by A_0^{-1}. Let $\hat{S}_{i,j}$ be the instantaneous response of variable i to shock j and $\hat{S}_{j,j}$ the instantaneous response of variable j to the structural shock j. For a given H we obtain an estimate of A_0, denoted $\hat{A}_0$, and the impact response matrix $\hat{A}_0^{-1}\hat{B}$. With the diagonal elements of $\hat{A}_0^{-1}$ normalized to 1, the off-diagonal elements can be written as:[6]

$$\hat{A}_0^{-1}(i,j) = \frac{\hat{S}_{i,j}}{\hat{S}_{j,j}}. \tag{2.3}$$

We obtain the distribution of impulse response functions (IRFs) by retaining only those models that satisfy prior constraints using the QR decomposition of Rubio-Ramírez et al. (2010), which works with the uniform Haar prior. Specifically, for each H we find the corresponding estimate of the IRFs such that $\hat{A}_0$ satisfies the restrictions on the size of spillovers. A numerical algorithm is employed to facilitate the search of models that are consistent with the constrained parameter space and data (see Appendix A).

The contemporaneous relations are constrained on a specific range, $\hat{A}_0^{-1}(i,j) \in (\underline{\hat{a}}_{i,j}, \bar{\hat{a}}_{i,j})$, and the lower and upper bounds are estimated using an event-study analysis, whose events are detailed in the next section. The event study analysis helps us estimating the range of contemporaneous spillovers from market i to market j using a simple regression, which takes the following form:

$$x_{i,d} = a_{i,j}x_{j,d} + \eta_{i,d}, \tag{2.4}$$

where $x_{i,d}$ and $x_{j,d}$ are respectively the daily changes in the yield of economies i and j on identified event dates, d. $x_{j,d}$ is the identified shock and the slope coefficients $\hat{a}_{i,j}$ are partial derivatives of the change in interest rate i due to shocks on interest rate j

[6] We normalise the effect of own shocks on yields to unity (reflected on the diagonal elements of matrix A_0^{-1}), by dividing each column vector of matrix A_0^{-1} by the respective element on the diagonal matrix B, which contains the standard deviation of the structural shocks. We restrict the elements of $\hat{A}_0^{-1}$ and not the elements of $\hat{A}_0$, because our interests lay in the overall contemporaneous spillovers from a given shock.

(i.e. spillovers), providing the mean estimates of the off-diagonal elements of the matrix $\hat{A}_0^{-1}(i,j)$. We use the estimated standard errors, $\hat{\sigma}_{a_{i,j}}$, to constrain the impact matrix such that $\hat{A}_0^{-1}(i,j) \ \in (\underline{\hat{a}}_{i,j}, \bar{\hat{a}}_{i,j})$ and we take a large confidence interval, $\underline{\hat{a}}_{i,j} = (\hat{a}_{i,j} - 4\hat{\sigma}_{a_{i,j}})$ and $\bar{\hat{a}}_{i,j} = (\hat{a}_{i,j} + 4\hat{\sigma}_{a_{i,j}})$, to reduce the probability of biased estimates of the bounds.

The identified structural shocks through the event study analysis could also be used to estimate the standard deviation of shocks, B. However, the identified events are in general larger shocks in the sample and an estimate of B based on these events could be biased upwards. Therefore we leave B unrestricted.

The sources of the shocks (i.e. country-specific supply developments or fiscal policy or conventional and unconventional monetary policies) remain unknown with our methodology. However, regardless of the economic interpretation, the identified shocks provide useful information about the country source of the risk and how it transmits across assets.

3 Events

Daily changes in asset prices embody the overall effect of shocks on that day. However, the estimation of the regression (2.4) features a reverse causality problem, if one uses the full length of the dataset. Hence, we select days in which we believe that the direction of causality is in one direction. Specifically, the events are selected on the basis of key historical developments that profoundly surprised financial markets, which can ensure the identification of the country source of the shocks. In this respect, the financial crisis is a helpful period, providing many occasions, such as market news, financial shocks and unexpected policy actions, which researchers can use to identify structural shocks.

Table 1 provides the detailed list of the selected events, pointing out the country source of the shock. We include the less controversial occurrences, although the list might not be exhaustive. For example, at the beginning of the financial crisis on 18 September 2007 the FED cut the reference rate by 50 basis points. On that day, the 2-year OIS rate declined by 16 basis points in the US, 10 basis points in the UK, 7 basis points in the euro area and it did not change in Japan. Similarly, on 11 January 2008, when Bank of America announced the purchase of Countrywide Financial for 4 billion US dollars, the 2-year OIS rates declined by 17 basis points in the US, 8 basis points in euro area, 7 basis points in the UK and 5 basis points in Japan.

Table 1: The impact of selected events on 2-year money market rates

Source	Date	Event	EA	US	UK	JP
UK	14-Sep-07	BoE grants emergency funding to Northern Rock	-2.4	0.5	**-7.1**	0.7
UK, EA	06-Nov-08	BoE and ECB interest rate cut by 150 and 50 bps, respectively	-7.5	-1.1	**-34.2**	0.3
UK	08-Jan-09	BoE interest rate cut by 50 bps	-2.8	-0.1	**-9.1**	0.8
UK	06-Aug-09	BoE extends Asset Purchase Facility (APF) programme	-1.5	-1.0	**-8.1**	0.6
UK	06-Nov-09	BoE extends APF	-3.6	-3.3	**-4.5**	-0.6
UK	24-Jun-16	BoE prepared to secure financial stability after Brexit	-5.1	-17.6	**-28.2**	-4.3
UK	30-Jun-16	Carney says that monetary policy easing is required	1.3	-3.4	**-8.8**	1.1
UK	04-Aug-16	BoE cut interest rates by 25 bps	-1.6	-3.3	**-3.6**	-0.1
UK	12-Sep-17	UK price inflation increases to 2.9% in August from 2.6% in July	1.0	1.5	**7.3**	0.3
US	25-Jun-07	Bear Stearns pledges USD 3.2 bn	-0.3	**-3.1**	-1.5	-0.7
US	18-Sep-07	FED cut interest rate by 50 bps	7.4	**-16.0**	9.8	0.0
US	11-Dec-07	FED cut interest rate by 25 bps	-4.8	**-18.4**	-4.3	-0.9
US	17-Dec-07	First Term Action Facility (TAF) auction takes place	-3.7	**-11.2**	-1.0	-1.8
US	11-Jan-08	Bank of America announces purchases of Countrywide Financial for USD 4 bn	-7.6	**-17.2**	-7.2	-5.3
US	22-Jan-08	FED cuts interest rates by 75 bps	0.8	**-26.3**	6.0	-8.3
US	30-Jan-08	FED cuts interest rates by 50 bps	-1.8	**-10.2**	-2.3	-0.9
US	14-Mar-08	FED approves purchase of Bear Stearns by JP Morgan	-2.8	**-20.1**	-8.3	0.8
US	17-Mar-08	FED creates the primary dealer credit facility	-9.0	**-17.6**	-17.2	-1.4
US	18-Mar-08	FED cuts interest rates by 75 bps	15.3	**22.0**	15.3	0.9
US	19-Mar-08	Fennie Mae and Freddie Mac capital requirements are eased	-2.7	**-6.9**	-2.2	-3.1
US	30-Apr-08	FED cuts interest rates by 25 bps	-3.3	**-9.9**	0.4	-14.0
US	15-Sep-08	Lehman bankruptcy	-23.4	**-49.8**	-35.7	-3.7
US	29-Sep-08	FED offers liquidity for Wachovia, key central banks supply US dollar liquidity	-29.1	**-36.7**	-22.8	-1.3
US	29-Oct-08	FED cut interest rates by 50 bps	-8.3	**-9.1**	-1.5	-4.1
US	25-Nov-08	FED announces the Large-Scale Asset Purchase (LSAP) programme	-5.3	**-13.8**	-11.6	-1.5

US	10-Feb-09	Geithner launches the Financial Stability Plan	3.9	**-7.7**	2.6	-0.5
US	02-Mar-09	FED and Treasury announce the joint restructuring plan for AIG	-8.1	**-8.8**	-5.7	0.5
US	18-Mar-09	FED announces to purchase USD 300 bn of Tresuries and to increase the purchase of agency debt	-12.7	**-12.0**	-16.5	0.0
US	09-Aug-11	FED forward guidance (unconditional)	1.8	**-5.9**	-0.4	0.1
US	22-May-13	FED announces tapering	0.0	**1.5**	-1.2	0.7
US	16-Dec-15	FED increases reates by 25 bps	0.6	**4.4**	-0.4	0.3
US	14-Dec-16	FED increases reates by 25 bps	-0.2	**9.0**	-1.1	0.2
UK, EA	06-Nov-08	BoE and ECB interest rate cut by 150 and 50 bps, respectively	**-7.5**	-1.1	-34.2	0.3
EA	04-Dec-08	ECB cuts interest rates by 75 bps	**11.6**	0.1	16.9	-0.5
EA	15-Jan-09	ECB cuts interest rate by 50 bps	**8.9**	1.3	2.5	-0.3
EA	02-Apr-09	ECB cuts interest rates by 25 bps	**17.4**	4.4	13.5	0.0
EA	05-May-11	ECB bails out Portugal	**-15.7**	-0.2	-1.0	0.0
EA	27-Jul-12	Draghi' "Whatever it takes" speech	**-9.7**	1.6	2.9	0.0
EA	11-Jun-14	ECB lowers rates in negative territory by 10 bps, TLTROs and ABSPP	**-2.4**	-0.6	0.6	0.0
EA	04-Sep-14	ECB committed to use additional unconventional instruments	**-6.0**	1.7	-0.2	0.0
EA	22-Jan-15	ECB announces expanded asset purchase programme (APP)	**-0.5**	-0.1	0.6	0.1
EA	10-Mar-16	Draghi indicates no need to reduce rates	**5.7**	5.2	2.8	2.2
EA	27-Jun-17	Draghi's speech in Sintra	**3.6**	2.5	1.9	0.1
JP	19-Dec-08	BoJ announces the increase of government bonds' purchases	3.5	-0.7	22.0	**-2.7**
JP	04-Apr-13	BoJ announces quantitative and qualitative monetary easing (QQE)	-1.6	-0.3	0.3	**0.6**
JP	31-Oct-14	BoJ announces the expansion of QQE programme and the purchase of ETFs	-0.9	2.2	2.9	**0.0**
JP	29-Jan-16	BoJ announces the introduction of negative interest rates	-3.4	-4.3	-8.1	**-9.6**
JP	29-Jul-16	BoJ announces an expansion of monetary policy considered modest by the markets	-0.1	-3.8	-0.4	**10.0**
JP	21-Sep-16	BoJ targets the yield curve	0.3	0.1	0.8	**2.4**

Source: Bloomberg and Thomson Reuters. Note: This table shows the daily change in the 2-year OIS rates in the euro area (EA), Japan (JP), the United Kingdom (UK) ad the United States (US). FED stands for Federal Reserve, ECB for European Central Bank, BoE for Bank of England and BoJ for Bank of Japan

On 24 June 2016, the statement from the Governor of Bank of England following the EU referendum result in favour of Brexit indicated that Bank of England would not hesitate to take additional measures to protect the UK economy moving forward. On that day, the 2-year OIS rate declined by 28 basis points in the UK, 18 basis points in the US, 5 basis points in the euro area and 4 basis points in Japan.

During the banking collapse and the expected global economic meltdown, the ECB cut its reference rates on 4 December 2008, 15 January 2009 and 2 April 2009. However, these decisions disappointed the markets as the 2-year OIS rates increased on average by 13 basis points in the euro area, 2 basis points in the US, 11 basis points in the UK with no impact in Japan. Or on 27 July 2012, after the ECB Governor gave the "whatever it takes" speech to rescue the euro project, the 2-year OIS rate declined by 10 basis points in the euro area and marginally increased or did no change in the other economies.

In most of the events under analysis, the effect is stronger for the UK, the US and the euro area. Instead, the impact of monetary policy announcements in Japan sometimes did not translate in sharp changes in neither the 2-year money market rate nor the 2-year sovereign yield.

Estimated coefficients and relative standard errors of the regression (2.4) are reported in Table 2.

Table 2: Spillovers at impact ($\hat{A}_0^{-1}(i,j)$) - Event study analysis for 2-year OIS rates

to/from	US	EA	UK	JP
US	1	0.116	0.257	0.026
		(0.069)	*(0.098)*	*(0.193)*
EA	0.431	1	0.204	0.108
	(0.069)		*(0.033)*	*(0.156)*
UK	0.488	0.719	1	0.084
	(0.085)	*(0.338)*		*(0.735)*
JP	0.108	0.003	0.039	1
	(0.039)	*(0.023)*	*(0.031)*	

Note: This table shows the estimated OLS coefficients and Newey-West (HAC) standard errors of the following equation $x_{i,d} = a_{i,j}x_{j,d} + \eta_i, d$, where $x_{i,d}$ and $x_{j,d}$ are respectively the daily changes in the 2-year OIS rate of economies i and j on identified event dates, d, in economy j, as reported in Table 1.

About half of the size of the shock from US spilled to Europe and only one tenth to Japan. The instantaneous spillover from the euro area to the UK is 0.72, while only one fifth of the shock from the UK spilled to the euro area. The spillover to the US is larger from the UK (0.26) than from the euro area (0.12). The spillovers to and from Japan are not statistically significant, except for the spillover from the US. Therefore, to address the Japanese case, we assume the more agnostic absolute magnitude restrictions as in De Santis and Zimic (2018) with bounds ranging between -1 and +1 for the instantaneous spillover from and to Japan. As a robustness check, we take into consideration the estimated spillover from the US, which is statistically significant.

4 Data and specification of the SVAR

An interest rate closely linked to the monetary policy rate is the uncollateralised overnight call rate; that is, the interbank interest charged by banks providing a loan with a short maturity, usually a maturity of 1 day (overnight). This base rate, which is steered by the central bank rate by calibrating the amount of liquidity to eligible commercial banks or other depository institutions, corresponds to the EONIA in the case of the euro area, the MUTAN in the case of Japan, the SONIA in the case of the UK and the effective FED fund rate in the case of the US. This interest rate has a major impact on the interest which banks charge on commercial products, such as loans and mortgages, or pay on products such as savings. Moreover, the entire term structure of OIS rates exists.

Developments in the uncollateralised overnight call rates and their respective 2-year OIS rates are plotted in Figure 1. They move in tandem. The policy rates and the overnight interbank rates declined sharply since end-2008 reaching values close to zero in the US and UK. Since then, the respective central banks communicated their desire to keep the financing conditions low for a prolonged period of time through forward guidance and the purchases of assets, such as government bonds. Therefore, the policy-maker targeted the risk-free rates at longer maturity more than in the past in normal circumstances. The euro area policy rates reached values close to zero in 2012 and turned negative in 2014. Japanese policy rates reached zero already in the first half of 2000. The MUTAN rose in 2006, but it returned back to zero with the global financial crisis in 2009 and in negative territory in 2016.

The uncollateralised overnight call rates and the corresponding 2-year OIS rates present important diverging developments in all considered economies during the low interest rate period. For example, the US 2-year OIS rate started to rise again since May 2013 after the taper tantrum and its trend increased further in the autumn of 2016 after the promises of the newly elected president Trump to expand government expenditures. Instead, the 2-year OIS rate of Japan declined in negative territory after the Bank of Japan announced the introduction of negative interest rates in January 2016 more than the MUTAN.

At the same time, it is useful to point out the high degree of comovement between the 2-year OIS rates with relationships that might have changed over time, against the background that the volatility of the money market rates declined sharply, after markets reached the lower bound or entered in negative territory (see Figure 2). Given that the relationships among variables and the size of the shocks change over time, we estimate the VAR using a two-year rolling window (500 business days) over the sample period 2 January 2003 - 4 December 2017. The estimation procedure is computationally intensive. Therefore, each window rolls with a 50 day step. All in all, we estimate 69 rolling windows. The VAR is estimated in levels with a constant and its lag length for each rolling window is selected using the Bayesian Information Criterion (BIC). To control for global factors affecting money market rates, we include exogenously the growth rate in oil prices in US dollar and the change in macro news of the G10 economies (i.e. VARX).[7] Appendix A describes the numerical algorithm employed to facilitate the search of IRFs that are consistent with the constrained parameter space and data.

[Insert Figures 1-2, here]

As a robustness check, we also investigate the role of foreign spillovers in the 2-year sovereign yield segment using the German Bund as a reference rate for the euro area.

The 2-year OIS rates are provided by Thomson Reuters for the euro area, the UK and the US and by Bloomberg for Japan. The 2-year sovereign yields and oil prices are provided by Thomson Reuters and the macro news of the G10 economies are made available by Citibank through Thomson Reuters.

5 Results

The key empirical results are summarized by the standard deviation of the shocks in Section 5.1, the IRFs in Section 5.2 and the variance decomposition of the shocks in Section 5.3. We zoom in some of the findings carrying out an historical decomposition of shocks in Section 5.4. We also compare the key results with those obtained using absolute

[7]Over the sample period, the G10 macroeconomic news is highly contemporaneously correlated with the economy-specific macro news for the US (75%), the euro area (74%), the UK (45%) and Japan (29%). Similar results are obtained if the correlations are computed over the last two years of the sample since the beginning of 2016: US (88%), the euro area (82%), the UK (64%) and Japan (33%). Therefore, it is appropriate to use this variable to control for global factors. Macro news is rather persistent. Given that they are included as exogenous regressors, we use them in first difference.

magnitude restrictions ranging between -1 and 1 (see Section 5.5) or generalised impulse response functions (GIRFs) (see Section 5.6). We carry out a number of robustness checks (see Section 6), particularly we apply the same method to the 2-year sovereign yield segment (see Section 6.1).

Before describing the results, it is useful to assess whether the chosen events referring to asset i in Table 1 match with the estimated structural shocks originated from asset i. Figure 3 shows a tight relationship with a slope coefficient equal to 0.94.

[Insert Figure 3, here]

5.1 Standard deviation of shocks

We can assess the developments of the estimated standard deviation of the shocks to money market rates in Figure 4. They increased globally after the FED interest rate cut in September 2007 following the interbank credit crisis and reached the peak after Lehman's bankruptcy in September 2008. The standard deviation of shocks started to decline in Japan and the US in 2009 and in the UK and the euro area in 2010. The standard deviation of shocks in the euro area increased again during the intensification of the euro area sovereign debt crisis in 2011, but begun a steady decline after Draghi's "whatever it takes" speech in July 2012.

After the sharp fall from 2009, the standard deviation of shocks in the US reverted with the FED tapering announcement on 22 May 2013, while shocks in Japan started to increase with the introduction of the negative interest rates in January 2016. On the contrary, with the introduction of the negative interest rates in the euro area in June 2014, shocks in the euro area continued to decline until 2016 when they stabilised. Shocks in the UK resemble developments in the US, except the flatter path in 2016 possibly associated with the uncertainty from Brexit.

[Insert Figure 4, here]

5.2 Impulse responses

The transmission of the shocks can be summarized with the help of IRFs. Given that we consider 4 markets and 69 500-day rolling windows, presenting and discussing all IRFs is impractical. Here, we present a sub-set.

First, we show the IRFs estimated before the financial crisis over the period 31 July 2003 - 29 June 2005 (see Figure 5). The shocks generated in the US and the UK were strongly statistically significant, positive and persistent vis-à-vis all economies. Instead, the shocks from the euro area, while having a positive impact in the UK and Japan, affected negatively US rates, pointing to a portfolio reallocation in this specified period. Conversely, foreign economies seemed to be insulated from shocks generated in Japan. These findings support the overall view that US and European rates were the driving forces of monetary market rates before the financial crisis. All the results at impact are consistently in line with the event-study findings discussed in Table 2. However, it is important to highlight that the positive contemporaneous spillovers from the euro area to the US suggested by the event-study analysis are estimated with the SVAR to be statistically insignificant before the global financial crisis.

[Insert Figures 5, here]

Second, we show the IRFs estimated during the global financial crisis over the period 18 October 2007 - 16 September 2009 (see Figure 6). Also in this period, the US and the UK generated positive, persistent and significant spillovers vis-à-vis all other economies, while the spillovers from Japan continued to be statistically insignificant. Instead, the shocks from the euro area, while having a positive impact in the UK and Japan, did not have a significant effect on US rates. This might suggest that in this period the US and UK were the main driving forces behind developments in shorter-term money market rates worldwide due to the nature of the banking crisis.

[Insert Figures 6, here]

Third, we show the IRFs estimated during the hikes of the euro area sovereign debt crisis over the sample period 11 November 2010 - 10 October 2012 (see Figure 7). The shocks generated in the US and the UK continued to be strongly statistically significant, positive and persistent vis-à-vis all economies; while the shocks from the euro area had only a positive impact on the UK possibly due to the regional nature of the sovereign debt crisis. In this period, also shocks from Japan affected all economies.

[Insert Figures 7, here]

Finally, we show the IRFs estimated over the period 11 September 2014 - 10 August 2016, during the adoption of asset purchase programs by the ECB and the introduction of negative rates in the euro area and Japan (see Figure 8). The spillovers from the US continued to be positive, persistent and statistically significant vis-à-vis all economies, while the shocks from the UK were positive and statistically significant vis-à-vis the euro area and somewhat vis-à-vis the US. The spillovers from the euro area were negative versus the US and positive, persistent and statistically significant versus the UK and Japan, while the shocks from Japan were not statistically significant. It is very interesting to point out that the spillovers to the euro area from all other economies were much more muted: at impact, 0.15 from the US and 0.09 from the UK, compared to 0.4-0.5 from the US and 0.2 from the UK in the course of previous periods. This suggests that the ECB' more aggressive unconventional monetary policies helped the domestic financing conditions to be less dependent from foreign shocks.

[Insert Figures 8, here]

In summary, the US and the UK shocks have a positive and persistent impact in all economies, while shocks from Japan are the least important outside Japan. Shocks from the euro area also spill to other economies, but the impact on US rates are sometime negative, possibly due a portfolio reallocation motive.

5.3 Relative importance of foreign shocks

Are the identified IRFs economically relevant? The overall impact on variables depends on the size of the shocks as well as the dynamics of the transmission mechanism. The variance decomposition of the shocks is a useful tool, which combines these two features of SVAR analysis. Figure 9 shows the relative importance of foreign shocks from market j to market i in the dynamics of the money market rates and, on the diagonal, the relative importance of the own shock. The predictive horizon is set at $h = 12$ days to capture a medium-run horizon. The predictive horizon one quarter ahead (i.e. $h = 65$) is provided as a robustness check.

The own shock shows very important differences across economies. The US money market rates are mainly driven by domestic shocks, as the own shock explained more than 80% of the variance of the US rates.

The own shock plays a major role in explaining the dynamics of money market rates in all other economies, but its importance changed over time declining during the global financial crisis in 2008 and 2009 and increasing in Europe during the euro area sovereign debt crisis.

In the euro area, the own shock explained only 60% of the variance of the euro area rate before the financial crisis, which implies that the euro area 2-year OIS rate was highly exposed to foreign macroeconomic developments. The euro area shocks explained only 40% of the variance of the euro area asset after Lehman. The contribution of the domestic shocks reverted back to 60% in 2010 and rose further to 80-90% in the hikes of the sovereign debt crisis in 2011 and 2012 and subsequent upturns in 2013, when forward guidance was formally introduced, followed by the introduction of more aggressive unconventional monetary policies in 2014-2015, such as negative monetary policy rates and asset purchases of government bonds, as a response by the central bank to low inflation and output below potential in the euro area.[8] The role of the US as a source of spillover for the euro area has again been steadily increasing since the first hike in US policy rates in December 2015. Particularly in 2017, the contribution of the US shocks to euro area rates reached 25%, levels similar to those recorded before the financial crisis.

In the UK, the own shock explained 70% of the variance of the UK rates before the financial crisis. The domestic contribution declined to 45% in the second half of 2007 and 2008 given the role played by the inter-bank credit crisis in the US during this period. The contribution of the domestic shocks in the UK rose after the introduction of quantitative easing in March 2009 and declined again with the outbreak of the euro area sovereign debt crisis in 2011. The role of the domestic shock in the UK rose above 70% after the FED communication of the unconditional forward guidance in August 2011, followed by the normalization in the financial markets after the "whatever it takes" speech in July 2012 and then it continued to increase steadily until 2015. Subsequently, shocks from the US possibly associated with the improved macroeconomic outlook had a slightly larger impact on money market rates also in the UK.

In Japan, the own shocks explained about 90% of the variance of the Japanese medium-term money market rates before the financial crisis. The contribution of the domestic shocks declined sharply to 45% after Lehman, mostly due to developments in US rates, but then it rose steadily reaching again 90% in 2012. The role of the domestic shocks declined sharply in 2016 and 2017, as the FED started to raise their reference rates with the improvement of the macroeconomic outlook. The contribution of foreign shocks to Japanese rates is in some periods rather forceful.

All in all, medium-term interest rates in the euro area, Japan, UK and US are affected by domestic and foreign shocks. The US is less exposed to foreign shocks and is the main

[8]In general, as monetary policy rates approach zero, central banks carry out further loosening by providing forward guidance about the expected future path of interest rates and by lowering term premia through large-scale asset purchase programmes.

source of spillovers globally, while Japan is the market with the least influence abroad. As for Europe, euro area money market rates were mostly driven by domestic shocks only during the intensification of the euro area sovereign debt crisis and after the ECB started more aggressive monetary policies, while UK interest rates were mostly driven by domestic shocks after the FED communication of the unconditional forward guidance in August 2011, which reduced and stabilised the US shocks. The contribution of domestic shocks to Japanese rates is more volatile, suggesting that foreign economic developments can have a large influence on Japanese financing conditions.

[Insert Figure 9, here]

5.4 Historical decomposition of the shocks

The variance decomposition of shocks provides the average contribution of each shock on the dynamics of the endogenous variable of interest over the sample period under consideration. A complementary approach to appreciate the results and the identification method is to look at the historical decomposition of the shocks. Due to space constraint, we focus only on the last window covering the 2016-2017 period, which is characterized by a relatively large number of recognizable country-specific shocks that can be placed under a magnifying glass: the Bank of Japan's announcements of negative interest rates on 29 January 2016 followed by an additional stimulus on 29 July 2016, the EU referendum in the UK (i.e. Brexit) on 23 June 2016, the election of Trump as US president on 8 November 2016, the political risk from the French elections held on 23 April and 7 May 2017, the Sintra speech by the ECB president Draghi on 27 June 2017, and the unexpected sharp rise in the UK's inflation rate to 2.9% in August 2017 announced by the British Office for National Statistics on 12 September ahead of Bank of England policy meeting.[9] First of all, Figure 10-13 show that domestic shocks and US shocks play a key role in explaining developments in money market rates, corroborating the key results of the paper that 2-year money market rates are by and large affected by domestic shocks, and the US is a key source of spillover globally.

[Insert Figures 10-13, here]

As for the country-specific shocks, the impact of the US Presidential elections is evident in November 2016. OIS rates in the US surged to their highest levels in months

[9]The historical decomposition of shocks is carried out only using estimates based on one rolling window. We have compared the results estimated with overlapping windows and the main findings are corroborated.

in anticipation of a fiscal stimulus: by the end of 2016, due to US shocks the 2-year OIS rates increased by about 30 basis points in the US (75% of the overall 40 basis point increase), 10 basis points in the UK (38% of the overall 28 basis point increase), and 5 basis points in the euro area and Japan, partly counteracting the decline in the OIS rates recorded by these two economies over this period. It is worth mentioning that Trumps's election is not part of the event studies used to restrain the parameter estimates of the impact matrix characterising the VAR. Yet, we can track the dynamic developments after the elections.

Immediately after the results of the EU referendum in June 2016 in favour of Brexit, Bank of England loosened its monetary policy stance. The increasingly uncertain economic outlook and the expansionary monetary policy by Bank of England led to a fall in the 2-year OIS rates due to the UK shocks within one week by about 35 basis points in the UK (90% of the overall 40 basis point decline), 10 basis points in the US (50% of the overall 20 basis point increase), 3 basis points in the euro area and Japan. Similarly, the unexpected sharp rise in the UK's inflation rate announced in September 2017 within ten days led to a 21 basis point rise in the UK 2-year OIS rates (82% of the overall 25 basis point increase) with negligible spillover effects to other economies.

The speech by Draghi in Sintra (Portugal) in June 2017, which was interpreted by the markets as indicative of the ECB monetary policy becoming less accommodative in 2018, let to a rise in the 2-year OIS rates due to euro area shocks by about 5 basis points in the euro area, 2 basis points in the UK, and no impact in Japan and the US. In the course of 2017, the euro area 2-year OIS rate fluctuated quite substantially mostly due to euro area-specific shocks, possibly reflecting improved economic growth prospects, receding fears of deflation and the resulting ECB monetary policy implications. Also the political risk from the French elections played an important role in the spring of 2017. One of the key contestants was the National Front, whose campaign centred on the national interests of France and, most importantly the exit from the euro area. After both rounds of the French presidential elections, the euro area interest rates declined pointing out that investors were pricing a political risk, which was posing a threat to the future of the euro and did not materialize. This risk remained regional, as it did not affect the monetary market rates in other economies.

Finally, the Bank of Japan's announcements of negative interest rates on 29 January 2016 caused a decline in the Japanese 2-year OIS rate by about 15 basis points within two days entirely due to such shock and the subsequent announcement of the additional stimulus on 29 July 2016 raised it by a similar magnitude, because the policy was considered modest by the markets. The spillover of both Japanese shocks on the other economies was contained, corroborating the results of the event-study analysis.

In summary, the event-study magnitude restriction method is able to capture specific events, which are uncontroversial.

5.5 Event-study versus absolute magnitude restrictions

In most of the events under analysis described in Table 1, the instantaneous response of the interest rate on the market where the event occurred was larger in absolute term than the response of all other money-market rates. Therefore, a more agnostic magnitude restriction identification, where we assume that at impact the spillovers to other assets are smaller in absolute value than the direct effect on the asset where the shock is originated, is imposed: $\hat{A}_0^{-1}(i,j) \in (-1,1)$.

The comparisons of the variance decomposition of the shocks between the results obtained with the event-study magnitude restriction method and the magnitude restriction below unity in absolute value (see the red lines in the Figure 14) indicate that the median value is somewhat similar with some mild exception for the US shocks on the own rate, while the error bands are far narrower under the event-study magnitude restriction, except for shocks originated in Japan where however no additional information is provided and, therefore, results are consistent.

Not only the error bands are narrower under the event-study magnitude restriction, but also the IRFs vis-à-vis Japan (here not reported) are more precise. This implies that the event-study magnitude restriction identification sharpens the inference of SVAR analysis relative to the more agnostic absolute magnitude restriction identification scheme.

[Insert Figure 14, here]

5.6 Event-study magnitude restrictions versus GIRFs

Following the suggestion of Diebold and Yilmaz (2014), often practitioners use GIRFs to assess the source of spillovers. However, this is imprecise because GIRFs cannot address causality. They can only provide the contemporaneous correlations between asset prices.

The comparisons of the variance decomposition of the shocks between the results obtained with the event-study magnitude restrictions and those obtained with GIRFs (see the red lines in the Figure 15) suggest significant differences particularly for the US. According to GIRFs, the shock contribution from the euro area to the US was four times as larger before the financial crisis and it rose with the deepening of the interbank credit crisis explaining one quarter of the dynamics of the US 2-year OIS rate in 2007 and 2008. If we add the shock contribution from the UK, which is also larger under GIRFs, about 40-50% of the dynamics of the US 2-year OIS rate is explained by shocks originated in Europe. We think that these findings are not in line with common wisdom.

[Insert Figure 15, here]

6 Robustness checks

6.1 Importance of foreign shocks in the sovereign yield segment

An alternative risk-free rate is the sovereign yield. Therefore, we substitute the 2-year OIS rates with the 2-year sovereign yields and use the German Bund (DE) as a measure of risk free rate for the euro area. All other characteristics of the model remain invariant.

First, we estimate the matrix of the contemporaneous spillovers using the events described in Table 1 applied to the 2-year sovereign yield segment. The results are somewhat similar to those obtained for the OIS rates (see Table 3).

Table 3: Spillovers at impact ($\hat{A}_0^{-1}(i,j)$) - Event study analysis for 2-year sovereign yields

to/from	US	DE	UK	JP
US	1	0.320	0.100	-0.044
		(0.138)	*(0.083)*	*(0.293)*
EA	0.323	1	0.083	0.233
	(0.070)		*(0.051)*	*(0.346)*
UK	0.295	0.942	1	0.457
	(0.074)	*(0.301)*		*(0.224)*
JP	0.024	0.008	0.045	1
	(0.027)	*(0.042)*	*(0.021)*	

Note: This table shows the estimated OLS coefficients and Newey-West (HAC) standard errors of the following equation $x_{i,d} = a_{i,j}x_{j,d} + \eta_i, d$, where $x_{i,d}$ and $x_{j,d}$ are respectively the daily changes in the 2-year sovereign yield of economies i and j on identified event dates, d, in economy j, as reported in Table 1.

Figure 16 shows the relative importance of shocks in the dynamics of the 2-year sovereign yields from market j to market i. The predictive horizon remains set at $h = 12$ days. The domestic shock, shown on the diagonal, plays a major role in explaining the dynamics of the medium-term sovereign yields in all economies, but its importance has been fluctuating over time around 80% for the US, 70% for Germany and the UK and has been more volatile for Japan. As for Germany, the domestic shock played the most important role during the euro area sovereign debt crisis, when its contribution in the developments of the German Bund was about 80%. The domestic shocks in the UK move in tandem with the domestic shock in Germany. All in all, the comparison over time with the results obtained with the 2-year OIS rates shows qualitative similar conclusions.[10]

[Insert Figure 16, here]

Hence, the key results of the paper are confirmed: (i) medium-term interest rates are by and large affected by domestic shocks, but their contributions change over time, (ii) foreign shocks are important in determining the medium-term interest rates, (iii) the US is well insulated from foreign shocks and is the main source of spillover globally during the global financial crisis, (iv) the role of domestic shocks becomes more prevalent in Europe during the euro area sovereign debt crisis and with the introduction of more aggressive unconventional monetary policies.

6.2 Importance of domestic shocks in the euro area

Foreign shocks play an important role in the dynamics of the euro area risk free rate. We investigate further this matter by controlling for monetary policy shocks in the euro area using the traditional approach in the literature. Specifically, we include in the SVAR the euro area 1-month OIS rate and impose a Cholesky ordering or zero restrictions: 1-month OIS rate shocks affect contemporaneously all the 2-year rates, while shocks to the 2-year OIS rates, identified using the event-study magnitude restrictions, do not affect contemporaneously the euro area 1-month OIS rate. The results for the euro area 2-year OIS rate indicate that the contribution of the domestic shocks, which is now the sum of the contributions of both shocks on the euro area 1-month and 2-year OIS rates, is very similar to the results obtained if the euro area 1-month OIS rate is not included in the model specification (see Figure 17).

[Insert Figure 17, here]

[10]The contribution of UK shocks to the Japanese yield increased sharply in 2012. This is due to the fact that the 2-year Gilt declined faster than the Bund during the hikes of the sovereign debt crisis. It should also be noted that the 2-year Japanese yield was stable at around 10 basis points for most of 2012 and 2013. Therefore, the absolute contribution of the UK shocks to the 2-year Japanese yield is very marginal in basis points.

6.3 Importance of domestic and foreign shocks in the long-run

The analysis in the previous sections was carried out using a predictive horizon equal to 12 business days to capture a medium-run horizon. Figure 18 shows the main results if the predictive horizon is set at 3-month (i.e. $h = 65$ days) in order to capture a long-run horizon. The results indicate that foreign spillovers are more important also for the US, particularly if the source of the shocks is Europe. Overall, however, the results remain robust, with the US being relatively less affected by other countries and being the main source of shocks globally. It is also interesting that the shock contribution among European countries almost double relative to the medium-run baseline, with shocks from the euro area contributing to 30-40% of the variance of UK OIS rates before the interbank credit crisis in 2007. Similarly, shocks from the UK contributed to 40% of the variance of euro area OIS rates after Lehman's collapse.

[Insert Figure 18, here]

6.4 Other

Given that the spillovers from Japan to the other economies and from Europe to Japan estimated using the event study are not statistically significant, we take into consideration the estimated spillover from the US only. The results are broadly invariant.[11]

7 Conclusion

Financial spillovers are an important topic in the macro-finance literature, because foreign-induced changes in interest rates can cause financial stability concerns, create tensions in sovereign debt markets and, more generally, bring about a change in economic growth through variations in the real interest rate. Moreover, since monetary policy rates reached the lower bound, central banks monitor closely the medium-term segment of the yield curve also to assess the success of the forward guidance communication. Therefore, understanding the role of foreign spillovers in the dynamics of the medium-term money markets rates is a relevant issue from a policy perspective.

However, the identification of the source of shocks is a challenge, because asset prices move simultaneously. We suggest a new method, which identifies structural shocks imposing lower and upper bounds on the contemporaneous impact of the shocks in different

[11] All the figures not reported in the paper are available upon request.

asset markets, guided by an event-study analysis. Relative to the existing literature, our approach combines the appeal of the event-study analysis with the advantages of SVARs, whose structural parameters are identified using magnitude restrictions.

We apply the method to study the importance of foreign shocks in the dynamics of 2-year money market rates of the euro area, Japan, the UK and the US, economies characterised by large capital flows and freely floating exchange rates.

We find that domestic shocks play a predominant role in explaining the dynamics of 2-year money market rates, but they are time-varying. Except for the US, the domestic money market rates are highly affected by foreign spillovers and this can pose a challenge to the success of the forward guidance. Specifically, we find that the US is less exposed to foreign shocks and is the main source of spillover globally, as US shocks have a positive and persistent impact in all economies, which is economically significant, while the foreign spillovers from Japan are very much limited. Euro area medium-term interest rates were mostly affected by domestic shocks during the euro area sovereign debt crisis and after the ECB introduced more aggressive monetary policy actions, such as asset purchases and forward guidance, thereby successfully steering the domestic rates. The contribution of domestic shocks in the UK played a more important role after the FED unconditional forward guidance in 2011, which contained the shocks from the US, and then moved in tandem with the developments in the euro area.

All in all, relative to other methods, the identification supported by the event studies is highly informative, as it sharpens the inference and reduces markedly the uncertainty around the median estimate.

The suggested method can identify the country source of the risk, but it cannot quantify the implications of monetary policies across economic areas. International monetary policy spillovers have been the subject of an important debate since Keynes, which turned in the 1960s in the Mundell-Fleming model. These spillovers are very important particularly when monetary policy rate differentials widen among economic areas. However, this requires a consistent joint combination of magnitude and sign restrictions, which we leave for future research.

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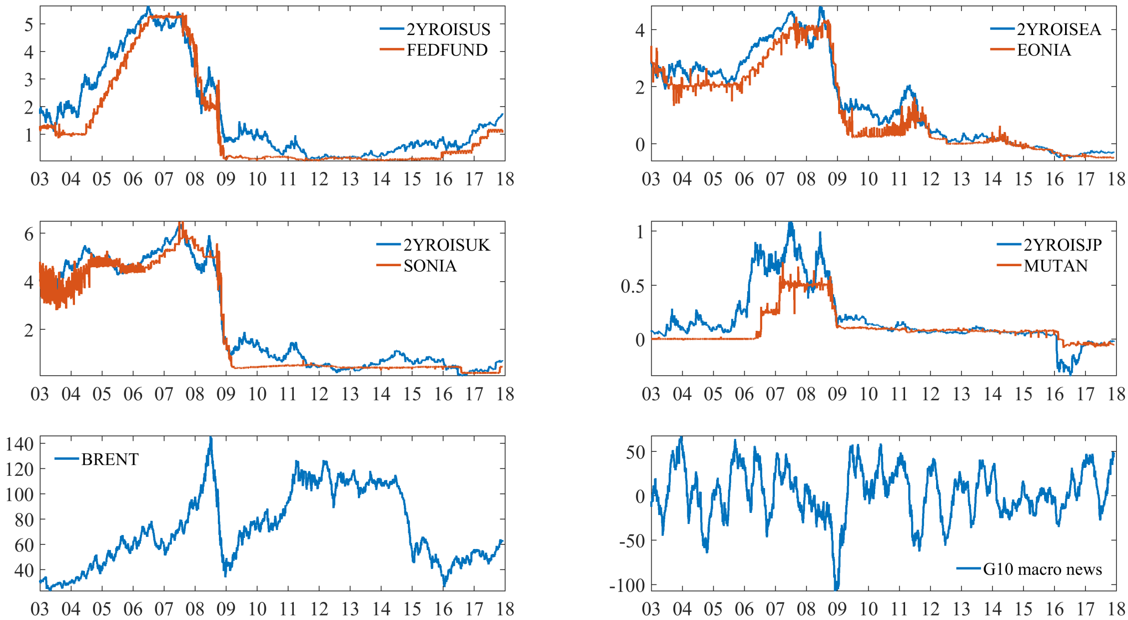
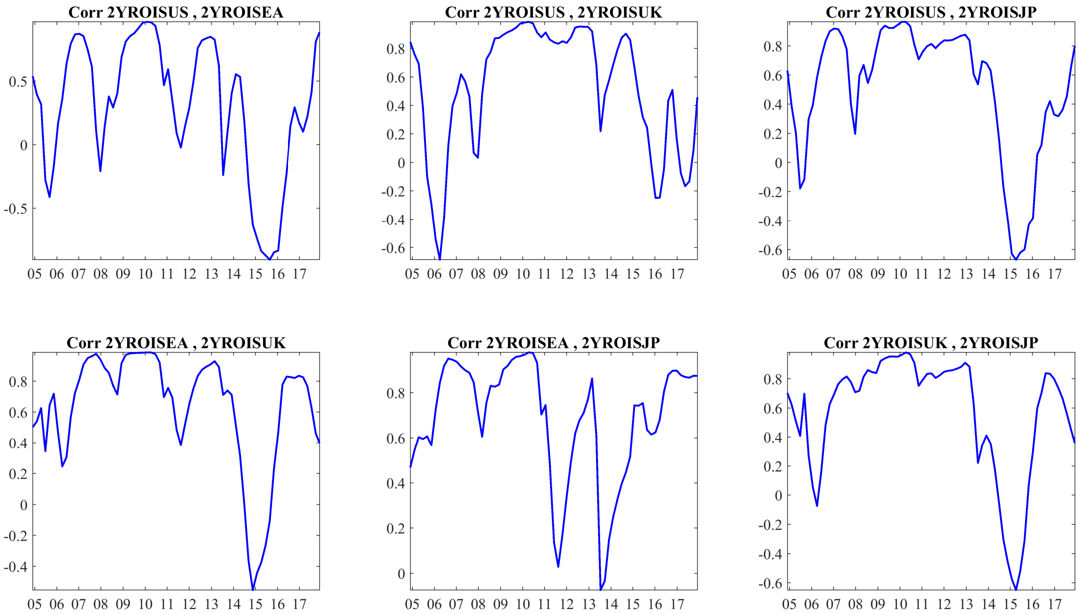
Figure 1: Money market rates, oil prices and macro news



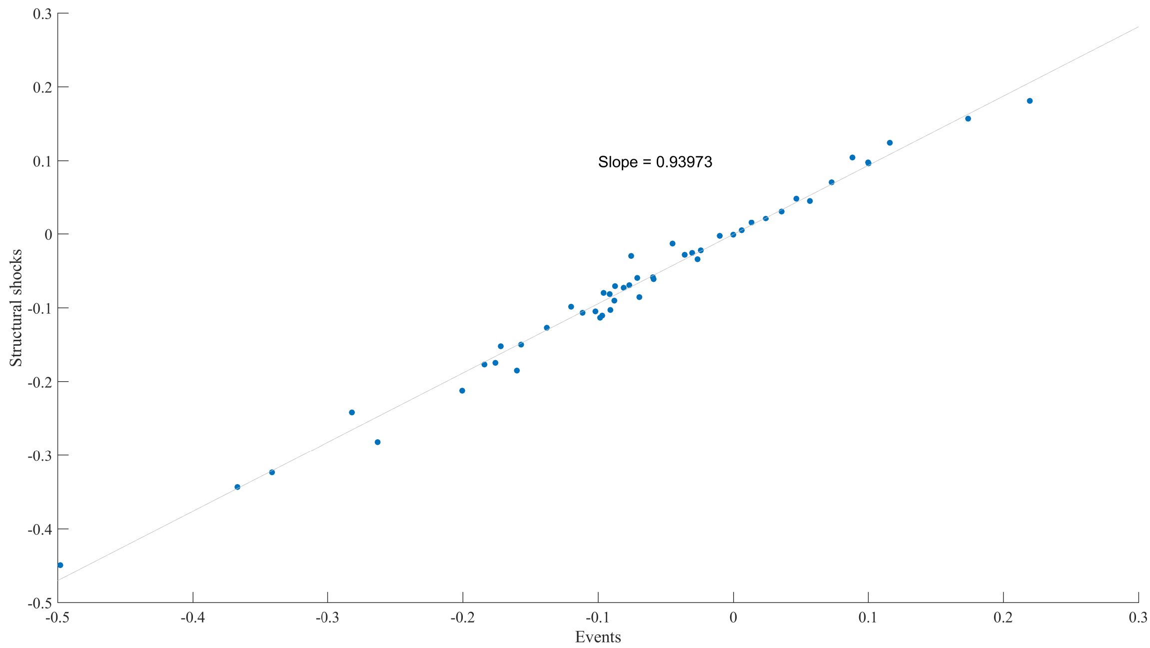
Source: Bloomberg and Thomson Reuters.
Note: This figure shows the unsecured overnight lending in the euro area (EONIA), Japan (MUTAN), the United Kingdom (SONIA) and the United States (Fed Fund rate) together with the respective 2-year OIS rates; the Brent crude oil price per barrel in US dollar and the macro news of the G10 economies.

Figure 2: Dynamic correlations between 2-year OIS rates



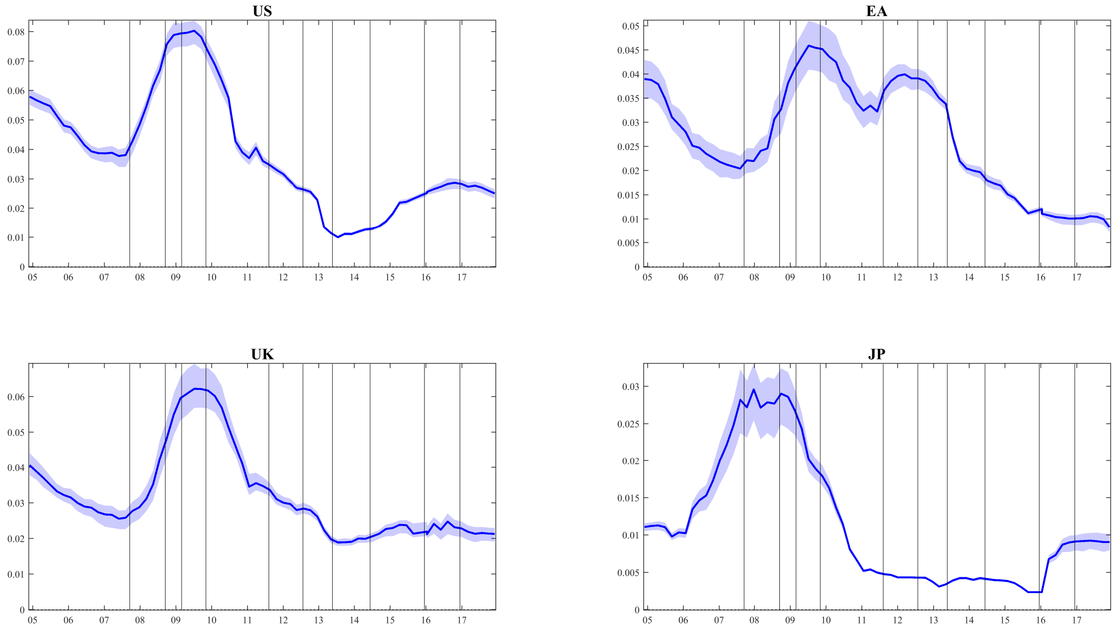
Source: Bloomberg and Thomson Reuters.
Note: This figure shows the unconditional correlations between 2-year OIS rates using a 500 business days rolling window.

Figure 3: Strctural shocks to the 2-year OIS rates and corresponding events



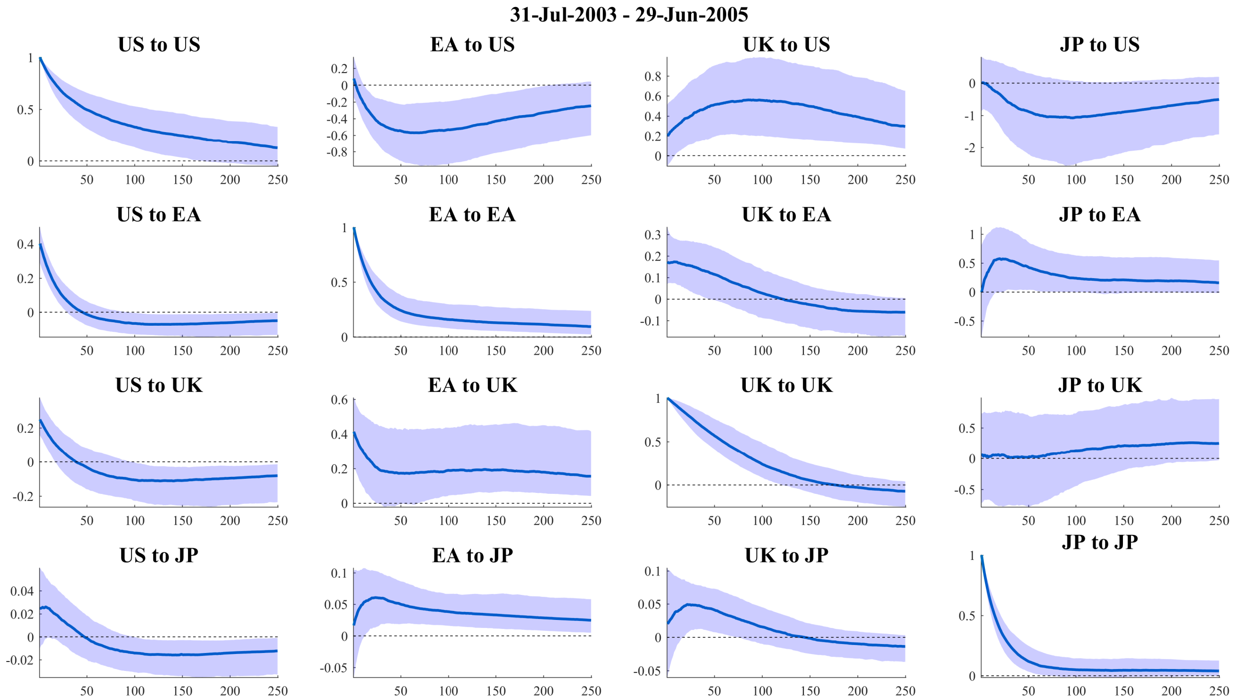
Note: This figure shows the estimated 2-year OIS structural shocks (vertical line) against the changes in 2-year OIS rates (horizhontal axis) for all economies during the events described in Table 1.

Figure 4: Standard deviation of the shocks to the 2-year OIS rates



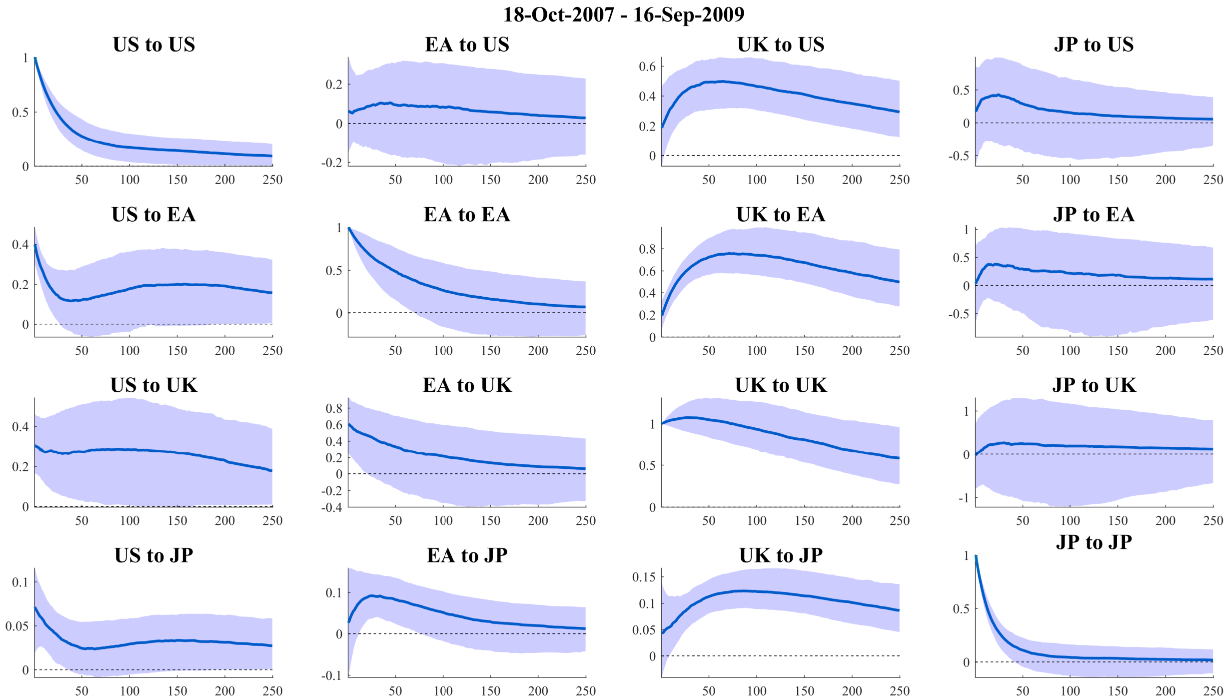
Note: This figure shows the estimated standard deviation of 2-year OIS shocks. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The vertical bars denote 18 September 2007 (FED interest rate cut following the interbank credit crisis), 15 September 2008 (Lehman's bankruptcy), 2 March 2009 (FED and US Treasury announce the joint restructuring plan for AIG), 5 November 2009 (the Greek revised budget deficit), 9 August 2011 (FED unconditional forward guidance), 27 July 2012 (Draghi's speech), 22 May 2013 (FED tapering announcement), 11 June 2014 (ECB lowers rates in negative territory , TLTROs and ABSPP), 16 December 2015 (FED increases rates), 14 December 2016 (FED increases rates). Sample period: 2 January 2003 - 4 December 2017.

Figure 5: IRFs during the pre-financial crisis period



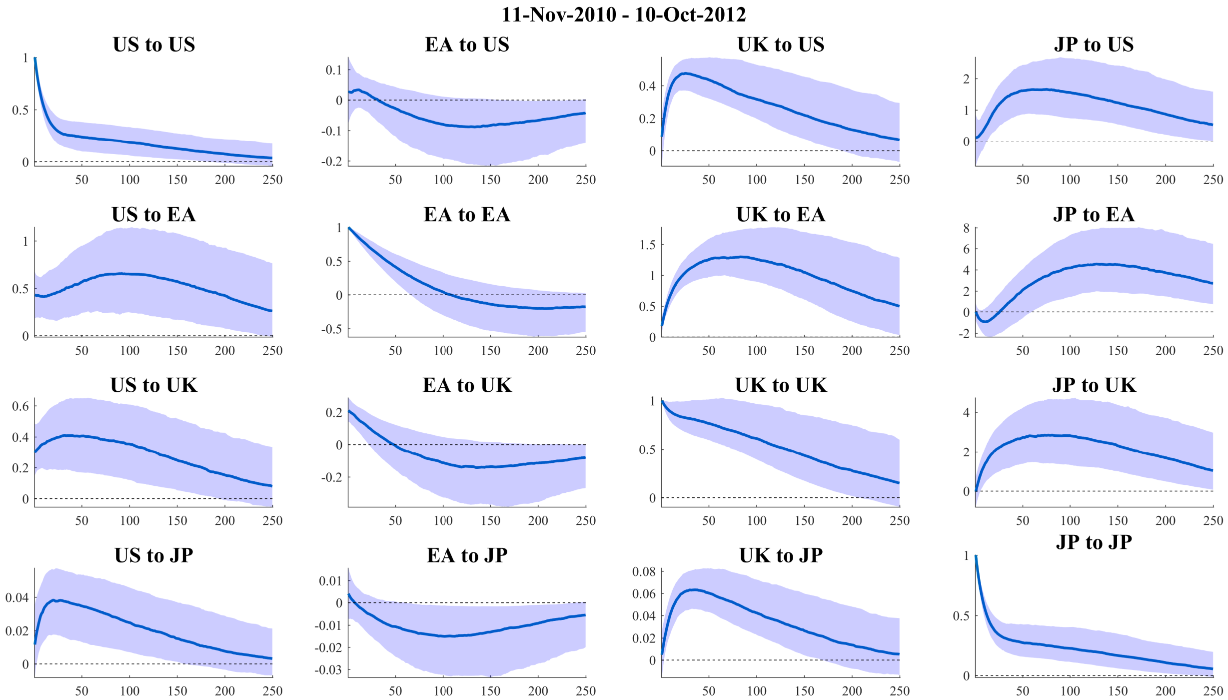
Note: This figure shows the IRFs due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 31 July 2003 - 29 June 2005. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method.

Figure 6: IRFs during the global financial crisis



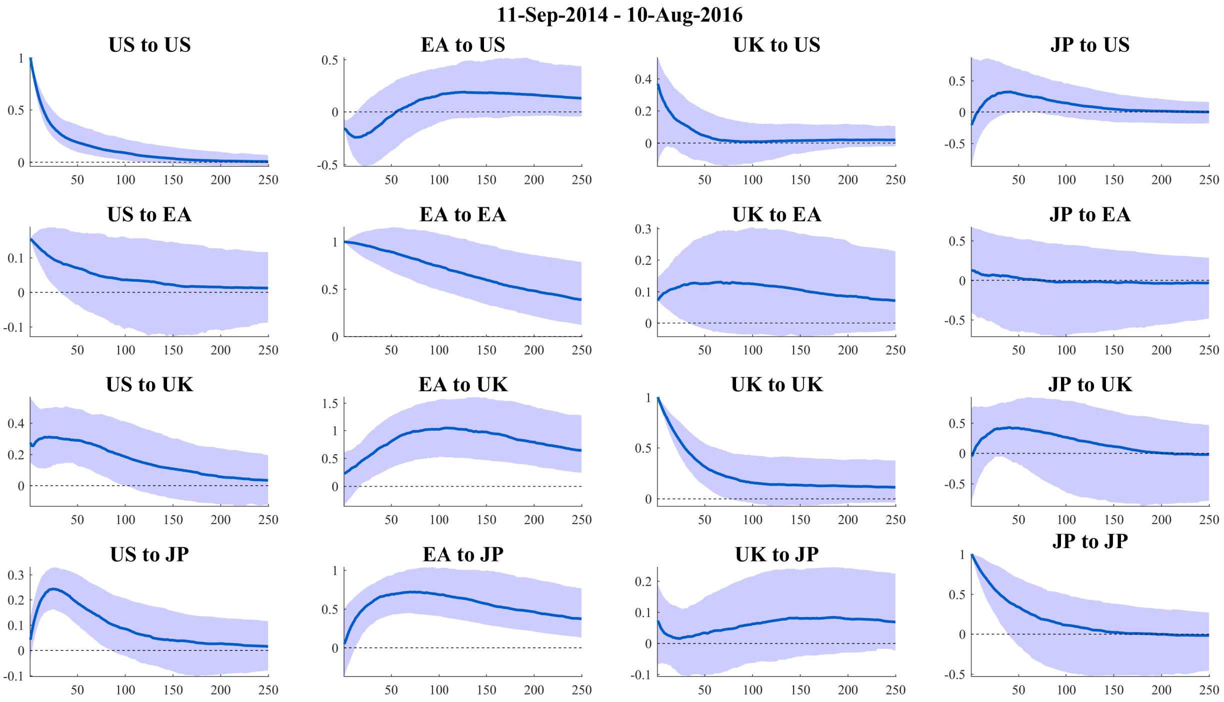
Note: This figure shows the IRFs due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 18 October 2007 - 16 September 2009. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method.

Figure 7: IRFs during the euro area sovereign debt crisis



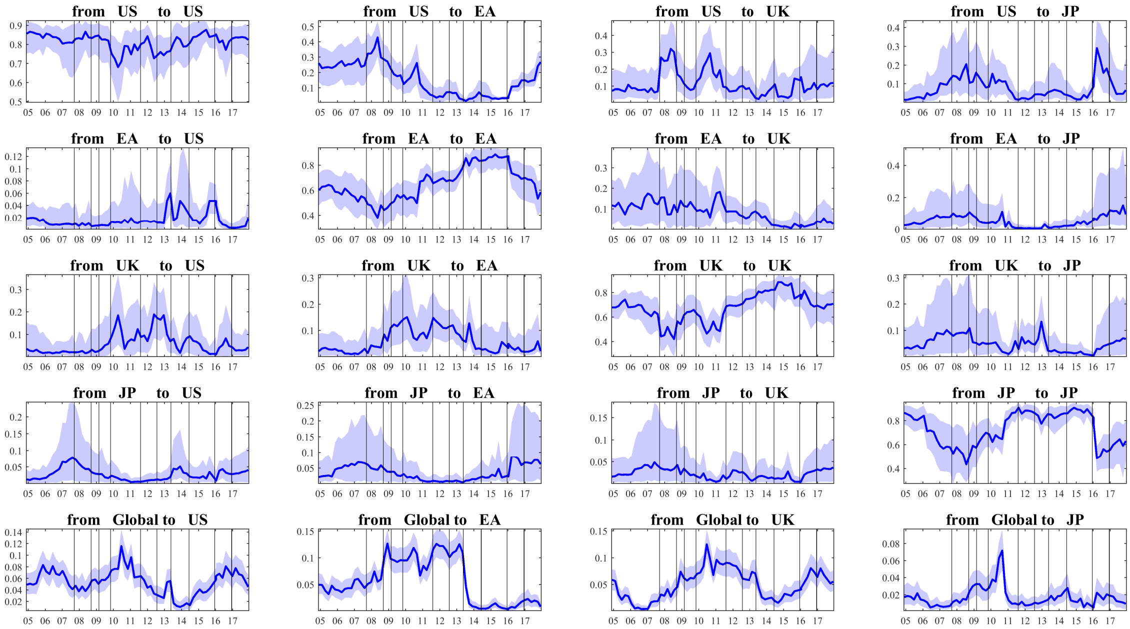
Note: This figure shows the IRFs due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 11 November 2010 - 10 October 2012. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method.

Figure 8: IRFs during the QE policy in the euro area and negative rates



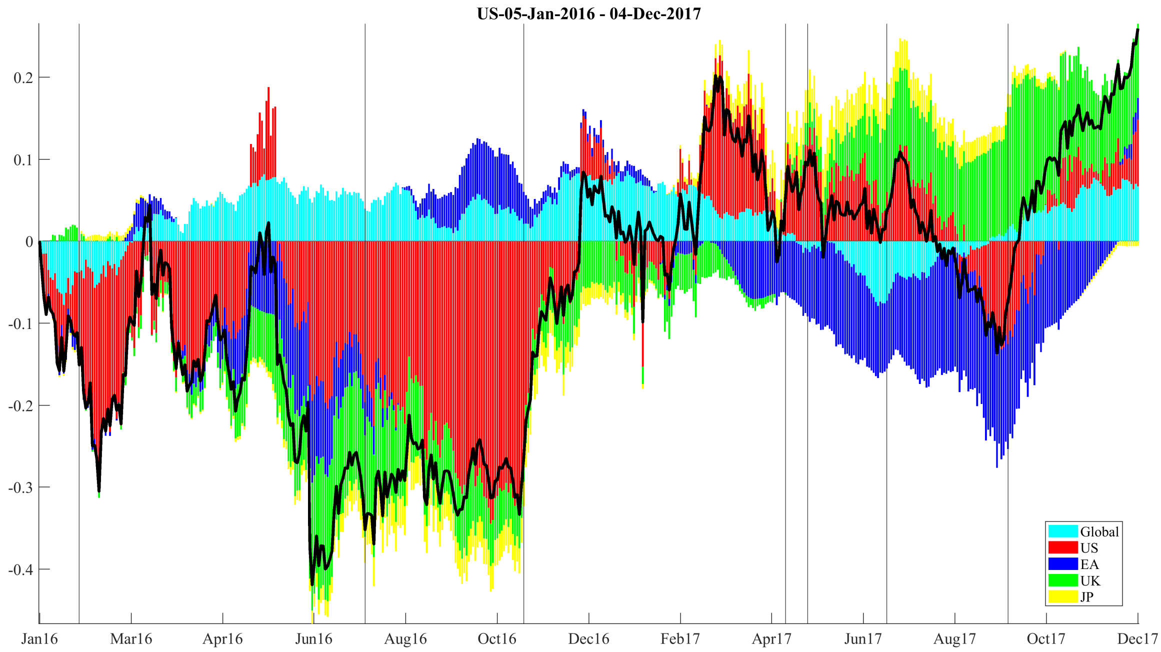
Note: This figure shows the IRFs due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 11 September 2014 - 10 August 2016. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method.

Figure 9: Relative importance of domestic and foreign shocks to the 2-year OIS rates



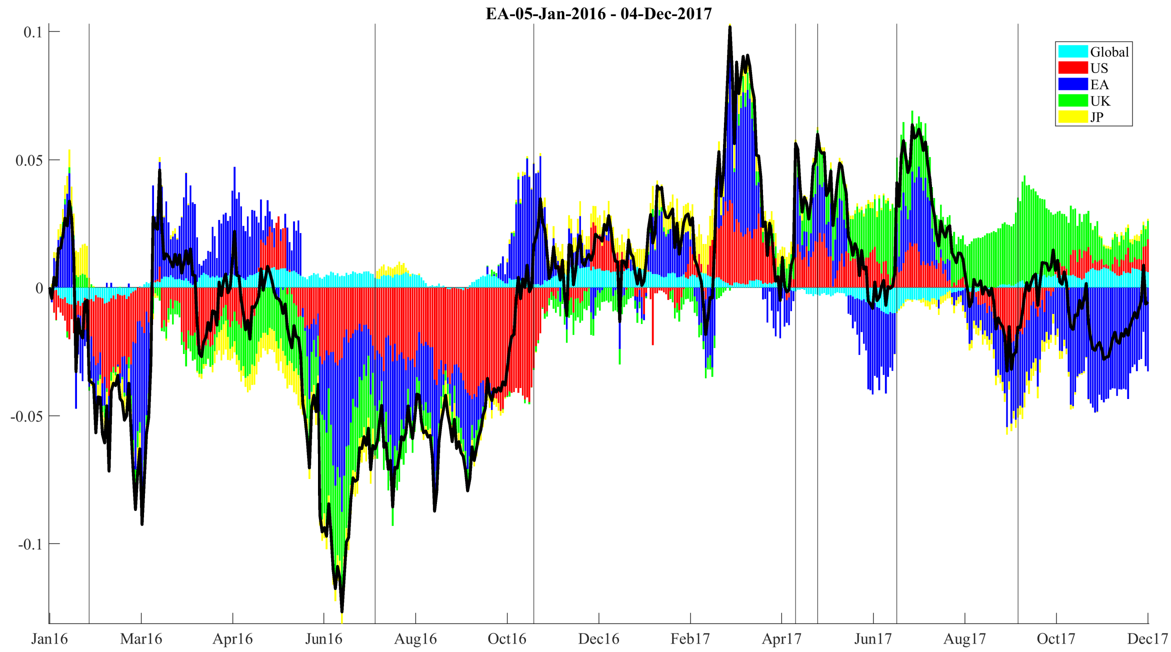
Note: This figure shows the contribution of 2-year OIS shocks from country j to country i. The predictive horizon is set at $h = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The vertical bars denote 18 September 2007 (FED interest rate cut following the interbank credit crisis), 15 September 2008 (Lehman's bankruptcy), 2 March 2009 (FED and US Treasury announce the joint restructuring plan for AIG), 5 November 2009 (the Greek revised budget deficit), 9 August 2011 (FED unconditional forward guidance), 27 July 2012 (Draghi's speech), 22 May 2013 (FED tapering announcement), 11 June 2014 (ECB lowers rates in negative territory , TLTROs and ABSPP), 16 December 2015 (FED increases rates), 14 December 2016 (FED increases rates). Sample period: 2 January 2003 - 4 December 2017.

Figure 10: Historical decomposition of shocks in 2016 and 2017: US 2-year OIS rate



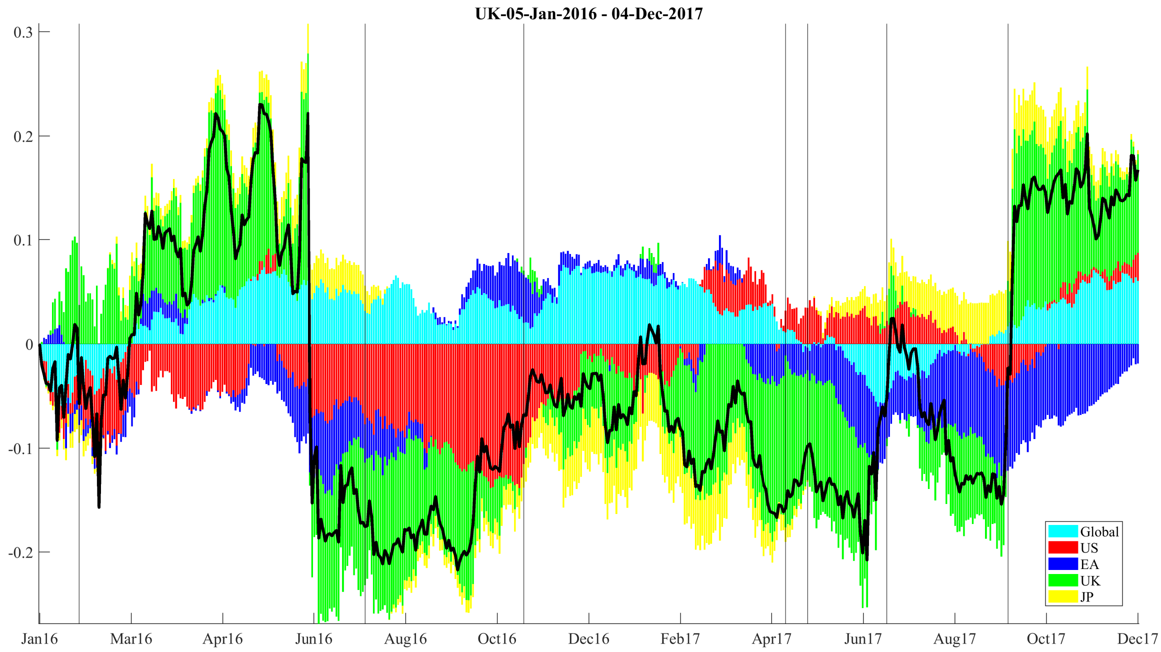
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the US 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. The vertical bars denote 29 January 2016 (Bank of Japan's announcement of negative interest rates), 23 June 2016 (the EU referendum in the UK (i.e. Brexit)), 29 July 2016 (Bank of Japan's announcement of an additional stimulus), 8 November 2016 (election of Trump as US president), 23 April and 7 May 2017 (French Presidential elections), 27 June 2017 (Sintra speech by the ECB president Draghi), 12 september (unexpected sharp rise in the UK's inflation rate to 2.9%). Sample period: 5 January 2016 - 4 December 2017.

Figure 11: Historical decomposition of shocks in 2016 and 2017: EA 2-year OIS rate



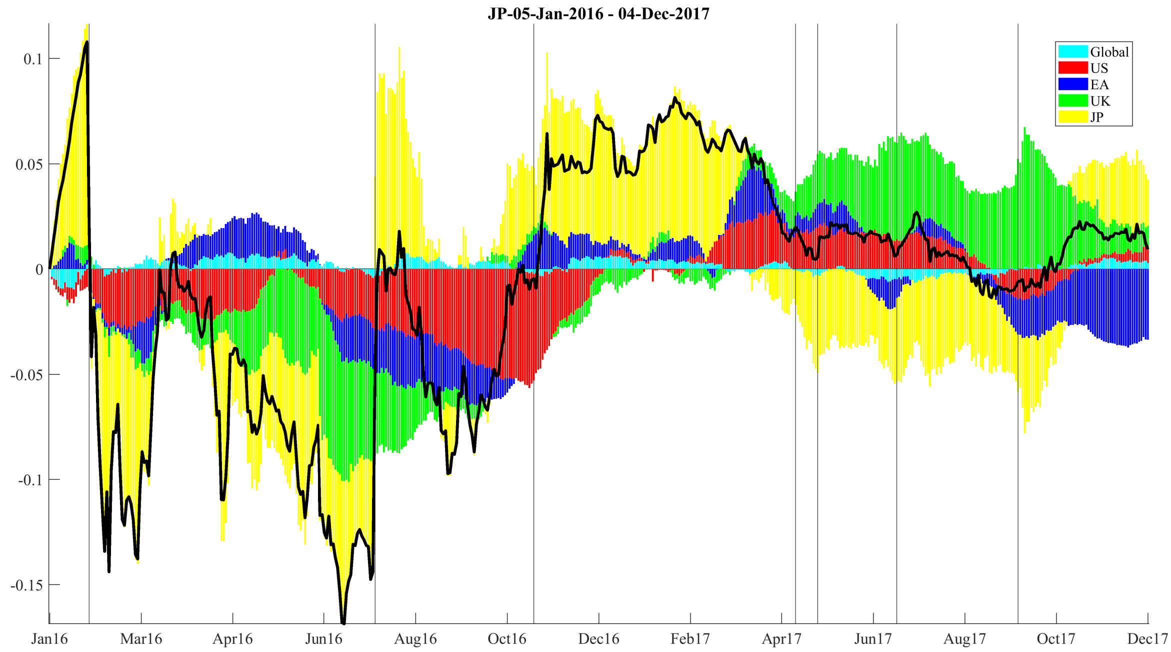
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the euro area 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. The vertical bars denote 29 January 2016 (Bank of Japan's announcement of negative interest rates), 23 June 2016 (the EU referendum in the UK (i.e. Brexit)), 29 July 2016 (Bank of Japan's announcement of an additional stimulus), 8 November 2016 (election of Trump as US president), 23 April and 7 May 2017 (French Presidential elections), 27 June 2017 (Sintra speech by the ECB president Draghi), 12 september (unexpected sharp rise in the UK's inflation rate to 2.9%). Sample period: 5 January 2016 - 4 December 2017.

Figure 12: Historical decomposition of shocks in 2016 and 2017: UK 2-year OIS rate



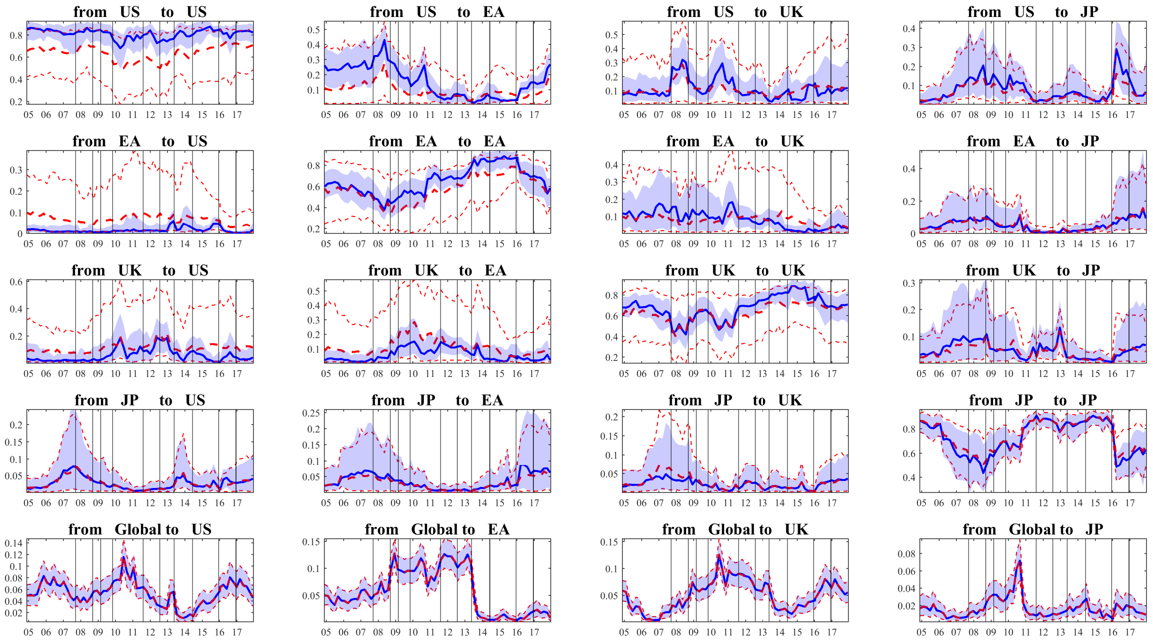
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the UK 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. The vertical bars denote 29 January 2016 (Bank of Japan's announcement of negative interest rates), 23 June 2016 (the EU referendum in the UK (i.e. Brexit)), 29 July 2016 (Bank of Japan's announcement of an additional stimulus), 8 November 2016 (election of Trump as US president), 23 April and 7 May 2017 (French Presidential elections), 27 June 2017 (Sintra speech by the ECB president Draghi), 12 september (unexpected sharp rise in the UK's inflation rate to 2.9%). Sample period: 5 January 2016 - 4 December 2017.

Figure 13: Historical decomposition of shocks in 2016 and 2017: JP 2-year OIS rate



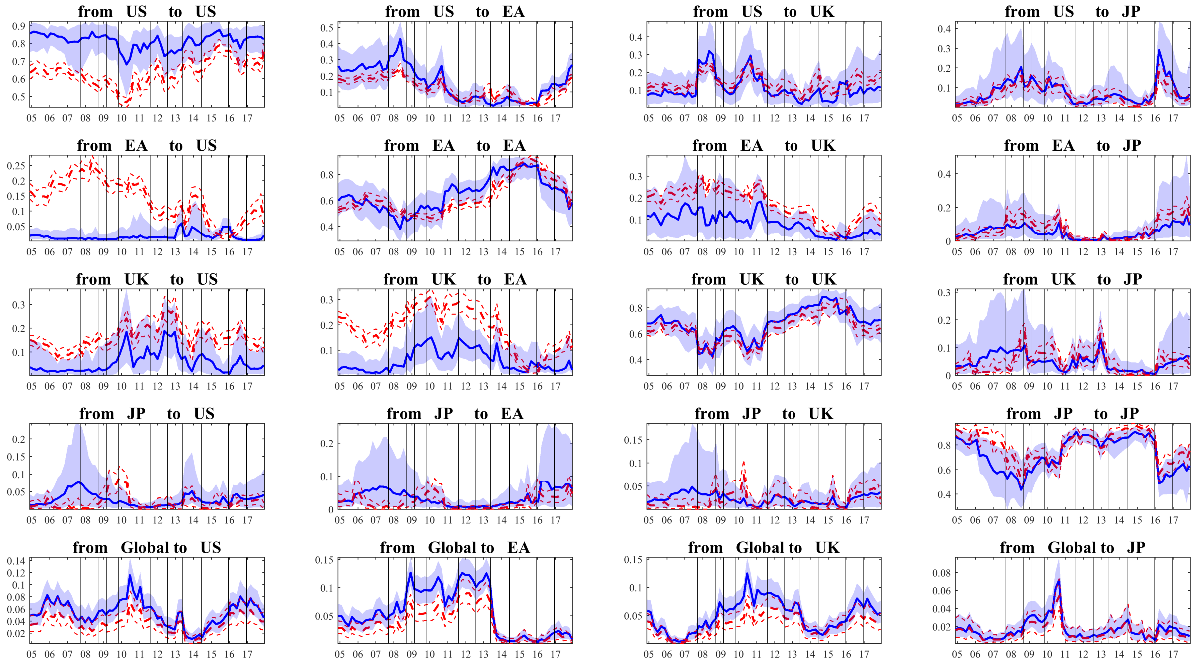
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the Japanese 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. The vertical bars denote 29 January 2016 (Bank of Japan's announcement of negative interest rates), 23 June 2016 (the EU referendum in the UK (i.e. Brexit)), 29 July 2016 (Bank of Japan's announcement of an additional stimulus), 8 November 2016 (election of Trump as US president), 23 April and 7 May 2017 (French Presidential elections), 27 June 2017 (Sintra speech by the ECB president Draghi), 12 september (unexpected sharp rise in the UK's inflation rate to 2.9%). Sample period: 5 January 2016 - 4 December 2017.

Figure 14: Relative importance of domestic and foreign shocks to the 2-year OIS rates - Event-study versus +/-1 absolute magnitude restrictions



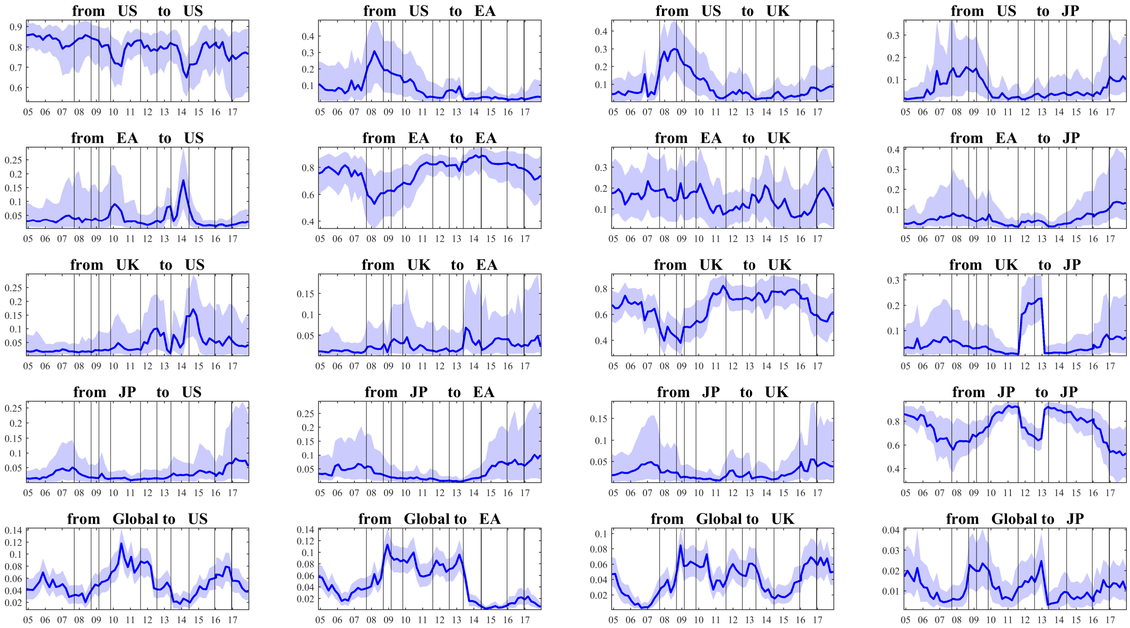
Note: This figure shows the contribution of 2-year OIS shocks from country j to country i. The predictive horizon is set at $h = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error bands obtained using the -/+ 1 magnitude restriction method. The vertical bars denote 18 September 2007 (FED interest rate cut following the interbank credit crisis), 15 September 2008 (Lehman's bankruptcy), 2 March 2009 (FED and US Treasury announce the joint restructuring plan for AIG), 5 November 2009 (the Greek revised budget deficit), 9 August 2011 (FED unconditional forward guidance), 27 July 2012 (Draghi's speech), 22 May 2013 (FED tapering announcement), 11 June 2014 (ECB lowers rates in negative territory , TLTROs and ABSPP), 16 December 2015 (FED increases rates), 14 December 2016 (FED increases rates). Sample period: 2 January 2003 - 4 December 2017.

Figure 15: Relative importance of domestic and foreign shocks to the 2-year OIS rates - Event study magnitude restriction versus GIRFs



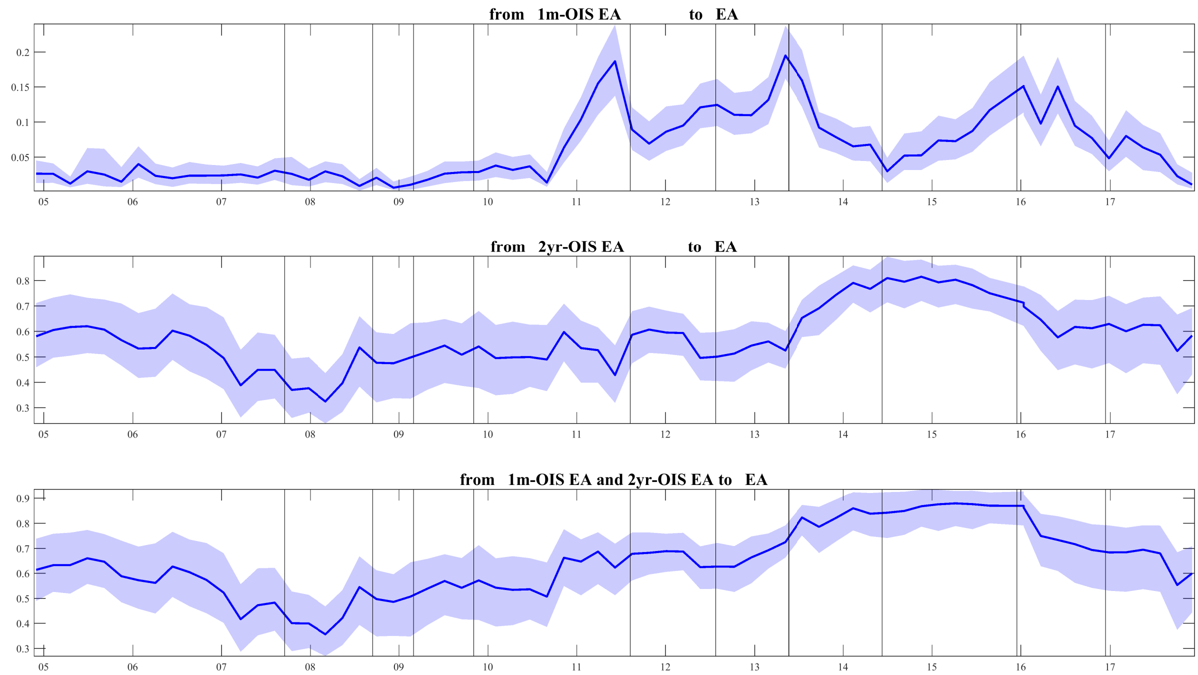
Note: This figure shows the contribution of 2-year sovereign yield shocks from country j to country i. The predictive horizon is set at $h = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error bands obtained using GIRFs. The vertical bars denote 18 September 2007 (FED interest rate cut following the interbank credit crisis), 15 September 2008 (Lehman's bankruptcy), 2 March 2009 (FED and US Treasury announce the joint restructuring plan for AIG), 5 November 2009 (the Greek revised budget deficit), 9 August 2011 (FED unconditional forward guidance), 27 July 2012 (Draghi's speech), 22 May 2013 (FED tapering announcement), 11 June 2014 (ECB lowers rates in negative territory , TLTROs and ABSPP), 16 December 2015 (FED increases rates), 14 December 2016 (FED increases rates). Sample period: 2 January 2003 - 4 December 2017.

Figure 16: Relative importance of domestic and foreign shocks to the 2-year sovereign yields



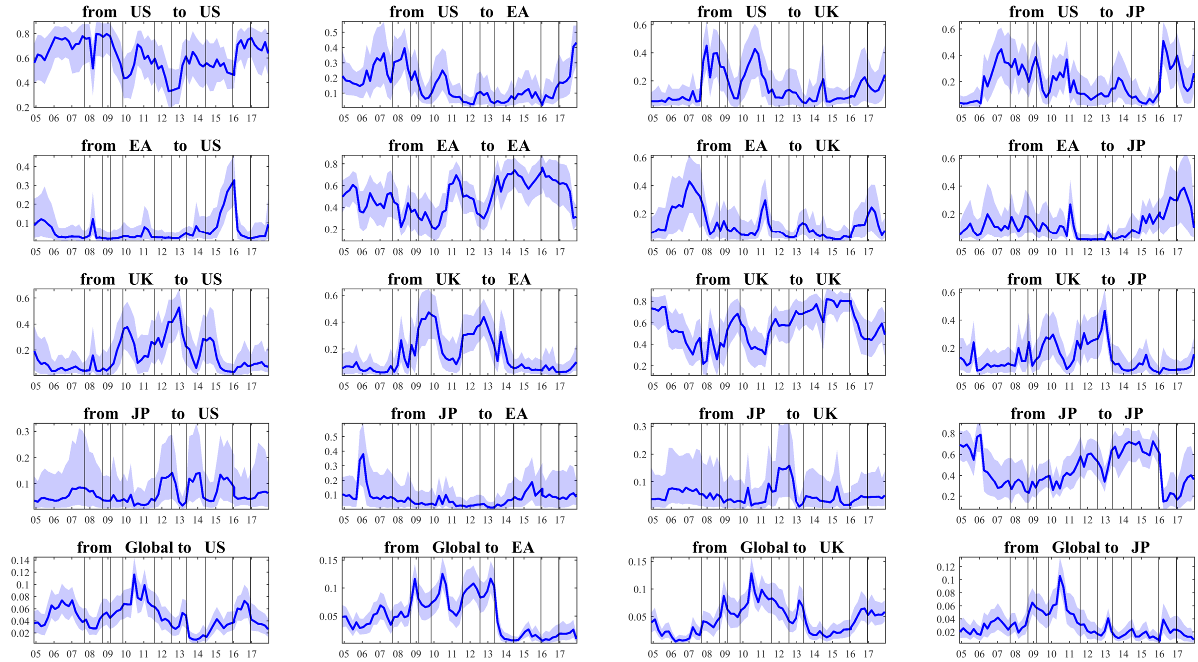
Note: This figure shows the contribution of 2-year sovereign yield shocks from country j to country i. The predictive horizon is set at $h = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error bands obtained using the -/+ 1 magnitude restriction method. The vertical bars denote 18 September 2007 (FED interest rate cut following the interbank credit crisis), 15 September 2008 (Lehman's bankruptcy), 2 March 2009 (FED and US Treasury announce the joint restructuring plan for AIG), 5 November 2009 (the Greek revised budget deficit), 9 August 2011 (FED unconditional forward guidance), 27 July 2012 (Draghi's speech), 22 May 2013 (FED tapering announcement), 11 June 2014 (ECB lowers rates in negative territory , TLTROs and ABSPP), 16 December 2015 (FED increases rates), 14 December 2016 (FED increases rates). Sample period: 2 January 2003 - 4 December 2017.

Figure 17: Relative importance of domestic shocks in the euro area



Note: This figure shows the contribution of 1-month and 2-year OIS rates to the euro area 2-year OIS rate. The predictive horizon is set at $h = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The vertical bars denote 18 September 2007 (FED interest rate cut following the interbank credit crisis), 15 September 2008 (Lehman's bankruptcy), 2 March 2009 (FED and US Treasury announce the joint restructuring plan for AIG), 5 November 2009 (the Greek revised budget deficit), 9 August 2011 (FED unconditional forward guidance), 27 July 2012 (Draghi's speech), 22 May 2013 (FED tapering announcement), 11 June 2014 (ECB lowers rates in negative territory , TLTROs and ABSPP), 16 December 2015 (FED increases rates), 14 December 2016 (FED increases rates). Sample period: 2 January 2003 - 4 December 2017.

Figure 18: Relative importance of domestic and foreign shocks to the 2-year OIS rates in the long-run



Note: This figure shows the contribution of 2-year OIS shocks from country j to country i. The predictive horizon is set at $h = 65$ days to capture a long-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The vertical bars denote 18 September 2007 (FED interest rate cut following the interbank credit crisis), 15 September 2008 (Lehman's bankruptcy), 2 March 2009 (FED and US Treasury announce the joint restructuring plan for AIG), 5 November 2009 (the Greek revised budget deficit), 9 August 2011 (FED unconditional forward guidance), 27 July 2012 (Draghi's speech), 22 May 2013 (FED tapering announcement), 11 June 2014 (ECB lowers rates in negative territory , TLTROs and ABSPP), 16 December 2015 (FED increases rates), 14 December 2016 (FED increases rates). Sample period: 2 January 2003 - 4 December 2017.

A Estimation algorithm

The estimation procedure consists of two steps. The reduced form VAR model is estimated in the first step. The structural shocks are identified in the second step.

While randomly drawing orthonormal matrices using the QR decomposition is feasible when a small number of variables are used, numerical optimization becomes necessary when the number of variables is large because the probability of obtaining a successful draw is decreasing with the size of the system. Therefore, we introduce a numerical algorithm for computational convenience. Formally, the steps of the algorithm are the following:

1. **Estimate reduced-form VAR:** Given a chosen number of lags, $\widehat{K}$, a $VAR(\widehat{K})$ is estimated by assuming diffuse Normal-Wishart prior to obtain the distribution of the autoregressive coefficients $A(L)$ and of the variance-covariance of reduced form errors, $\widehat{\Sigma_u}$.

2. **Identification restrictions:** The reduced form IRF, $C(L)$, is randomly drawn from the distribution obtained in the first step. $C(L)$ is related to the structural IRF via $B(L) = C(L)A_0^{-1}B$ and reduced form errors, u_t, are related to structural shocks as $u_t = A_0^{-1}B\varepsilon_t$. The impact matrix, $S = A_0^{-1}B$, must satisfy: $\Sigma_u = SS'$.

   (a) The initial estimate of $\hat{S}$ is obtained by a Cholesky decomposition of the variance-covariance matrix of reduced form errors, $\hat{\hat{S}} = chol(\hat{\Sigma}_u)$, giving an initial estimate of the IRF is $\hat{\hat{B}}(L) = \hat{C}(L)\hat{\hat{S}}$.

   (b) A random matrix $\tilde{A}_0^{-1}$ is drawn satisfying the identifying restrictions. In particular, in the baseline estimation, we construct a matrix with 1s on the diagonal and with random numbers drawn from $[0, 1)$ on the off-diagonal elements.

   (c) Given $\tilde{A}_0^{-1}$, the matrix $\hat{Q}$ is defined through the following minimization problem:

$$\begin{aligned} \hat{Q} \quad = \quad argmin \qquad & (\hat{A_0}^{-1} - \tilde{A}_0^{-1})^2 \\ subject\ to \qquad \hat{Q}\hat{Q}' &= I \\ \hat{S} &= \hat{\hat{S}}\hat{Q} \\ \hat{A_0}^{-1}(i,j) &= \hat{S}_{ij}/\hat{S}_{jj}\ \forall\ i,\ j \\ c(\hat{A_0}^{-1}) &\geq 0 \end{aligned} \tag{A.1}$$

   where $c(.) \geq 0$ represents the identifying restrictions. In other words, we select an orthonormal matrix, $\hat{Q}$, such that $\hat{\Sigma}_u = (\hat{\hat{S}}\hat{Q})(\hat{\hat{S}}\hat{Q})'$ and the resulting matrix of impact coefficients, $\hat{A_0}^{-1}$, is close to $\tilde{A}_0^{-1}$ and satisfies the identifying restrictions.[12]

(d) In case the minimization does not converge to a feasible solution, steps 2b and 2c are repeated. Once the minimization converges, the candidate IRF is calculated as $\hat{B}(L) = \hat{C}(L)\hat{\tilde{S}}\hat{Q}$.

The point estimates and confidence bands are given by the median and relevant percentiles of the distribution of the retained IRFs.

[12]The minimization problem could be carried out without the matrix $\tilde{A_0}^{-1}$, for example using a constant objective function. The use of $\tilde{A}_0^{-1}$ in the algorithm ensures that the search ofthe the identifying restrictions is carried out in the full space of permissible matrices.