The Importance of Foreign Shocks on Money Market Rates: Event-Study Magnitude Restriction*

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Abstract

We show that US short-term money market rates are less exposed to foreign shocks and are the main source of spillovers globally. European rates were mainly driven by domestic shocks only with the intensification of the sovereign debt crisis and the introduction of more aggressive monetary policies. Asset price shocks are identified by combining the appeal of the event-study analysis with the advantages of structural vector autoregressions. In the admissible set of structural parameters, we retain those that ensure that at impact impulse responses agree with established occurrences. This approach sharpens the inference and reduces the error bands substantially.

Keywords: Spillovers, Risk-Free Rates, SVAR identification.
JEL Classification: C3, G2

1 Introduction

Short-term money market rates are key reference rates to finance economic activity. Their dynamics is influenced by foreign developments and such spillovers may be undesired, if

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they conflict with the goals of the monetary policymaker.[1] The dynamics of the short-term rates is particularly important, when economies are in different phases of the business cycle. In this case, even an increase in the foreign short-term interest state due to positive demand or supply shocks, which spills over the domestic financing conditions, might be perceived as unacceptable by the domestic policymaker, if for example the domestic output gap is expected to remain negative or the inflation rate is below its target.

Establishing the importance of foreign spillovers in the dynamics of short-term money market rates is an important policy question, particularly in a world where (i) central banks attempt to keep low the domestic interest rates for a prolonged period of time (i.e. through forward guidance and quantitative easing), (ii) the spillovers from the US are found to be economically important across developed countries and emerging markets (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))),[2] and (iii) the US is considered to be a key driver of the global financial cycle (Miranda-Agrippino and Rey (2015); Rey (2016); Jorda et al. (2017)).[3]

The asset price spillovers from the United States are typically identified in the literature using event study analyses through interest rate or macroeconomic news. In this paper, we address the role of foreign spillovers in the context of structural vector autoregressions (SVARs) with the advantage that one can study and describe the dynamic behaviour of the time series after the realization of the shock.

However, causal identification is not straightforward, because asset price shocks are

[1]Monetary policymakers achieve their goals typically by steering the central bank reference rates in order to influence the short-term money market rates and the entire yield curve.

[2]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 short-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)). In the more extreme case of emerging markets holding a relatively large foreign debt in foreign currency, the use of a second instrument (macroprudential policy) is suggested to insulate the domestic economy from foreign monetary policy shocks (Aoki et al. (2016)).

[3]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 short maturity (Diebold et al. (2008) and Jotikasthira et al. (2015)).

less consensual in theory.[4] Inspired by both the narrative restriction identification, where structural shocks and the historical decomposition of the data are constraint around key historical occurrences (Antolín-Diaz and Rubio-Ramírez (2016)), and by the absolute magnitude restriction identification, where the magnitude of the instantaneous direct effect of the shock is larger in absolute value than the magnitude of its instantaneous spillover (De Santis and Zimic (2017)); in this paper, the spillover is constraint around key events. In the admissible set of structural parameters, we retain those that ensure that at impact the impulse response functions (IRFs) agree with the upper and lower bounds provided by the event-study analysis.

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. (2012), Mertens and Ravn (2013), Caldara and Herbst (2016), Gertler and Karadi (2015)).

There are two important differences between our method and the existing literature. First, as in Antolín-Diaz and Rubio-Ramírez (2016), we use a small number of key historical events alleviating the issue of measurement error in the narrative times series. Second, we do not select the models on the basis of a plausible historical decomposition of shocks as in Antolín-Diaz and Rubio-Ramírez (2016); but we impose the estimated reaction of asset prices to foreign shocks based on key events, as a magnitude restriction on the impact matrix. Therefore, our method combines the appeal of the event-study analysis with the advantages of SVARs and we show that this approach is particularly suitable to address the source of spillovers across asset prices.

The identification by even-study magnitude restrictions bears similarity to those used in Kilian and Murphy (2012) and De Graeve and Karas (2014). Kilian and Murphy (2012) combines sign restrictions together with plausible bounds on the magnitude of the

[4]One useful approach that provides a causal interpretation of asset price shocks is the identification by heteroskedasticity (Sentana and Fiorentini (2001), Rigobon (2003)). As the variances of asset specific shocks change in different regimes, one can use additional moments in the data to identify the system and, thereby, extract the structural parameters. However, the identification by heteroskedasticity requires that the contemporaneous relationship between the variables do not change between the different volatility regimes. The volatility regimes are assumed to be known. Moreover, the statistical identification of the shocks is often associated with zero and sign restrictions in order to obtain a sensible economic identification (Ehrmann et al. (2011), Ehrmann and Fratzscher (2015)).

short-run oil supply elasticity and on the impact response of real activity. De Graeve and Karas (2014) imposes heterogeneous restrictions to different cross-sectional units in panel SVARs to identify the bank runs shock using sign restrictions. The similarity is related to the fact that we also use bounds on the impact matrix to identify shocks. More specifically, the magnitude restrictions can be mapped into the heterogeneity restrictions as in De Graeve and Karas (2014), if the IRFs are normalised and the bound is 1. Finally, the numerical approach, which is adopted in this paper to find models consistent with data and prior, requires explicit definition of the upper and lower bounds.[5] The advantage of the even-study magnitude restriction identification is that it can be applied to a variety of issues, countries and asset prices. Key is the proper selection of the events to identify the shocks.

We focus the analysis on the importance of foreign spillovers in the dynamics of shorter-term money market rates of the G4 economies, the euro area, Japan, the United Kingdom (UK) and the United States (US), because these flexible exchange rate economies are fully integrated into the global economy, their shocks can affect asset prices globally and their business cycles can distinctly diverge.

After central bank reference rates were perceived by the markets to have reached the lower bound, money markets rates were heavily influenced by unconventional monetary policies. However, addressing the relative importance of foreign shocks is even more challenging in these periods, because of their very low volatility.

We compare the results of the models based on the event-study magnitude restrictions with the more agnostic absolute magnitude restriction identification used in De Santis and Zimic (2017) as well as with those obtained using generalised impulse response functions (GIRFs). We show that the identification supported by the event studies can be highly informative, as it reduces markedly the uncertainty around the median estimate.

We show that 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 that 80% of the variance of the US rates over almost the entire sample period.

Moreover, we find that euro area short-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,

[5] Heterogeneity restrictions are defined as follows: $\frac{\partial X}{\partial \varepsilon} > \frac{\partial Y}{\partial \varepsilon}$ where X and Y are variables included in the VAR and ε is the shock to be identified. Instead, the absolute magnitude restrictions impose bounds on the response of variables to a specific shock, $\frac{\partial X}{\partial \varepsilon} \in (a, b)$, where a and b are the lower and upper bounds, respectively.

euro area rates were mainly driven by domestic shocks. The UK money market rates are highly affected by developments in the euro area and the US. Finally, global money market rates are more immune if shocks are originated in Japan.

As a robustness check, we also conducted the same exercises using the 2-yr sovereign yields or adding the one-month euro area risk free rate in the model in order to increase by construction the importance of the domestic shock in the region. The results remain qualitatively similar.

The remaining sections of the paper are structured as follows. Section 2 describes the methodology. Section 3 identifies the key events. Section 4 presents the data and the empirical model. Section 5 describes the results. Section 6 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 errors of the structural shocks.

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) cannot be estimated directly, but needs to be 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 $B(L) = A_0 C(L)$. In other words, to identify the structural shocks and obtain the structural impulse responses, A_0 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 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. In this paper, rather than imposing a set of $N(N-1)/2$ restrictions that guarantees unique identification, we obtain the distribution of impulse response functions 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, we impose restrictions on the size of contemporaneous spillovers at impact.

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 $\hat{A}_0$ normalized to 1, the off-diagonal elements can be written as:

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

For each H, we keep the corresponding estimate of the impulse response functions (IRFs) only if the resulting $\hat{A}_0$ satisfies the restrictions on the size of spillovers. The instantaneous spillovers are constrained on a specific range, $\hat{A}_0^{-1}(i,j) \in (\underline{\hat{a}}_{i,j}, \hat{\bar{a}}_{i,j})$. The lower and upper bounds are estimated using the event-study methodology, as explained in the next session. Intuitively, the event studies help us estimating the range of contemporaneous spillovers from market i to market j. A numerical algorithm is employed to facilitate the search of models that are consistent with priors and data (see Appendix A).

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 source of the risk and how it transmits across assets.

2.3 An illustrative example

The magnitude restriction method can be appreciated with a simple example. Consider a system with two variables, and let:

$$A_0^{-1} = \begin{bmatrix} 1 & b \\ c & 1 \end{bmatrix} \qquad B = \begin{bmatrix} \sigma_1 & 0 \\ 0 & \sigma_2 \end{bmatrix}$$

so that

$$A_0^{-1}B = \begin{bmatrix} \sigma_1 & b\sigma_2 \\ c\sigma_1 & \sigma_2 \end{bmatrix} \qquad \Sigma_u = \begin{bmatrix} \sigma_1^2 + b^2\sigma_2^2 & c\sigma_1^2 + b\sigma_2^2 \\ c\sigma_1^2 + b\sigma_2^2 & c^2\sigma_1^2 + \sigma_2^2 \end{bmatrix}$$

The identification problem arises because the variance-covariance matrix is symmetric and the system is characterized by three equations and four parameters: b, c, σ_1 and σ_2. Define the estimated variance-covariance matrix as $\hat{\Sigma}_u = \begin{bmatrix} \hat{\Sigma}_{11} & \hat{\Sigma}_{12} \\ \hat{\Sigma}_{21} & \hat{\Sigma}_{22} \end{bmatrix}$, then the three equations can be written as follows:

$$\begin{aligned} \sigma_1^2 + b^2\sigma_2^2 &= \hat{\Sigma}_{11} \\ c\sigma_1^2 + b\sigma_2^2 &= \hat{\Sigma}_{21} \\ c^2\sigma_1^2 + \sigma_2^2 &= \hat{\Sigma}_{22}. \end{aligned}$$

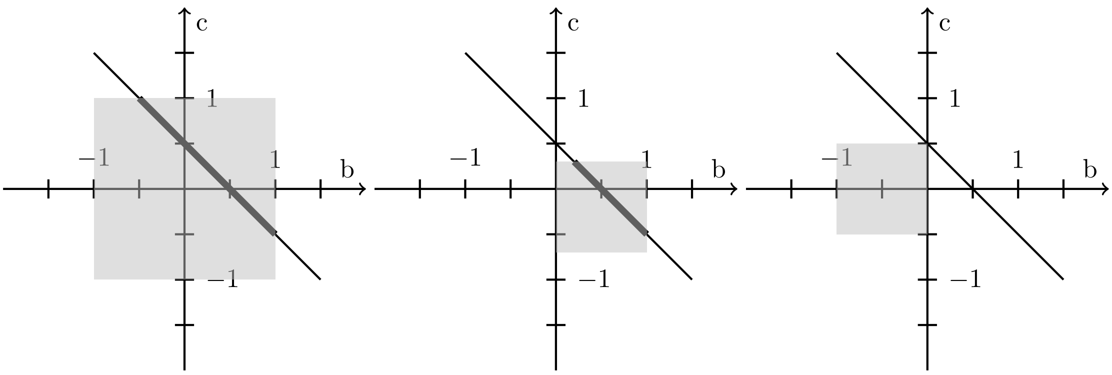
A typical unique solution of this system is a zero restriction (i.e. $b = 0$). Alternatively, one can impose prior information provided by sign restrictions (i.e. $b > 0$ and $c > 0$) or absolute magnitude restrictions (i.e. $|b|, |c| < 1$). The latter two methods provide a set of models that are consistent with prior information and data. We refine the more agnostic absolute magnitude restriction identification with magnitude restrictions based on event studies, with the advantage that the method can be applied to a variety of issues, countries and asset prices.

In order to explain the magnitude restriction method graphically, assume that the standard errors of the shocks are equal to one, $\sigma_1 = 1$ and $\sigma_2 = 1$. This allows us to discard two equations of the system, which reduces to one equation, $c + b = \hat{\Sigma}_{21}$, and two unknowns, b and c. Given the estimated covariance $\hat{\Sigma}_{21}$, all solutions that identify b and c can be plotted.

Consider the case that the true $b = 0.6$ and $c = -0.1$, which implies that $\hat{\Sigma}_{21} = 0.5$. The black line in Figure 1 provides an infinite number of solutions to this equation, which however are bounded by the combinations of b and c. The true values are unknown; therefore, three cases under alternative prior bounds on b and c are considered.

The first plot to the left shows the case when we impose the absolute magnitude restriction proposed in De Santis and Zimic (2017), where at impact the spillovers to other assets are smaller in absolute value than the direct effect on the asset where the shock originates, $|b|, |c| < 1$. The restriction is represented by the shaded grey area. The bold black line shows the intersection of the magnitude restrictions with all possible combinations of parameters consistent with data. This identified set is relatively smaller compared to the set of solutions when restrictions are not imposed and these restrictions lead to a large set of accepted models. In this illustrative example, all models consistent with $b, c \in [-0.5, 1]$ and the corresponding data are retained.

Figure 1: Identification with magnitude restrictions: Solutions to $c + b = 0.5$



$b \in [-1, 1]$, $c \in [-1, 1]$ $b \in [0, 1]$, $c \in [-.7, .3]$ $b \in [-1, 0]$, $c \in [-.5, .5]$

Specific events can provide more precise information on the bounds. Assume that the event-study analysis suggests an estimate of $\hat{b} = 0.5$ and $\hat{c} = -0.2$ with $\hat{\sigma}_b = 0.125$ and $\hat{\sigma}_c = 0.125$. Bounds are set such that all observations can be considered and this corresponds to 4 standard deviations of the mean: $b \in [\hat{b} - 4\hat{\sigma}_b, \hat{b} + 4\hat{\sigma}_b]$ and $c \in [\hat{c} - 4\hat{\sigma}_c, \hat{c} + 4\hat{\sigma}_c]$. As described in the middle panel of Figure 1, in this specific case $b \in [0, 1]$ and $c \in [-0.7, 0.3]$. Bounds are tighter and the set of models, which are consistent with data and prior restrictions, is smaller: $b \in [0.2, 1]$ and $c \in [-0.5, 0.3]$. It is important to notice that posterior bounds are smaller than prior bounds. This implies that data provide additional information, because the likelihood of the models' set is not constant.

The panel to the right shows the case when $\hat{b}$ and $\hat{c}$ are highly biased: $\hat{b} = -0.5$ and $\hat{c} = 0$, with the same standard errors $\hat{\sigma}_b = 0.125$ and $\hat{\sigma}_c = 0.125$. In this case, the estimated bounds are $b \in [-1, 0]$ and $c \in [-0.5, 0.5]$, but the set of models consistent with the data and the prior bounds is empty: the shaded grey area in the graph does not intersect the black line. This implies that using mean estimates of the spillovers that are fully inconsistent with the data leads to empty set and this is revealed by the posterior.

In summary, these illustrative examples indicate that tighter prior bounds containing the true estimates lead to smaller set of accepted models and more precise estimates. Importantly, the posterior may differ from the prior, which suggests that data are informative about the set of models. However, using tighter bounds is not a panacea, if mean estimates of the spillover are highly biased. In the latter case, the posterior set of models would also feature biased estimates, though still consistent with data.

3 Events

The identification of the events is very important and the dates are selected on the basis of key historical developments that surprised financial markets. In this respect, the financial crisis is a helpful period, providing many occasions, such as market news and policy actions, which researchers can use to identify 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 no 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.

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. 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.

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 Overnight Indexed Swap (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

In most of the events under analysis, 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. 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 translated in sharp changes in neither the 2-year money market rate nor the 2-year sovereign yield.

A simple OLS regression allows us to estimate the average effect together with standard errors of an asset shock on all other yields. The regression takes the following form:

$$x_i = a_{i,j} x_j + \epsilon_i, \tag{3.1}$$

where x_i and x_j are respectively the daily changes in the yield of economies i and j on identified event dates in economy j. The slope coefficient $\hat{a}_{i,j}$ is the estimate of the average spillover from asset j to asset i and is used to constraint the impact matrix. We use the estimated standard errors to construct the bounds and we take a large confidence interval, $\underline{\hat{a}}_{i,j} = (\hat{a}_{i,j} - 4\hat{\sigma}_{a_{i,j}})$ and $\hat{\hat{a}}_{i,j} = (\hat{a}_{i,j} + 4\hat{\sigma}_{a_{i,j}})$, in order to reduce the probability of biased estimates. Estimated OLS coefficients and relative standard errors are reported in Table 2.

Table 2: Contemporaneous spillovers: An 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 relative standard errors of the following equation $x_i = a_{i,j}x_j + \epsilon_i$, where x_i and x_j are respectively the daily changes in the 2-year OIS rate of economies i and j on identified event dates in economy j, as reported in Table 1.

About half of the size of the shock from US spilt 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 spilt to the euro area. The spillover to the US is larger from the UK (0.25) 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 magnitude restrictions as in De Santis and Zimic (2017) with bounds between -1 and +1 for the instantaneous spillover from and to Japan. As a robustness check a model without Japan is also considered.

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 Overnight Indexed Swap (OIS) rates, which are fixed-floating interest rate swaps where the floating rate is indexed to the uncollateralised overnight call rate, exist.

Developments in the uncollateralised overnight call rates and their respective 2-year OIS rates are plotted in Figure 2. They tended to move in tandem before the global financial crisis in 2008. 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 policymaker targeted the risk-free rates at longer maturity more than in the past in normal circumstances. On the contrary, the euro area policy rates reached values close to zero in 2012 and turned negative in 2014, when also forward guidance was introduced. 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 correspondent 2-year OIS rates present important diverging developments in all considered economies during the lower bound period. For example, the US 2-year OIS rate started to rise again since mid-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 3). This is the reason why a SVAR approach is required, as it allows to identify from which economic area the shock is originated. To control for other global factors affecting money market rates, we include exogenously the growth rate in oil prices in US dollar and the macro news of the G10 economies (i.e. VARX).

[Insert Figures 2-3, here]

Given that the relationships among variables and the size of the shocks may change over time, we estimate the VARX using a two-year rolling window (500 business days) over the sample period 1 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 67 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).

As a robustness check, we also investigate the role of foreign spillovers in the 2-year sovereign yield segment using the German Bund, which is more affected by flight-to-quality considerations.

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 summarised by the standard deviation of the shocks in Section 5.1, the impulse response functions (IRFs) in Section 5.2 and the variance decomposition of the shocks in Section 5.3. In all reported figures, 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. We zoom in some of the findings carrying out an historical decomposition of shocks in Section 5.4. We also show the key results obtained using GIRFs (see Section 5.5), we apply the method to the 2-year sovereign yield segment (see Section 5.6) and we carry out a number of robustness checks (see Section 5.7).

The results suggest that the error bands obtained using the event-study magnitude restriction are much smaller than those obtained using the -/+1 magnitude restriction identification, except for shocks originated in Japan where however no additional information is provided and, therefore, results are consistent. This applies to the estimated size of the shocks, the IRFs and the variance decomposition of shocks. Moreover, results obtained using GIRfs seem to be less plausible.

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 to the uncertainty from BREXIT.

[Insert Figure 4, here]

5.2 Impulse responses

The transmission of the shocks can be summarised with the help of IRFs. Given that we consider 4 markets and 67 500-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 30 July 2003 - 28 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. 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. We 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. Moreover, the dynamic transmission turns even negative, pointing to a portfolio reallocation in this specified period. Finally, the error bands are far narrower under the event-study magnitude restriction than under the absolute magnitude restriction.

[Insert Figures 5, here]

Second, we show the IRFs estimated during the global financial crisis over the period 17 October 2007 - 15 September 2009 (see Figure 6). In this period, not only the US and the UK, but also the euro area generated positive, persistent and significant spillovers vis-à-vis all other economies, while the spillovers from Japan continued to be statistically insignificant. These suggest that the US and Europe were the main driving forces behind developments in shorter-term money market rates worldwide due to the nature of the banking crisis. Also in this period, the error bands are far narrower under the event-study magnitude restriction with mean values that are in line with the event-study analysis. In this period, spillovers at impact under the absolute magnitude restriction are never statistically significant.

[Insert Figures 6, here]

Third, we show the IRFs estimated during the hikes of the euro area sovereign debt crisis over the sample period 10 November 2010 - 09 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 an impact on the UK due to the regional nature of the sovereign debt crisis. In this period, also shocks from Japan affected both Anglo-Saxon economies.

[Insert Figures 7, here]

Finally, we show the IRFs estimated over the period 10 September 2014 - 09 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 and the UK continued to be positive, persistent and statistically significant vis-à-vis all economies. The spillovers from the euro area were 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 are 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 spilt to other economies, but the statistical significance of such spillovers is time-varying. As for the comparison across method, not only the error bands are narrower under the event-study magnitude restriction, but also the IRF vis-à-vis Japan are more precise, despite the assumption about the spillovers from all other economies to Japan remain the same across approaches. 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.

5.3 Relative importance of foreign shocks

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 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; except in 2010, when the euro area sovereign debt crisis steadily become a global source of uncertainty.

The own shock plays a major role in explaining the dynamics of the shorter-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, followed by the introduction of more aggressive unconventional monetary policies in 2014-2015, such as negative monetary policy rates, asset purchases of government bonds and forward guidance, as a response by the central bank to low inflation and output below potential in the euro area.[6] 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 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. The role of the domestic shock in the UK rose above 70% with the normalization in the financial markets after the "whatever it takes" speech in 2012 and then it continued to increase steadily until 2015. Subsequently, shocks from the US possibly associated to the improved macroeconomic outlook had a slightly larger impact on money market rates also in the UK.

In Japan, the own shocks explained 90% of the variance of the Japanese short-term money market rates before the financial crisis. The contribution of the domestic shocks declined sharply to 50% after Lehman, mostly due to developments in US rates, but then

[6] In general, as short-term policy rates approached 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.

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 can be more forceful.

All in all, it can be argued that the US is less exposed to foreign shocks and is the main source of spillovers globally, while Japan is the market with the least influence abroad. As for Europe, European short-term interest 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. Shocks from the euro area are also important for the dynamics of UK money market rates.

[Insert Figure 9, here]

To better assess the role of each economy as a source of foreign shocks, Figure 10 shows the relative importance of foreign shocks in the dynamics of the money market rates in aggregate from a specific market j, $C^H_{\bullet \leftarrow j}$. As in Diebold and Yilmaz (2014), it is computed as follows:

$$C^H_{\bullet \leftarrow j} = \frac{1}{N-1} \sum_{\substack{i=1 \\ i \neq j}}^{N} \omega^2_{i,j}(h), \tag{5.1}$$

where $N = 4$ is the number of assets, $\omega^2_{i,j}(h)$ provides the contribution of shock j to the h-step forecast error variance of variable i with a predictive horizon $H = 12$ days.

US shocks were relatively more important before the euro area sovereign debt crisis with contribution ranging between 15% and 35% and in 2017 with the economic recovery. Their relative importance declined to 5-10% with the intensification of the euro area sovereign debt crisis in 2011 and 2012 and the adoption of more aggressive monetary policies by the ECB in 2014 and 2015. Over the entire sample period, the contribution of the European rates fluctuated around 10%, while the contribution of Japanese rates was rather limited, fluctuating around 5%.

[Insert Figure 10, here]

Lastly, Figure 11 shows the relative importance of foreign shocks in the dynamics of the shorter-term money market rates globally, C^H, which is computed after Diebold and Yilmaz (2014) as follows:

$$C^H = \frac{1}{N} \sum_{i=1}^{N} \sum_{\substack{j=1 \\ i \neq j}}^{N} \omega_{i,j}^2(h). \tag{5.2}$$

The largest foreign spillovers were recorded during the global financial crisis in the second half of 2007 and 2008. In 2005-2006, about 25% of the variation in money market rates globally were due to foreign developments. The importance of foreign shocks increased over time during the financial crisis reaching the highest level (about 40%) just before Lehman's bankruptcy in 2008. They decreased substantially during the euro area sovereign debt crisis reaching the lowest point (about 15%) at the end of 2014 and rising again thereafter at about 30% in 2017.

Under the alternative absolute magnitude restriction, 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, the relative importance of foreign shocks globally is always higher on average than that estimated using the event-study magnitude restrictions with a gap ranging between 2% in 2008 and 15% in 2014 and in some years this difference is statistically significant.

[Insert Figure 11, here]

5.4 Historical decomposition of the shocks

A complementary approach to appreciate the identification method is to look at the historical decomposition of the shocks. Due to space constraint, we focus only on the 2016 and 2017 period, which is characterised by a relatively large number of country-specific shocks that can be placed under a magnifying glass: the FED's first five interest rates hikes after the global financial crisis starting from 16 December 2015, 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, the Bank of Japan's announcements of negative interest rates on 29 January 2016 followed by an additional stimulus on 29 July 2016.

First of all, a common factor that explains developments in the 2-year OIS rates is global macroeconomic news. Macro news tend to fluctuate significantly and this is reflected in the dynamics of the 2-year OIS rates in the G4 economies. For example, in the first half of 2017, they have increased the 2-year OIS rates by about 30 basis points in the US, 20 basis points in the UK, 5 basis points in the euro area and 2 basis points in Japan (see Figures 12-15).

[Insert Figures 12-15, here]

As for the country-specific shocks, it is evident the impact of the US Presidential elections in November 2016. OIS rates in the US surged to their highest levels in months in anticipation of a fiscal stimulus, but such shocks lasted only few weeks: due to US shocks by the end of 2016, the 2-year OIS rates increased by about 35 basis points in the US, 15 basis points in the UK, and 5 basis points in the euro area and Japan.

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, 10 basis points in the US, 5 basis points in Japan and only 2 basis points in the euro area.

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.

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 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 quantity restriction is able to capture specific events, which are not controversial.

5.5 Event-study magnitude restrictions versus GIRFs

Given the contemporaneous correlations between asset prices, often practitioners use GIRFs to assess the source of spillovers. However, this is imprecise because GIRFs cannot address causality.

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 16) suggest significant differences particularly for the US. According to GIRFs, the shock contribution from the euro area was four times as larger before the financial crisis, 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, and rose further with the developments of the sovereign debt crisis in 2010. If we add the shock contribution from the UK, which is also larger under GIRFs, about 50-60% of the dynamics of the US 2-year OIS rate is explained by shocks originated in Europe. We think that this is implausible.

[Insert Figure 16, here]

5.6 Importance of foreign shocks in the sovereign yield segment

The results are expected to be relatively similar using the 2-year sovereign yields, because the credit risk of these economies is minimal. Therefore, we substitute the 2-year OIS rates with the 2-year sovereign yields and use the German Bund 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).

The key results of the paper are confirmed: (i) foreign shocks are important in determining the shorter-term interest rates, (ii) the US is well insulated from foreign shocks and is the main source of spillover globally during the global financial crisis, (iii) 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, (iv) the error bands are far smaller under the event-study magnitude restriction approach.

Table 3: Contemporaneous spillovers: An 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
	(0.07)		*(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 relative standard errors of the following equation $x_i = a_{i,j,0}x_j + \epsilon_i$, where x_i and x_j are respectively the daily changes in the 2-year sovereign yield of countries i and j on identified event dates in country j, as reported in Table 1.

Figure 17 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 short-term sovereign yields in all economies, but its importance has been fluctuating over time around 80% for the US, 70% for the euro area 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.[7]

[Insert Figure 17, here]

Lastly, Figure 18 shows the relative importance of foreign shocks in the dynamics of the 2-year sovereign yields globally. The share of the foreign spillovers increased from 20% in 2005 to 40% during the interbank crisis. The contribution of the foreign shocks globally declined after Lehman's bankruptcy, when all central banks cut reference rates and introduced unconventional monetary policies, such as asset purchases and longer-term refinancing operations, reaching the lowest point in 2011 in the middle of the euro

[7] 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.

area sovereign debt crisis. The role of foreign spillovers were muted also in 2014 and 2015 when the ECB and Bank of Japan launched more aggressive monetary policy actions, such as negative reference rates, asset purchases and forward guidance. The relative importance of foreign shocks has been increasing in 2017 reaching again 35%, possibly hinting to some normalisation in asset markets.

[Insert Figure 18, here]

5.7 Robustness checks

It could be argued that domestic shocks are not well identified because the model does not take into consideration the direct effect of the policy rate. Therefore, we include the euro area 1-month OIS rate and impose a zero restriction such that shocks to the 2-year OIS rates do not affect contemporaneously the euro area 1-month OIS rate, while shocks to the latter affect contemporaneously all the 2-year rate segment. The results for the euro area 2-year OIS rate indicate that the contribution of the domestic shocks, computed summing up the contribution of the own shocks to both 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 19).

[Insert Figure 19, here]

The analysis in the previous sections has been carried out using a predictive horizon equal to 12 days to capture a medium-run horizon. Figure 20 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 to UK OIS rates contributing to 45% during the interbank credit crisis and during the sovereign debt crisis. Similarly, shocks from the UK to euro area OIS rates contributed to 40% after Lehman's collapse.

[Insert Figure 20, here]

Given that the coefficients from the event study to and from Japan are not statistically significant, we also exclude Japan from the model. The results on the other three economies are invariant.[8]

We also consider the case of oil prices in levels treated as an endogenous variable in the VAR system and assume that oil price developments can affect contemporaneously all money market rates, while shocks to money market rates affect oil prices only after one period. Also in this case, the results are broadly invariant.

6 Conclusion

Spillovers are an important subject with a long history in the macro-finance literature. However, the identification of structural shocks is an important issue, because asset prices move simultaneously and are influenced instantaneously by foreign developments.

We suggest a new method, which identifies structural shocks imposing restrictions on the relative size of the contemporaneous impact of the shocks in different asset markets, guided by the event-study methodology. This new method imposes bounds on the impact matrix, but it remains agnostic about the sign of the responses. Relative to the existing literature, our approach combines the appeal of the event-study methodology with the advantages of SVAR analysis.

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

All in all, except for the US, the domestic money market rates are highly affected by foreign spillover. 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, while the foreign spillovers from Japan are very much limited. Euro area short-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. Shocks from the euro area are also important for the dynamics of UK money market rates.

Lastly, we show that, by pinning down the impact matrix to bounds suggested by key historical events, the inference improves and error bands reduce dramatically relative to

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

other established methods.

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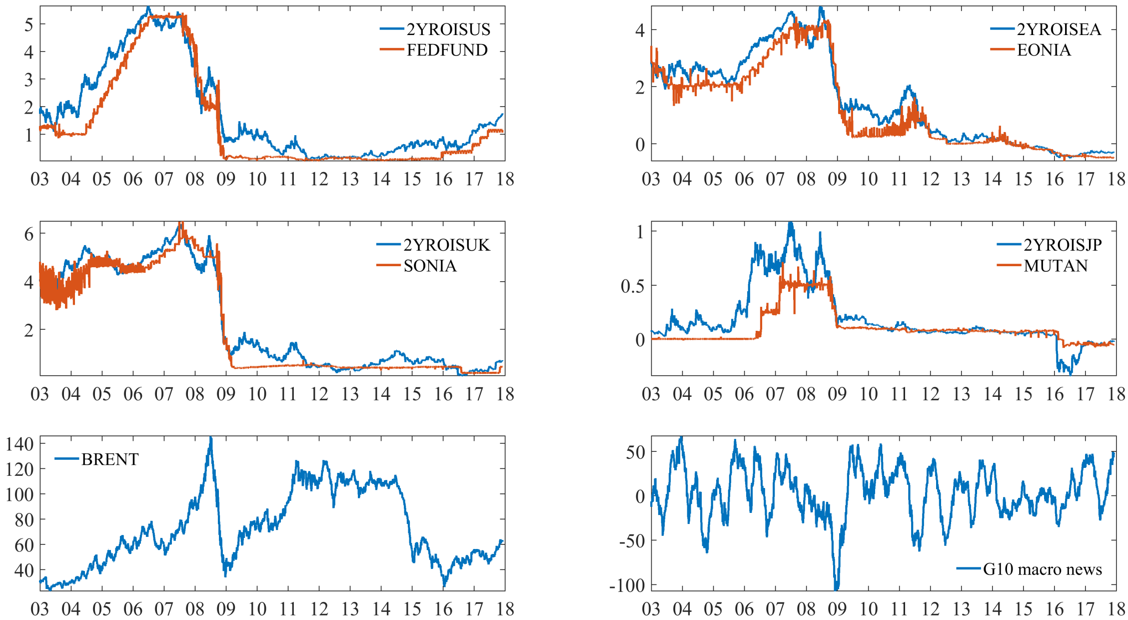
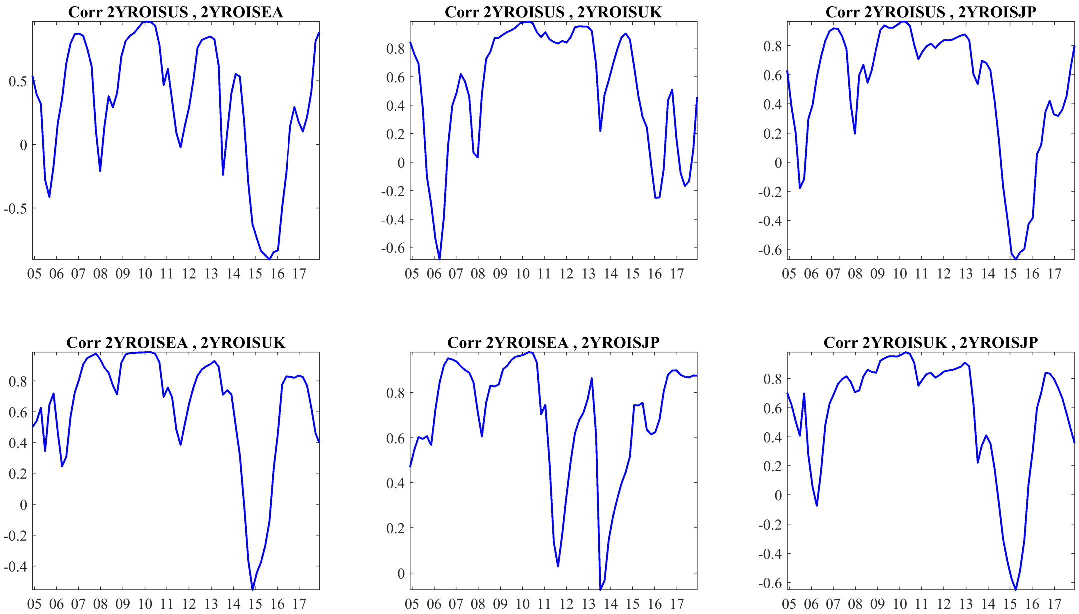
Figure 2: Short-term money market rates, oil prices and macro news



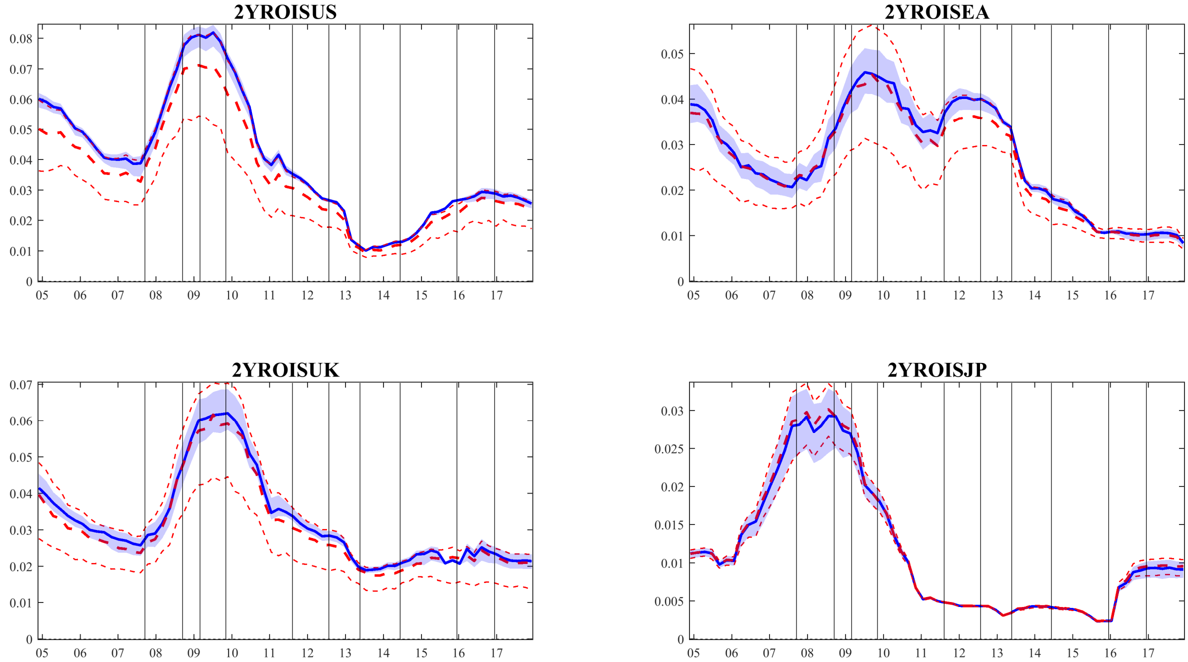
Source: Bloomberg and Thomson Reuters.
Note: This figure shows the unsecured overnight lending in the euro area (EONIA), Japan (MUTAN), the United Kingdom (SONIA) and the United States (Fed Fund rate) together with the respective 2-year OIS rates; the Brent crude oil price per barrel in US dollar and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

Figure 3: Dynamic correlations between 2-year OIS rates



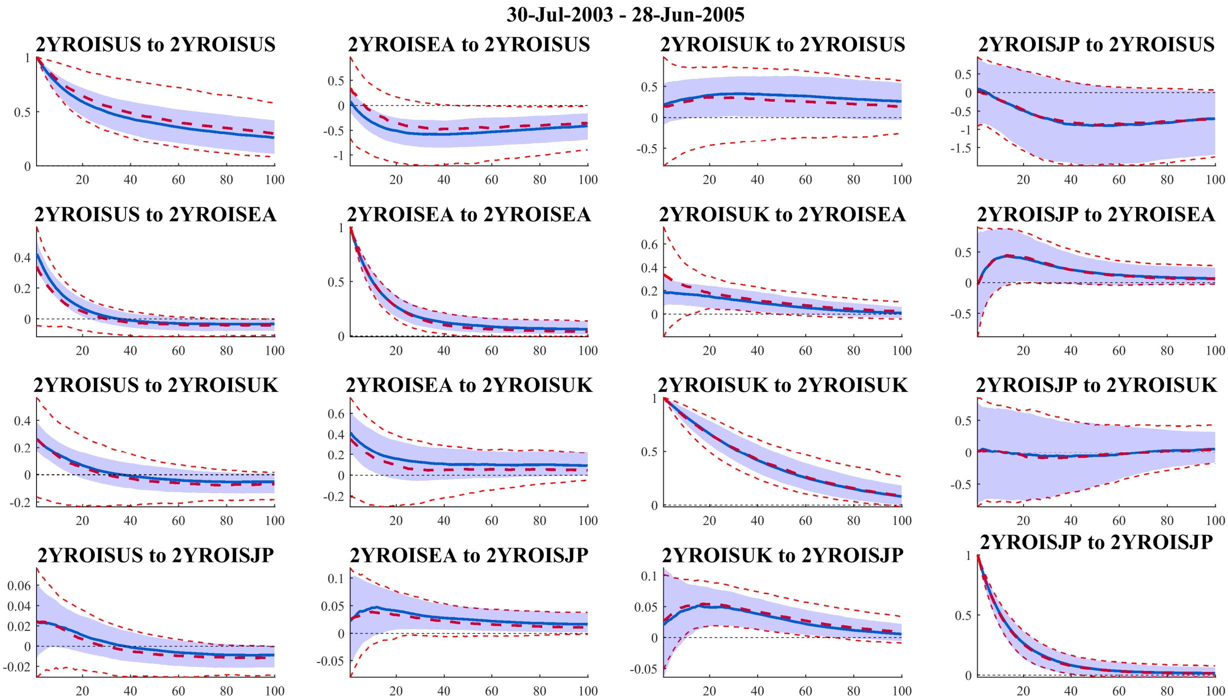
Source: Bloomberg and Thomson Reuters.
Note: This figure shows the unconditional correlations between 2-year OIS rates using a 500 business days rolling window.

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



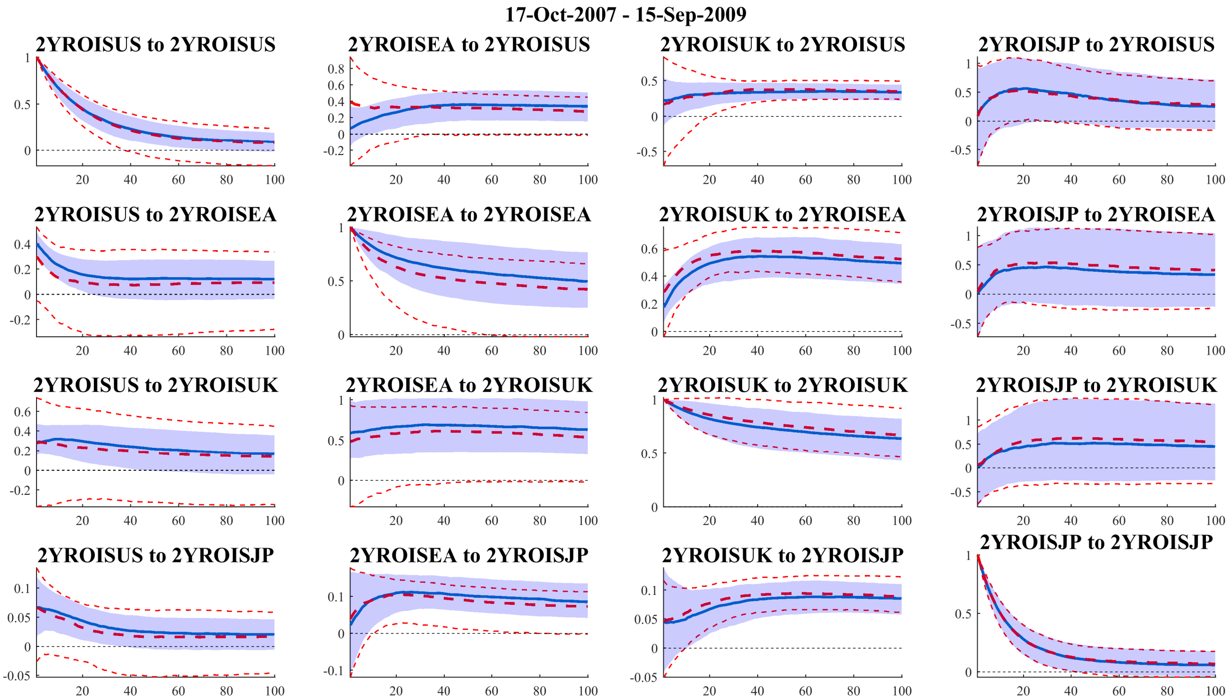
Note: This figure shows the estimated standard deviation of 2-year OIS shocks. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error 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: 1 January 2003 - 4 December 2017.

Figure 5: IRFs during the pre-financial crisis period



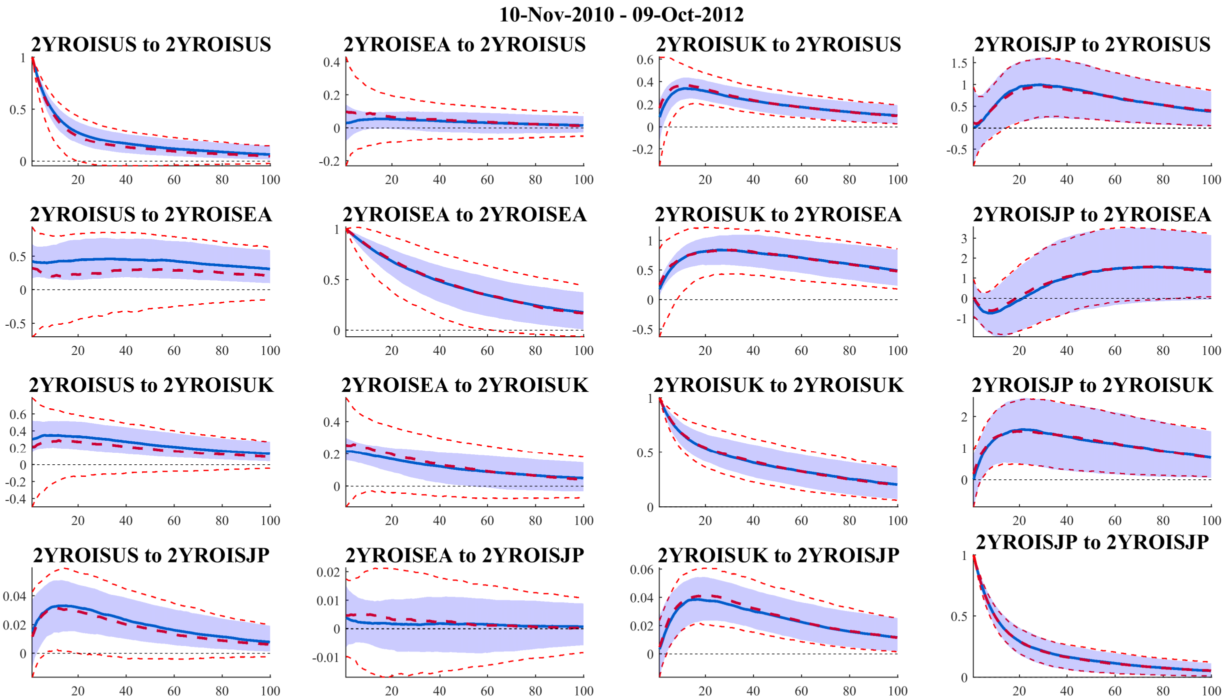
Note: This figure shows the impulse response functions (IRFs) due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 30 July 2003 - 28 June 2005. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error bands obtained using the -/+ 1 magnitude restriction method.

Figure 6: IRFs during the global financial crisis



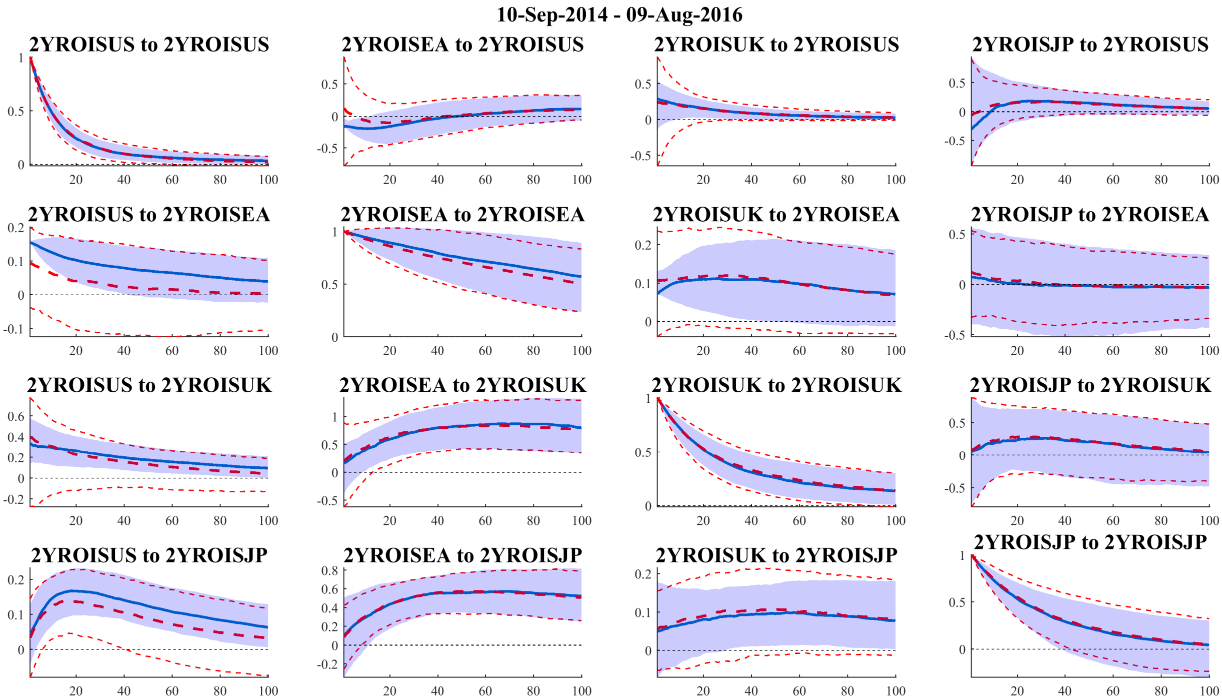
Note: This figure shows the impulse response functions (IRFs) due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 17 October 2007 - 15 September 2009. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error bands obtained using the -/+ 1 magnitude restriction method.

Figure 7: IRFs during the euro area sovereign debt crisis



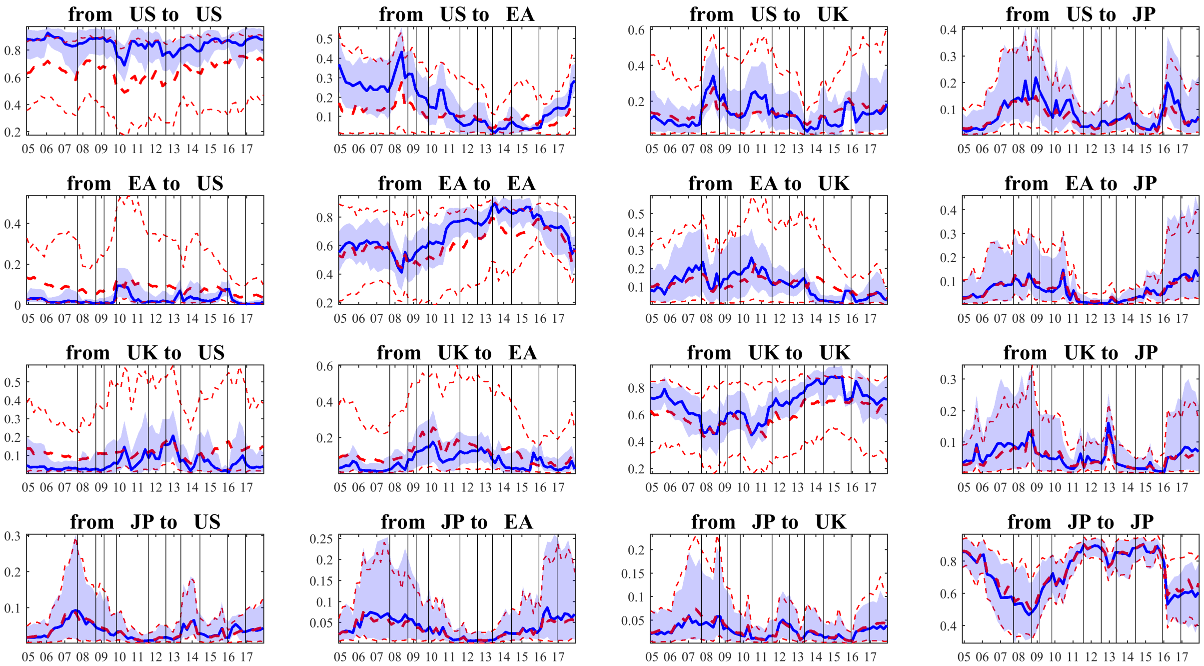
Note: This figure shows the impulse response functions (IRFs) due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 10 November 2010 - 09 October 2012. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error bands obtained using the -/+ 1 magnitude restriction method.

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



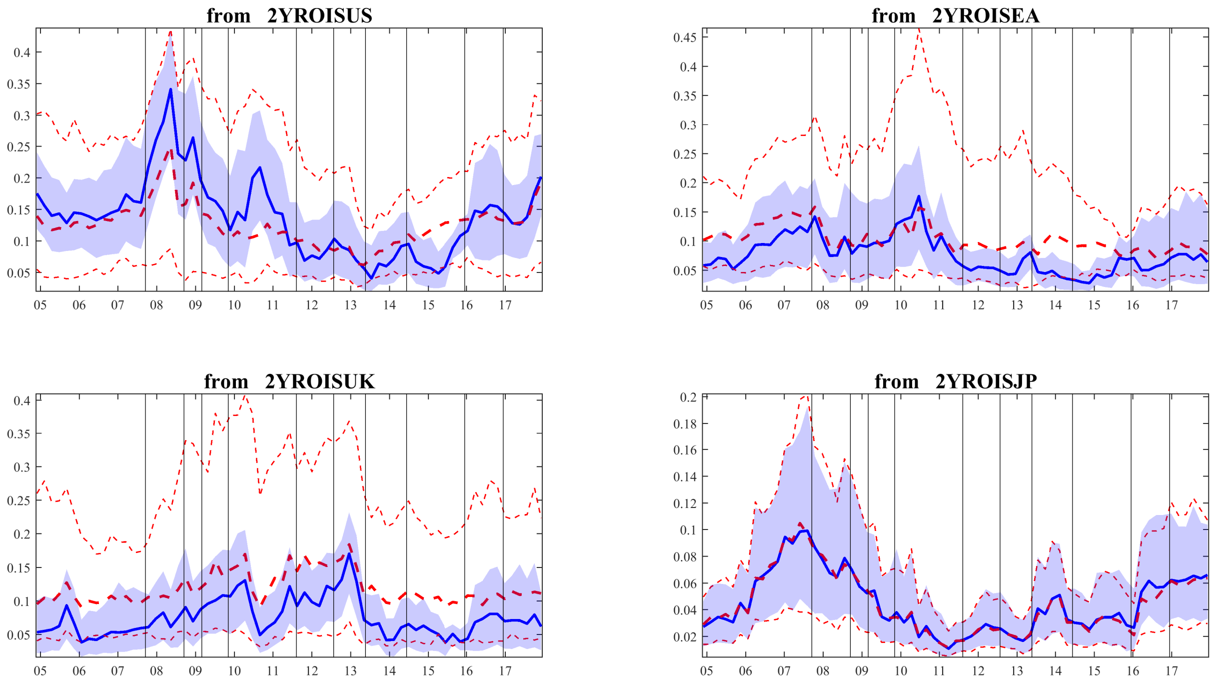
Note: This figure shows the impulse response functions (IRFs) due to shocks to 2-year OIS rates in euro area, Japan, the UK and the US estimated over the sample period 10 September 2014 - 09 August 2016. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study magnitude restriction method. The dotted red lines provide the median estimate and the 68% error bands obtained using the -/+ 1 magnitude restriction method.

Figure 9: The relative importance of domestic and foreign shocks to the 2-year OIS rates: From country j to country i



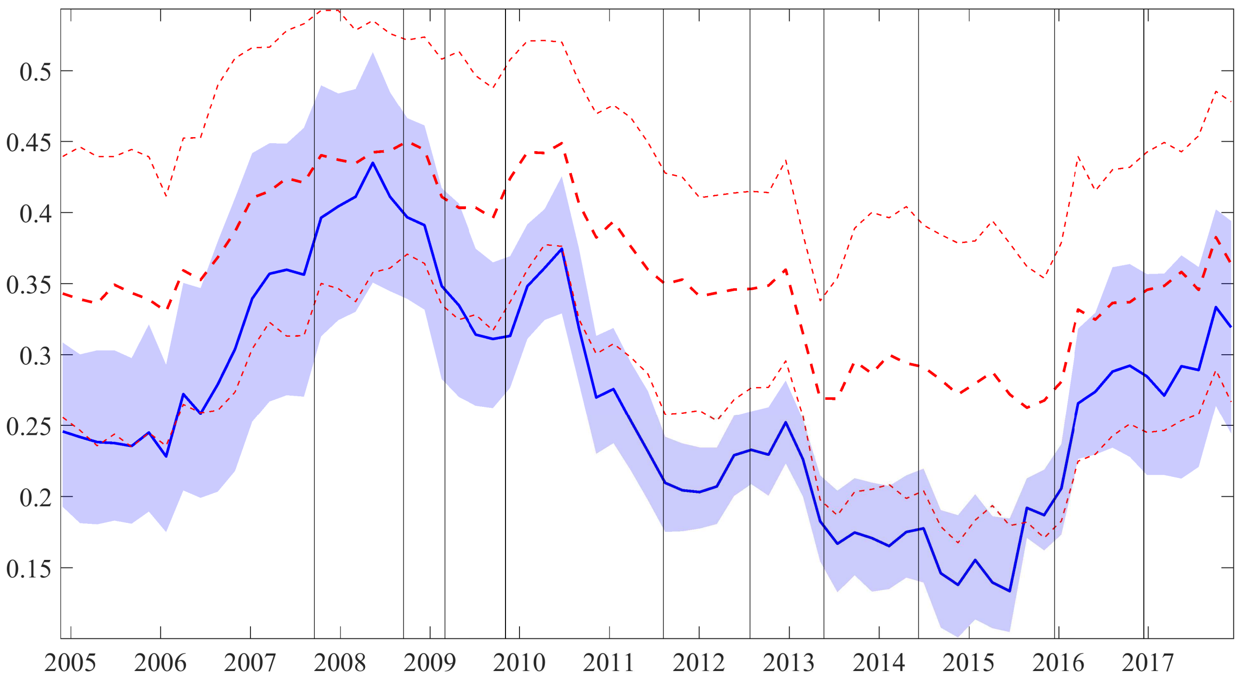
Note: This figure shows the contribution of 2-year OIS shocks from country j to country i. The predictive horizon is set at $H = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the event-study 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: 1 January 2003 - 4 December 2017.

Figure 10: The relative importance of foreign shocks to the 2-year OIS rates: From country j to the rest of the world



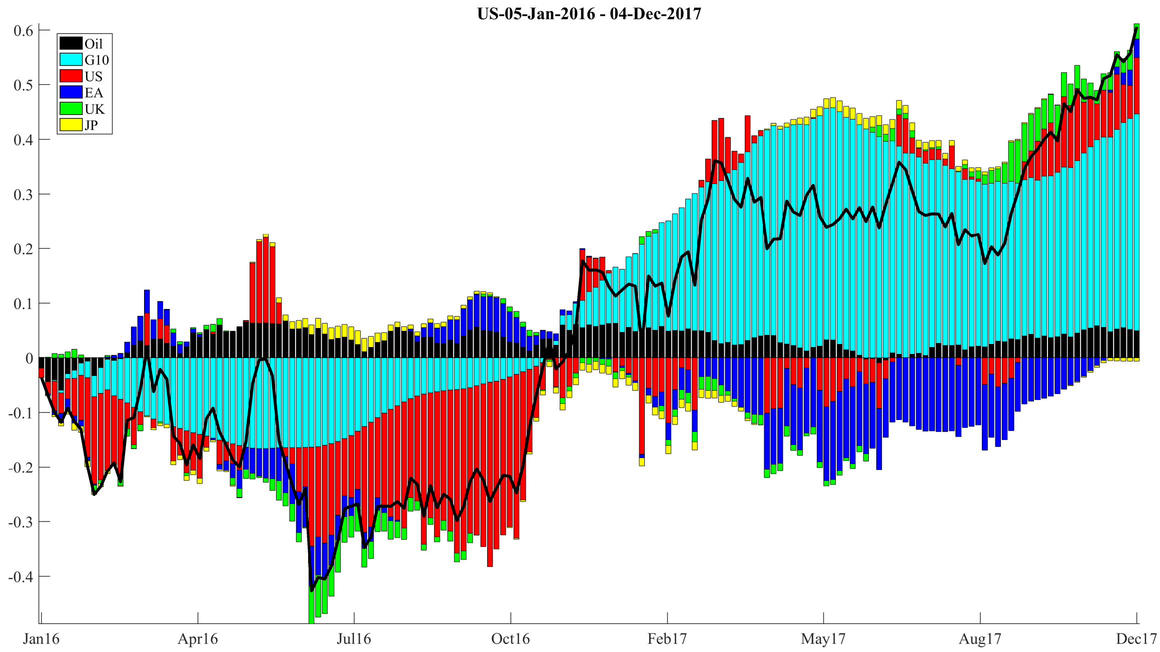
Note: This figure shows the contribution of 2-year OIS foreign shocks from country j to all other 2-year OIS rates. The predictive horizon is set at $H = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained 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: 1 January 2003 - 4 December 2017.

Figure 11: The relative importance of foreign shocks to the 2-year OIS rates globally



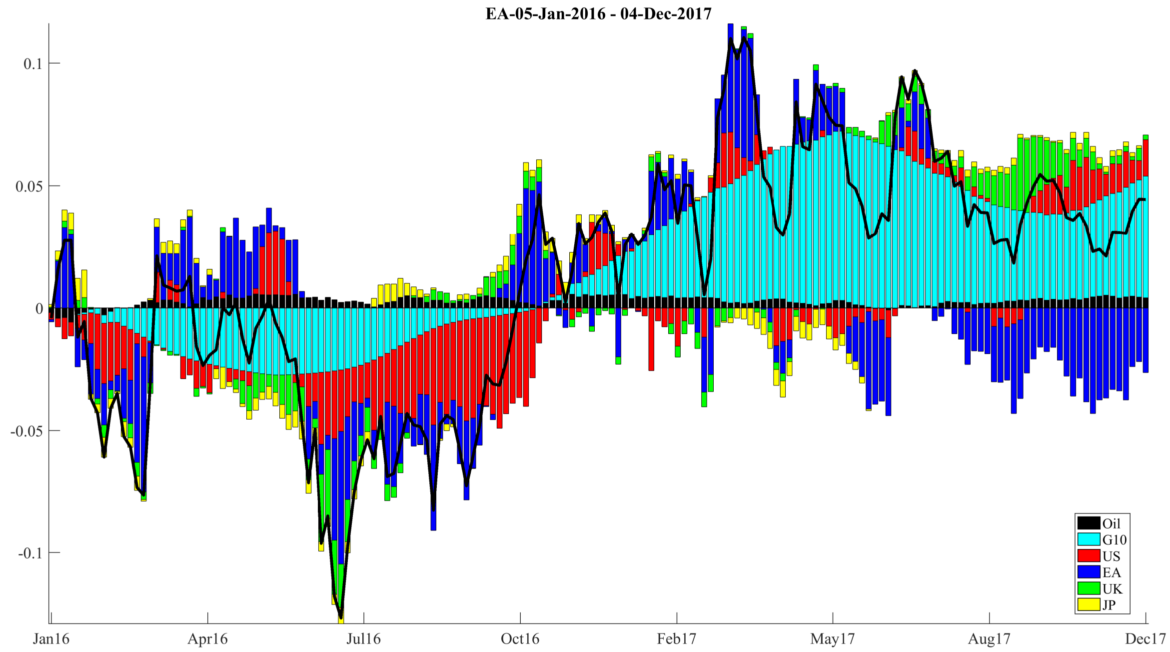
Note: This figure shows the contribution of 2-year sovereign yield foreign shocks to 2-year sovereign yield globally. The predictive horizon is set at $H = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained 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: 1 January 2003 - 4 December 2017.

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



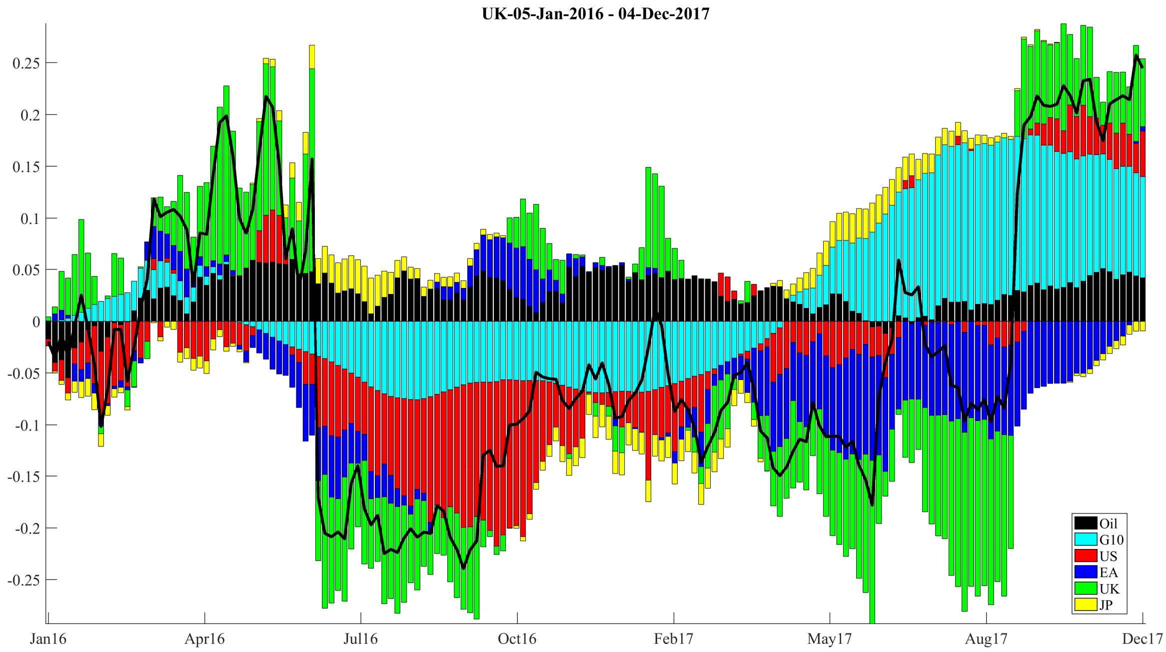
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the US 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. Sample period: 5 January 2016 - 4 December 2017.

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



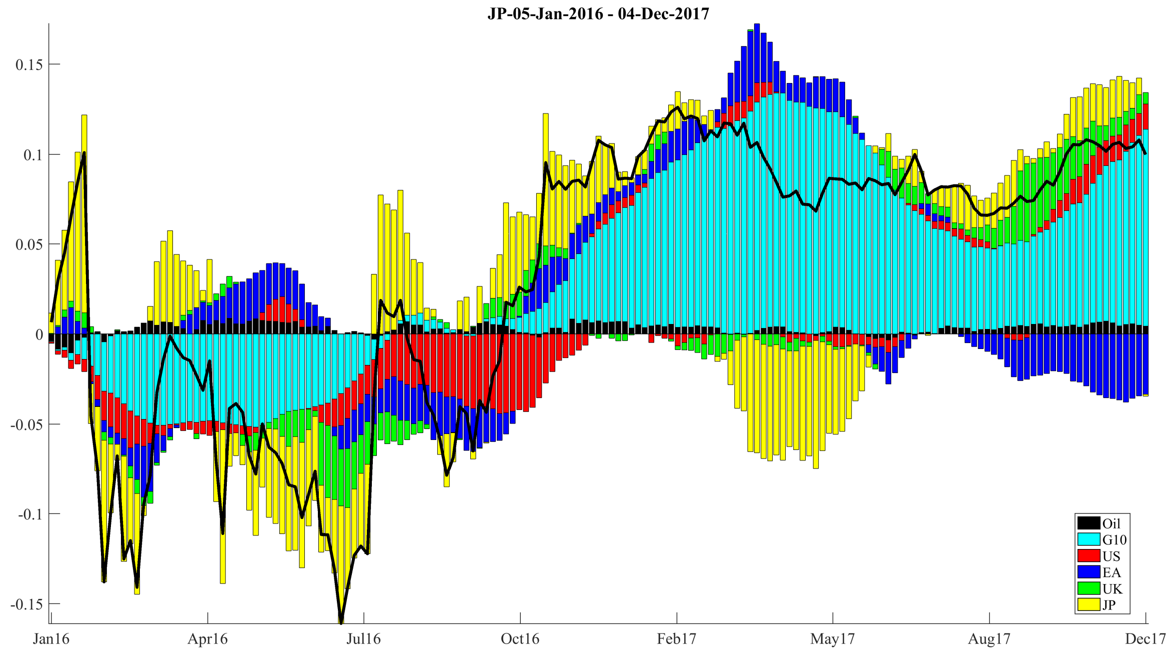
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the US 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. Sample period: 5 January 2016 - 4 December 2017.

Figure 14: Historical decomposition of shocks in 2016 and 2017: UK 2-year OIS rate



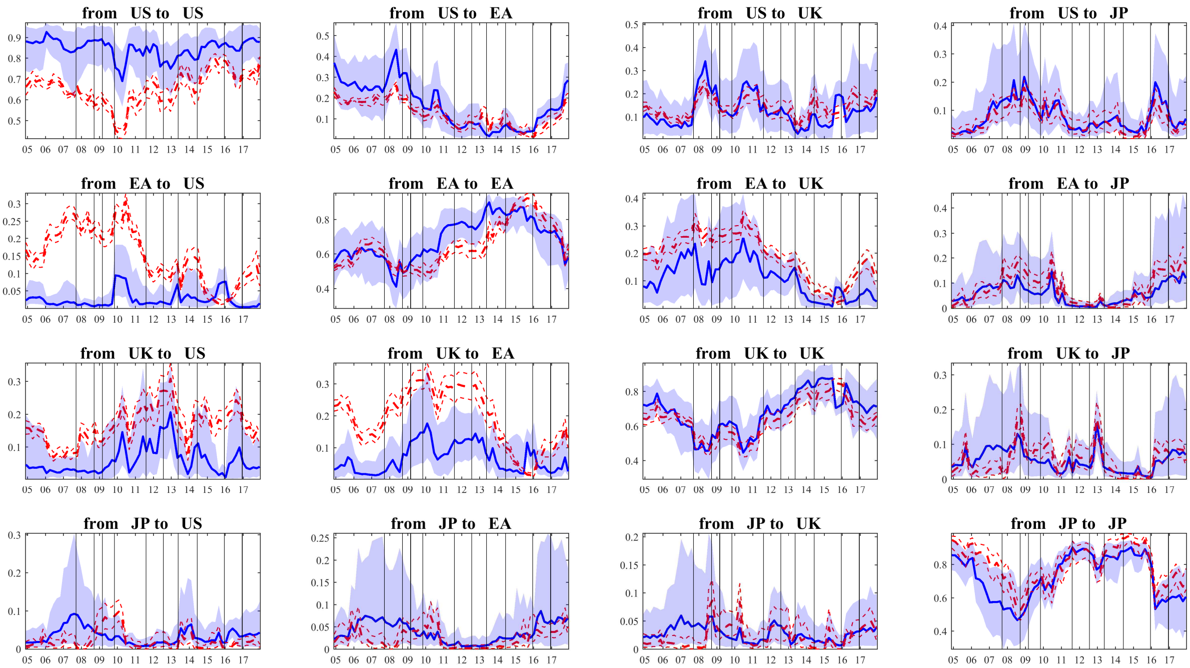
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the US 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. Sample period: 5 January 2016 - 4 December 2017.

Figure 15: Historical decomposition of shocks in 2016 and 2017: JP 2-year OIS rate



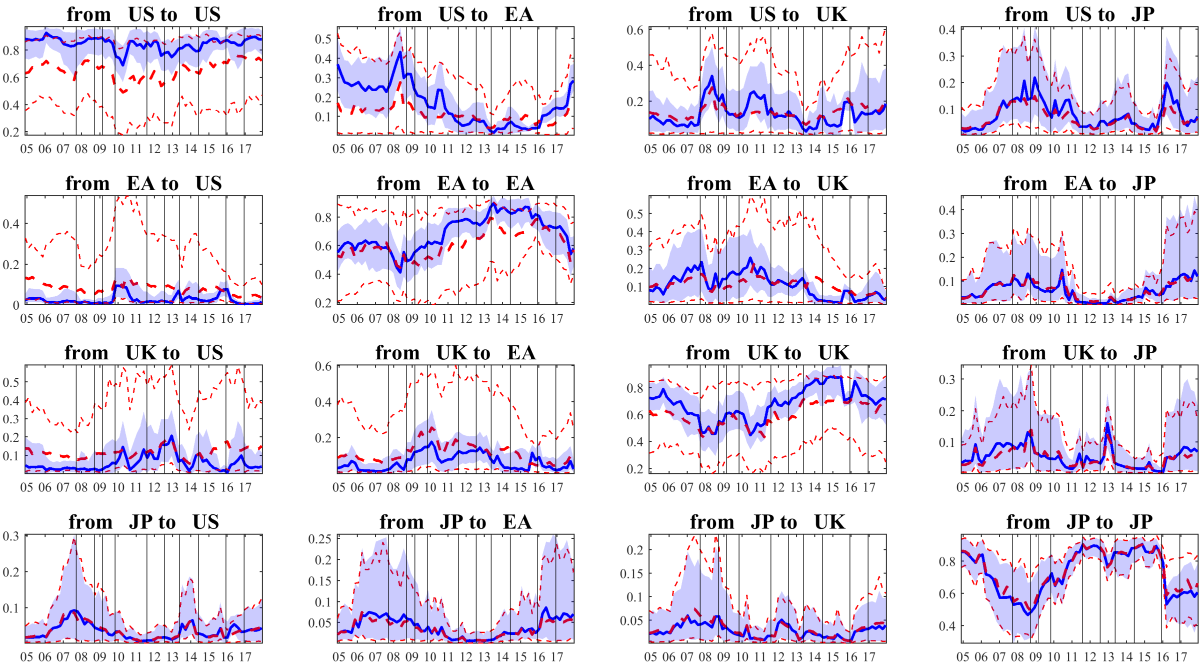
Note: This figure shows the contribution of 2-year OIS rate shocks and global shocks to the US 2-year OIS rate. Shocks are identified using the event-study magnitude restriction method. Sample period: 5 January 2016 - 4 December 2017.

Figure 16: The relative importance of domestic and foreign shocks to the 2-year OIS rates - Event study magnitude restriction versus GIRFs: From country j to country i



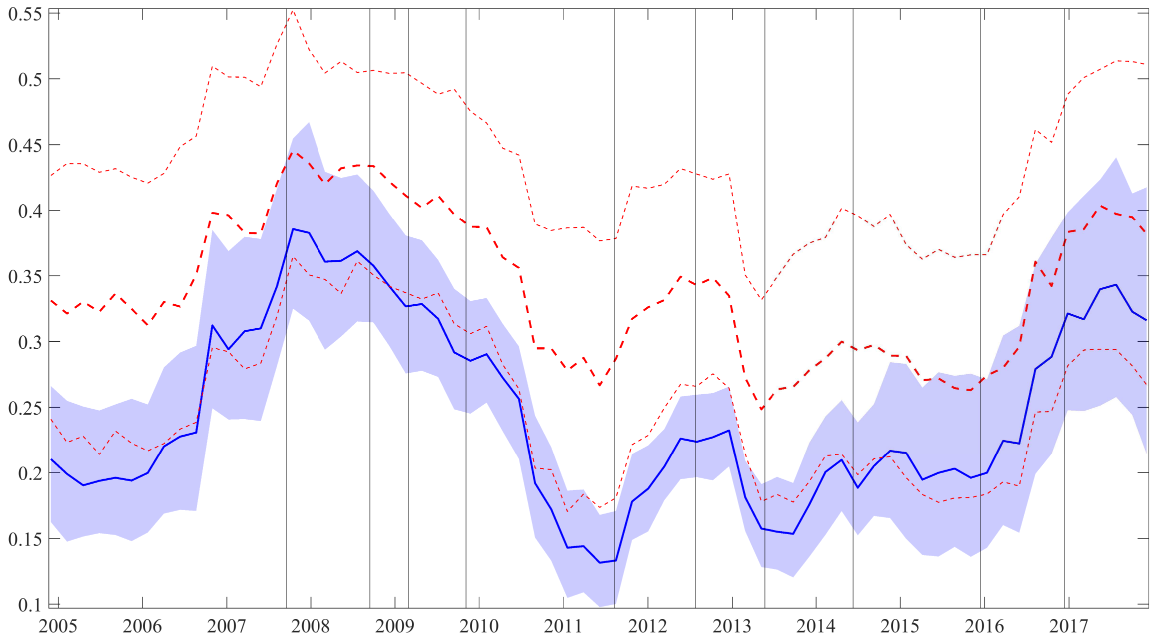
Note: This figure shows the contribution of 2-year sovereign yield shocks from country j to country i. The predictive horizon is set at $H = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the 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: 1 January 2003 - 4 December 2017.

Figure 17: The relative importance of domestic and foreign shocks to the 2-year sovereign yields: From country j to country i



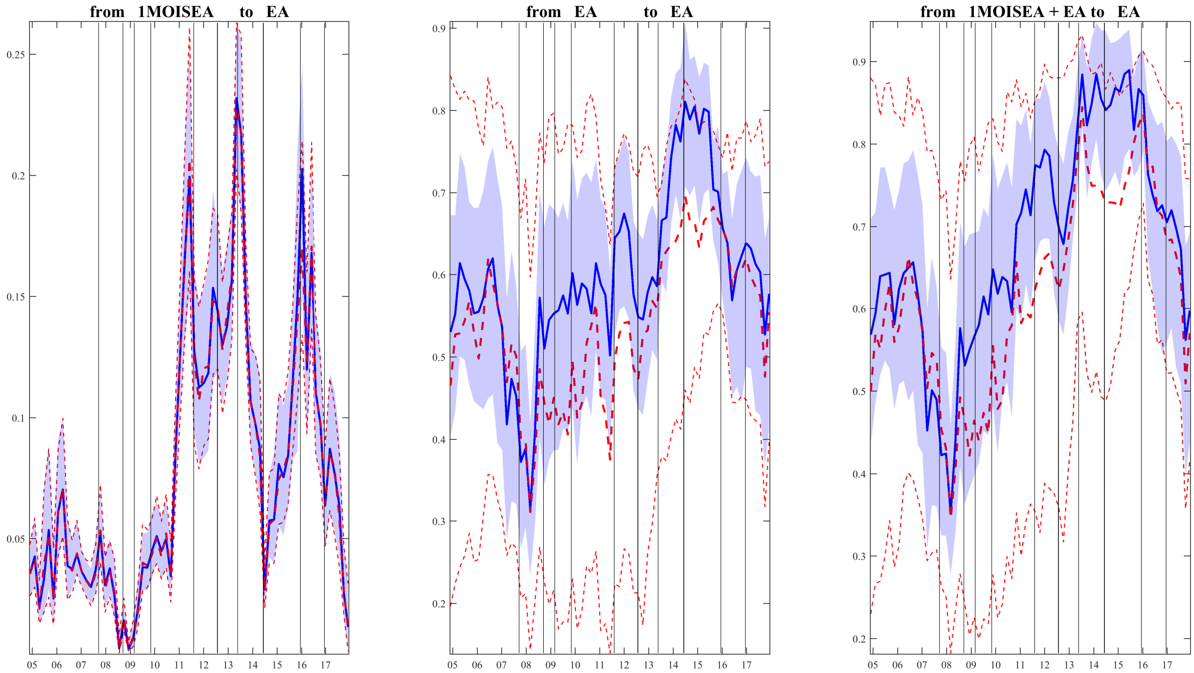
Note: This figure shows the contribution of 2-year sovereign yield shocks from country j to country i. The predictive horizon is set at $H = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained using the 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: 1 January 2003 - 4 December 2017.

Figure 18: The relative importance of foreign shocks to the 2-year sovereign yields globally



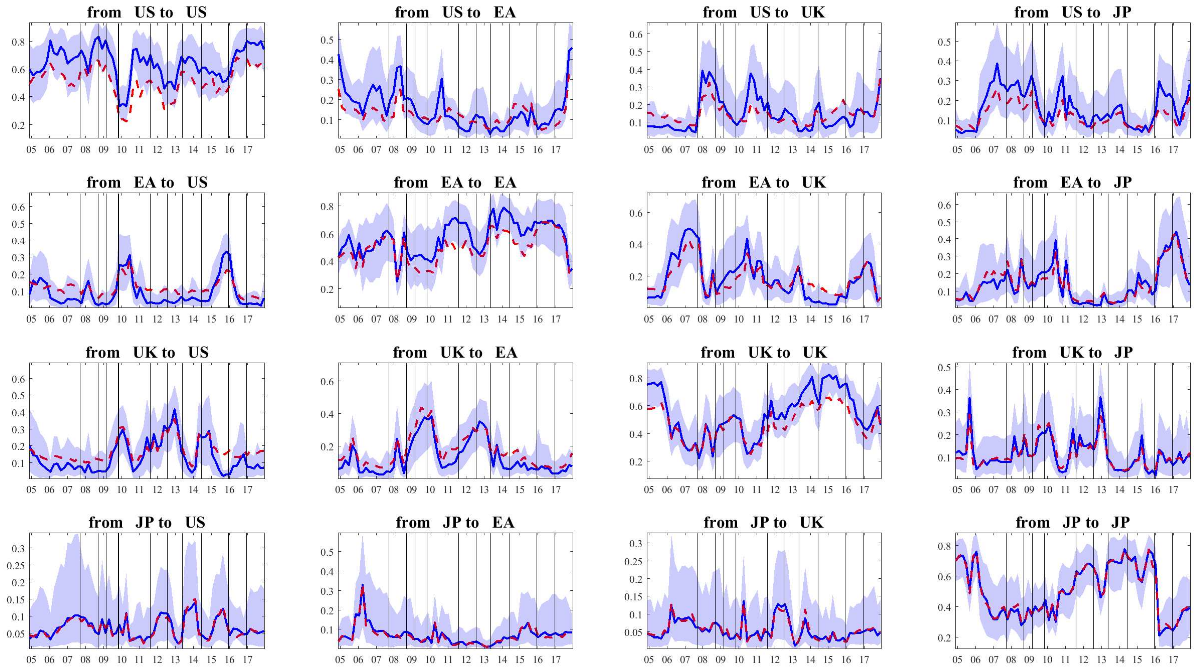
Note: This figure shows the contribution of 2-year sovereign yield foreign shocks to 2-year sovereign yield globally. The predictive horizon is set at $H = 12$ days to capture a medium-run horizon. The blue line and the shaded area provide respectively the median estimate and the 68% error bands obtained 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: 1 January 2003 - 4 December 2017.

Figure 19: The relative importance of domestic shocks in the euro area



Note: This figure shows the contribution of 2-year sovereign yield foreign shocks to 2-year sovereign yield globally. 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: 1 January 2003 - 4 December 2017.

Figure 20: The relative importance of domestic and foreign shocks to the 2-year OIS rates in the long-run: From country j to country i



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 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: 1 January 2003 - 4 December 2017.

A Estimation algorithm

The estimation procedure consists of three steps. The reduced form VAR model is estimated in the first step. The structural shocks are identified in the second step. The third step is introduced to account for estimation uncertainty.

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 Ordinary Least Squares (OLS) to obtain an estimate of 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 related to the structural IRF via $B(L) = A_0 C(L)$ 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:

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

   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.[9]

(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 $\hat{B}(L) = \hat{C}(L)\hat{\hat{S}}\hat{Q}$.

3. **Estimation uncertainty:** to account for estimation uncertainty, we repeat steps 1 and 2 1000 times, each time with a new artificially constructed data sample, Y^*. To construct data samples, we use re-sampling of errors. The new data sample is constructed recursively as $y_t^* = \hat{A}_1^* y_{t-1}^* + ... + \hat{A}_N^* y_{t-N}^* + \widehat{u_t}^*$, starting from the initial values $[y_0, ..., y_{N-1}]$. $\hat{A}_n^*$ are the estimated reduced form autoregressive coefficients and $\widehat{u_t}^*$ are drawn randomly, with replacement, from the estimated reduced form errors, $\widehat{u_t}$.

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

[9]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.