

# Heterogeneous effects in the international transmission of the US monetary policy: a factor-augmented VAR perspective

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**Abstract** This paper analyses the international transmission of US monetary policy shocks. We use a time-varying, factor-augmented VAR framework to examine how and to what extent the propagation of US policy shocks affects the South East Asian (SEA) and European Union (EU) economies, through various transmission channels. We find that in the SEA economies, the income absorption effect is the most pronounced channel as indicated by the significant worsening of the trade balance of these countries, which provokes a reduction in their output. In addition, wealth effects and the balance sheet channel have an important contribution in the transmission of the shock to these economies. In the EU, the initial rise observed in output as a result of the shock is driven more by exchange rate movements rather than movements in the trade balance. In terms of changes in the magnitude of the effect of the shock over time, we find that the deepening of global integration dampens the effect of the shock on the foreign economies in core macroeconomic and financial variables. Moreover, the impact of the shock on the foreign economies has increased in the post-crisis period.

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## 1 Introduction

In recent statements, the Federal Reserve (FED) announced that in the near future it will start raising short-term interest rates, thereby putting an end to the near-zero borrowing costs that have prevailed since the US financial crisis. This will be the first rate increase since 2007, when the FED raised the federal funds rate (FFR) four times to calm the domestic housing market dynamics. Nevertheless, the US economy is strongly interconnected with most of the world economies (hereafter rest of the world, RoW) via trade and financial linkages. This means that a US policy rate change will affect the country itself, and in addition, the effects will be transmitted to the RoW economies as well. This paper discusses the policy implications arising from the transmission of a contractionary US policy shock in an international context by determining whether the transmission of the shock has changed over time and how it has affected the international counterparts of the USA.

A large body of the literature has highlighted the international transmission of monetary policy shocks originated in the USA. Some of these studies use small-scale VAR models to examine the propagation of US policy shocks on foreign economies (Kim 2001; Neri and Nobili 2010; Miniane and Rogers 2007). However, the use of these models potentially creates an omitted variable bias with adverse consequences for structural analysis. For example, Christiano et al. (1999) point out that the price puzzle (positive reaction of prices in response to a monetary tightening) results from the omission of forward looking variables. In addition, central banks monitor and respond to a large information set. Therefore, the size limitation is problematic for applications which require the study of a larger set of variables than the key macroeconomic indicators. Recent studies (Bernanke et al. 2005; Korobilis 2013; Ellis et al. 2014; Bagzibagli 2014) have addressed this issue by using large-scale factor-augmented VAR (FAVAR) models to examine the monetary policy transmission in the domestic economies.<sup>1</sup> The authors find that these models successfully apply both in the context of forecasting and structural analysis by eliminating the price puzzle.

Another strand of the literature uses this methodology to investigate the transmission of different type of shocks in the international context. For instance, Boivin and Giannoni (2008) study the impact of international shocks on the US economy. They conclude that the effect of global shocks on the economy is only a recent phenomenon. In another study, Mumtaz and Surico (2009) examine the effects of various international shocks on the UK economy. They argue that an unanticipated fall in the world interest rate increases investment, GDP and consumption, while CPI and GDP defla-

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<sup>1</sup> In particular, Bernanke et al. (2005) and Korobilis (2013) use describe the US monetary transmission mechanism, Ellis et al. (2014) focus on the transmission mechanism within the UK, while Bagzibagli (2014) investigates monetary transmission in the euro area.

tors reach their maximum values 3 years after the shock. Our paper is related to this second strand of the literature which employs FAVAR models in order to examine the transmission of monetary policy shocks in open economies. However, we diverge from these studies in that we focus on the transmission of US policy shocks to the global economies as opposed to the impact of international shocks on the USA.

In the light of the above, this paper sets up two main policy questions. The first question aims to shed light on the channels through which a US policy shock is transmitted to the RoW economies. The second policy question explores the extent to which the magnitude of the effect of the policy shock has changed over time. We focus our analysis on two distinctive periods, reduced versus increased global integration periods and the pre- and post-2007 financial crisis period. Concerning the latter period, a further issue to be tackled is whether there is interplay between the monetary policy measures undertaken by the US policymakers and the responses by a significant number of foreign central banks that are acting as followers to the US monetary policy. To address our research questions formally, we derive a FAVAR framework with the following distinguishing features, in order to examine the international channels through which a US monetary policy shock is transmitted to the world economies.

The first distinguishing feature is the inclusion of time-varying parameters in our FAVAR model. Within this context, our study contributes in respect of similar studies (Korobilis 2013; Ellis et al. 2014) in at least two dimensions. First, it can reassess our policy questions in major economic events and time periods (e.g. the first US rate hike in almost a decade from the zero lower bound) considering the possibility that the effect of a change in policy stance might be different than before the 2007 financial crisis or/and the global integration starting in 1987. Moreover, it allows us to examine the US transmission mechanism in different time points, avoiding the estimation over different subsamples. Boivin et al. (2010) point out that the evolution of monetary transmission is too complex to be captured solely by splitting the sample. Using a large set of variables for the US, Asian and European economies, which covers a long history of major economic events, we compare changes in the magnitude of the effect of the US shock at different points of time.

Second, this paper employs a large dataset which jointly models three different dimensions of the USA and the foreign economies. These dimensions are: real activity, inflation and asset prices. In contrast to the relevant literature (Bernanke et al. 2005; Korobilis 2013; Mumtaz and Surico 2009), we add a fourth dimension, namely the trade factor; and this is another distinguishing feature of our study. The idea behind this is twofold; first, to use a wide information set that accounts for various trade activity variables and second, to investigate the effects of the shock in individual trade activity indicators such as exchange rates, terms of trade and the trade balance.

Our third distinguishable feature relates to the monetary policy transmission channels. According to the insights provided by a vast theoretical literature dating back to Mundell (1962) and Fleming (1962), the transmission of a monetary policy shock can be described by four different channels, which are briefly discussed here. The first channel is described under the Mundell–Fleming–Dornbusch (hereafter MFD)

model.<sup>2</sup> Under MFD, there are two different effects that move the trade balance in opposite directions: the income absorption effect and the expenditure switching effect. In the former, and under a contractionary policy, a decrease in domestic income decreases domestic import demand, which may improve the trade balance. As a result, the foreign trade balance deteriorates and foreign output falls. In the latter, a monetary tightening results in real exchange rate appreciation which, in turn, causes the trade balance to deteriorate and leads to an improvement of the foreign trade balance and a rise in the foreign output.

The second channel is described under the Redux model by Obstfeld and Rogoff (1995) and Svensson and Wijnbergen (1989). The Redux model is considered as the successor to the MFD, and it provides applications of the intertemporal model, equipped with sticky prices and/or wage rigidity, to the international transmission of monetary policy. Under this model, a rise in the key country's rate will reduce domestic output and consumption and moreover reduce foreign consumption and foreign output, thereby reducing the world real interest rate, which in turn accommodates worldwide decreases in current consumption. This implies that imports and exports in domestic and the foreign economies may decrease since residents in both parts decrease their demand for both domestic and foreign goods and services.

The third channel is based on the transmission of monetary policy via wealth effects on the domestic level, as denoted by Brumberg and Modigliani (1954) and later augmented by Ando and Modigliani (1963). The channel states that a monetary tightening leads to a fall in equities that lowers total wealth. As a result, consumption and output will decrease. The last channel is the balance sheet, developed by Bernanke and Gertler (1989) and Bernanke et al. (1999). Under this channel, a monetary tightening leads to a decline in asset securities, which lowers the net worth of firms. Lower net worth means that agents have less collateral, thereby increasing adverse selection and moral hazard problems, since the incentive to boost risk taking is amplified. Therefore, lenders will be more unwilling to give loans, either by cutting the quantity lent or by demanding higher risk premiums, thereby leading to a decline in spending and aggregate demand.

This paper takes a new perspective and extends both the wealth effects and the balance sheet channels into the international context. In particular, under the wealth effects the contractionary policy not only has an effect on the stock markets, but also leads to an appreciation of the domestic currency. This leads to the depreciation of the foreign currency and in turn an increase in the foreign inflation rate. Therefore, due to inflation of the foreign prices, there will be a decrease in employment (and the output) due to a contraction in total wealth and consumption. Regarding the balance sheet channel, a monetary tightening in a large world economy such as the USA may lead to significant decreases in foreign stock markets and a decline in credit. As a result, consumption declines in the foreign economies.

Our findings have important policy implications which add value to the existing literature in the following ways. First, we bring into light the channels that matter most in the transmission of the US monetary policy. In the SEA economies, the income

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<sup>2</sup> MFD model is described in: Mundell (1962), Fleming (1962), Mundell (1963, 1968) and Dornbusch (1976).

absorption effect plays an important role as indicated by the significant worsening of the trade balance of these countries, which provokes a reduction in their output. Therefore, our results verify the importance of this channel as described by the MFD model. Beyond movements in trade balance, wealth effects changes and changes in balance sheet, all have an important contribution in the transmission of the shock to these economies. In the EU, on the other hand, not all channels of monetary transmission are pronounced. We find that the initial rise observed in output in most EU countries as a result of the shock is more driven by exchange rate changes rather than movements in the trade balance. This result highlights the role of the exchange rates as the main transmission channel in Europe. The other channel that matters most in the region is wealth effects, as indicated by immediate depreciation in effective exchange rates and inflation pressures as a result of the shock.

Secondly, we find that the transmission mechanism of the US policy shock to the SEA and the EU economies is facing a great heterogeneity during the global integration and the pre- and post-US financial crisis period. In particular, the findings suggest that the deepening of global integration has dampened the effect of the shock on foreign economies in core macroeconomic and financial variables, while the transmitted shock has increased for the majority of the variables in the post-crisis period. This is motivated by the strong dynamic links with countries' policy reactions in response to the crisis, which create uncertainty and hamper financial flows by arbitraging investment opportunities. Finally, we argue that there is a homogeneous response of RoW's monetary stance to the US policy shock, such that the EU and the SEA central banks have acted as followers to the US policy shock, revealing a foreign policy endogeneity. In particular, central banks in the EU have responded by increasing short-term rates and reducing their money supply in order to cool inflationary pressures, while the SEA central banks have nullified depreciations in their currencies from the US policy shock.

The rest of the paper is organized as follows. Section 2 presents the time-varying FAVAR model setup, the estimation and the responses. Section 3 describes the data, while Sect. 4 illustrates the empirical findings, together with a discussion of the results and policy implications. Section 5 summarizes and concludes.

## 2 Model setup

### 2.1 The FAVAR model

The FAVAR model introduced by Bernanke et al. (2005) is a coherent approach for examining the monetary policy transmission in the sense that it allow us to use a large number of economic and financial variables and based on this information, to obtain a reduced number of unobserved latent variables that drive the systematic components of an economy. Without loss of generality, we illustrate the FAVAR model, assuming a  $p$ -order lag.

Consider the information concerning the US and the RoW economies as summarized in the vector  $f_t = [f_t^{\text{ROW}}, f_t^{\text{US}}]'$  with  $K$  latent factors, extracted from a large panel of  $N$  macroeconomic indicators. Let the monetary policy instrument (i.e. the FFR) be the only observable indicator, denoted as  $R_t$ . The dynamics of the unobserved factors

together with the observable factor are described in a standard finite  $p$ -order VAR model:

$$F_t = B_{1t}F_{t-1} + \dots + B_{pt}F_{t-p} + u_t \quad (1)$$

where  $F_t = [f_t, R_t]'$ ,  $f_t$  is the  $K \times 1$  vector of latent factors,  $R_t$  is the observable FFR,  $B_{it}$  is the  $K \times K$  matrix of coefficients, and  $u_t$  is a vector of  $K$  idiosyncratic shocks with zero mean and variance–covariance matrix  $\Omega_t$ . Following Cogley and Sargent (2005), the covariance matrix  $\Omega_t$  in Eq. (1) is decomposed as  $A_t\Omega_tA_t' = \Sigma_t\Sigma_t'$  with  $\Sigma_t = \text{diag}[\sigma_{1t}, \dots, \sigma_{K+1,t}]$ , while  $A_t$  is a lower triangular matrix with its diagonal elements equal to one.

Next, the vector of informational time series  $X_t$  with dimension  $N \times 1$  is known to the central bankers. It is linked to the factors and the monetary policy tool by the following equation:

$$X_t = \Lambda^f f_t + \Lambda^R R_t + w_t \quad (2)$$

where the factor loadings  $\Lambda_t^f$  and  $\Lambda_t^R$  are  $N \times K$  and  $N \times 1$ , respectively, and  $w_t$  is a  $N \times 1$  vector of error terms with zero mean and variance  $V_t$  defined as:  $V_t = \text{diag}[\exp(v_{1t}), \dots, \exp(v_{Nt})]$ .

## 2.2 Time-varying FAVAR

We enrich our model by allowing the parameters (i.e. coefficients and error covariance matrix) to vary over time; thus, it can capture the time-varying effect of the shock on the economy. In contrast to relevant studies that break the sample between pre- and post-crisis periods (Boivin and Giannoni 2002, 2006), the time-varying FAVAR model (TVP-FAVAR hereafter) allow us to examine the changing international transmission of the US policy shock for every point in time.<sup>3</sup> The time-varying parameters  $B_{it}$ ,  $A_t$ ,  $V_t$  are assumed to be evolved as random walk while the elements of  $\Sigma_t$  evolve as a geometric random walk. In particular, as concerns the observation equation given by (2), the diagonal elements of the covariance matrix  $V_t$  evolve as:

$$v_{i,t} = v_{i,t-1} + \psi_t \quad (3)$$

For the VAR model given by (1), the parameters evolve as:

$$B_t = B_{t-1} + \eta_t \quad (4)$$

$$a_t = a_{t-1} + \rho_t \quad (5)$$

$$\log \sigma_t = \log \sigma_{t-1} + \mu_t \quad (6)$$

<sup>3</sup> In particular, the superiority of this technique is underlined by Boivin and Giannoni (2006). They point out that the evolution of monetary policy transmission is more complex than what can be captured by splitting the sample with a single break date.

We assume that all innovations are normally distributed with the following assumptions on the variance–covariance matrix:

$$P = \text{Var} \begin{bmatrix} \psi_t \\ \eta_t \\ \rho_t \\ \mu_t \end{bmatrix} = \begin{bmatrix} I_K & 0 & 0 & 0 \\ 0 & Q & 0 & 0 \\ 0 & 0 & S & 0 \\ 0 & 0 & 0 & W \end{bmatrix} \tag{7}$$

where  $I_K$  is a  $K$  dimensional identity matrix and  $Q, S, W$  are positive definite matrices.

### 2.3 Factors and identification

We estimate the factors and the associated loadings from Eq. (2), by using PCA vari-max rotation analysis (Bernanke et al. 2005; Boivin et al. 2013) separately for the US and RoW economies. Our analysis indicates the need to include four international and four US domestic factors.<sup>4</sup> The first three factors capture the effects of real activity, inflation and asset prices correspondingly. We add a fourth factor that captures the effect of trade variables. The international factors are identified through the upper  $N \times K_1$  block of the matrix  $\Lambda^f$ , while the dynamics of the US domestic factors are identified through the bottom  $N \times K_2$  block of the  $\Lambda^f$  (Mumtaz and Surico 2009).

The US policy shock in Eq. (1) is identified as the only shock that does not contemporaneously affect the other series. Since all US variables are likely to respond more instantly to monetary policy innovations within the quarter, the contemporaneous relationship between the FFR and the variables must be removed. To address this, we first divide the number of US variables into two groups: the slow-moving and the fast-moving variables, depending on how fast they respond to the US policy shock. As Bernanke et al. (2005) point out, the fast-moving variables (financial indicators and asset prices) are those variables that are assumed to be contemporaneously responsive and sensitive to policy shocks, while the slow-moving variables are those that are assumed to be contemporaneously unresponsive to policy shocks. The US slow-moving factors (denoted as  $f^{US,slow}$ ) are extracted by PCA of the US slow-moving variables. Next, we extract the US domestic  $K_2 + 1$  principal components from all the US variables into  $X_t$ . Finally, following Mumtaz and Surico (2009), we estimate a regression of the form:

$$\hat{C} \left( f_t^{US}, R_t \right) = b_1 \tilde{C} \left( f_t^{US,slow} \right) + b_2 R_t + \theta_t \tag{8}$$

where  $C(f_t^{US,slow}, R_t)$  represents the common space spanned by the  $K_2 + 1$  principal components of the US domestic variables,  $\tilde{C} \left( f_t^{US,slow} \right)$  are obtained by extracting principal components from the subset of the slow-moving variables that are not affected contemporaneously by  $R_t$ ; and  $\theta_t$ , is the error term. The estimated factors  $\hat{f}_t^{US,slow}$  are

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<sup>4</sup> We employ the experiment with three and five factors, and the results show that there are no significant changes in our impulse responses. The results are not reported here, but they are available for the reader.

taken as the difference:  $\hat{C}(f_t^{\text{US}}, R_t) - b_2 R_t$ . Thus, the identification of the US policy shock is achieved by recursively ordering:  $f_t^w, \hat{C}(f_t^{\text{US}}, R_t) - b_2 R_t$ , with  $R_t$  being the last element in Eq. (1). The ordering assumed here imposes that both international and domestic US unobserved factors do not respond to monetary policy innovations within the quarter.

## 2.4 Model estimation and impulse responses

We estimate the model by using Bayesian techniques. In particular, the model is estimated using a Gibbs sampler algorithm to obtain the posterior distributions of our parameters. We use 20,000 iterations discarding the first 16,000 as burn in. A description of the prior and posterior distributions is provided in “Appendix”. Impulse responses are estimated by writing the structural form of the VAR Eq. (1), as:

$$F_t = B_{1t} F_{t-1} + \dots + B_{pt} F_{t-p} + A_t^{-1} \Sigma_t n_t \quad (9)$$

with the structural errors being equal to:  $u_t = A_t^{-1} \Sigma_t n_t$ . The matrix  $A_t^{-1}$  captures the contemporaneous relations of the shocks and  $n_t$  is the error term with zero mean and the identified covariance matrix. We extract the structural shocks  $n_t$  given the posteriors of  $B_t$  and  $\Omega_t$  at each point in time and also, the Cholesky decomposition of the covariance matrix  $\Omega_t$ , by setting  $\Omega_t = PP'$  where  $P = A_t^{-1} \Sigma_t$ .

## 3 Data

The majority of the data come from the Federal Reserve Economic database (FRED). In the cases where data are not available from the FRED, we use the DataStream and the World Bank databases to fill the relevant gaps. The time span includes quarterly data starting from the first quarter of 1986 to the last quarter of 2014. This time span was chosen as we wanted to extend the sample period as far back as possible, starting in the middle of 1980s when the global integration process began and reaching up to 2014, to incorporate the post-2007 financial crisis period.

We use a large set of variables that are derived from the US, South East Asian (SEA) and European Union (EU) economies,<sup>5</sup> which is in line with the relevant literature (Bernanke et al. 2005; Korobilis 2013; Mumtaz and Surico 2009). The SEA context covers eight countries, namely Hong Kong, South Korea, Singapore, the Philippines, Japan, China, Malaysia and Taiwan. The EU context covers five countries, namely Germany, France, Italy, Spain and the UK. These EU countries are large economies and full-fledged EU members. Even though the UK is not a member of the euro area, it adheres to the same coordinated EU monitoring framework. We assume a contractionary US policy shock for two reasons: First, the FFR has been at the zero lower

<sup>5</sup> We do not take into account the Latin American countries due to a lack of data availability for the majority of the countries (starting date on 1986 and data frequency). Germany's data before 1991 relate to West Germany. The classification of the SEA region is based on the United Nations' 2016 classification of income groups.



bound since 2008; thus, there is no room for further expansionary policy. Secondly, the FED will at some point increase rates and therefore it would be of great interest to explore the propagation of a US contractionary policy shock for the first time after the onset of the US financial crisis.<sup>6</sup>

The set of variables for the US and its foreign counterparts is first considered separately, and then, the variables are categorized into three dimensions which are: real activity, inflation and asset prices. For all the countries, we obtain seven variables as proxies for real activity, three variables for inflation, eight variables for trade and nine variables for asset prices.<sup>7</sup> Following Boivin et al. (2010), we use consumer credit variables as proxies for the ability of lenders to repay loans.<sup>8</sup> We enrich the credit sector dataset by including resident loans, since this variable is more informative to determine credit worthiness. Due to the availability of data, we consider resident loans for Hong Kong, Germany, France and Spain. The choice of these credit variables was made to illustrate how the balance sheet channel works. The balance sheet channel suggests that monetary policy can affect firms' and consumers' balance sheets and, in turn, their access to credit. Thus, we expect a reduction in the response of credit variables following a contractionary US policy shock.

In the case of the USA, we consider additional series, namely the yield spread between AAA corporate bonds and corresponding US Treasury bonds, for maturities of 1 and 10 years. Recent literature in the post-crisis period has highlighted the role of the yield spread in providing useful information about the future path of the US economic activity (Evgenidis and Siriopoulos 2014, 2016); suggesting the importance of including these variables in monetary policy analysis. Beyond that, our yield spread measures proxy the strength of the balance sheet channel by consisting of alternative indicators of external finance premium (the difference between a borrower's cost of raising funds externally and the opportunity cost of internal funds). The relevant literature has used yield spread variables to show that lower net worth increases asym-

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<sup>6</sup> For purposes of robustness, we conducted our analysis considering the effect of an expansionary policy shock. As expected, we find opposite effects compared to the tightened monetary policy in the responses of macroeconomic variables; however, their magnitude of the effect is lower.

<sup>7</sup> One could argue that an important aspect can be global risk aversion (such as VIX) in order to point out the importance of shifts in global investor sentiment and how they have an impact on the transmission of liquidity from advanced to emerging economies (McCauley 2012) by capturing any risk dynamics (possibly also complemented with commodity prices). However, investor sentiment could be applied in mapping for a higher frequency data sample. In our approach, we are interested in examining what a sufficient time is for a shock to be transmitted in all factors considered herein, with any other policy adjustments taken.

<sup>8</sup> We do not include financial openness variables (e.g., external assets and liabilities) in addition to the trade variables. Research studies highlight the importance of global banks in channelling liquidity across economies and how the presence of branches of these banks affects local economies. In short, these foreign branches tend to be more reactive to external conditions, channelling funds more heavily in good times but also retrenching and deleveraging in a more pronounced fashion when the tide turns (Hoggarth et al. 2013). Thus, the share of foreign banks in the domestic banking sector of these countries could be introduced (Claessens and van Hoeren 2012) and complemented with the bilateral exposures of the US banks to each of these countries using the BIS banking statistics. However, the population of banks that report to BankScope and the population of banks that is reflected in the BIS statistics are different. Therefore, the bilateral exposures should be interpreted as rough approximations of the true exposures, and the results should therefore not be taken too literally. For this reason, it is very unlikely that exposures can be determined from the BIS cross-border banking statistics with any degree of confidence.

metric information problems in debt financing, thereby increasing the external finance premium (Bernanke and Gertler 1989; Bernanke et al. 1999).

In addition, we use the one-year-ahead CPI inflation expectation index derived from the Michigan Survey, the 1-year-ahead CPI inflation expectation and the GDP implicit price deflator derived from the Survey of Professional Forecasters.<sup>9</sup> These variables are considered as alternative measures of expected inflation and therefore give us additional insights on the US transmission mechanism through the expectations channel. Table 1 summarizes all the variables used in the analysis.

To nail down the stationarity of all the variables in the sample, we implement the augmented Dickey Fuller (ADF) test. The results suggest that the hypothesis of unit root is rejected for all the cases except for unemployment, interest rates, yield spreads and the Michigan inflation expectations index. Therefore, we consider either first differences ( $P_t = D^1(P_t)$ ) or logarithmic first differences ( $P_t = D^1 \log(P_t)$ ) in order to achieve stationarity (as denoted in Table 1). Finally, all series are demeaned and standardized with a common scaling.

Next, we highlight some reference years that are associated with some well-known historical economic events, which might change the magnitude of the transmission of the US shock to the world economies. The following historical shocks considered herein are: (a) 1987—this reference year is often seen as the beginning of globalization (Kose et al. 2007); it is considered as the less-integrated period while it is also indicative as a period characterized by the *Great Moderation*, a significant decline in the volatility of output and inflation; (b) 1999—this reference year gauges the impacts of the gradual deepening of global integration (compared to 1987), works as the benchmark date for the euro area countries (euro currency introduction) and last, denotes the end of the South East Asian financial crisis that started in 1997; (c) 2007—this reference year denotes when the subprime mortgage crisis erupted in the US; (d) 2014—this year could be seen as representative of the post-crisis period. It can also be viewed as a period that captures the European sovereign debt crisis and its slow economic growth.

The sample may suffer from some potential drawbacks. A caveat is that not all the variables in the international context are available from the starting date (i.e. 1986).<sup>10</sup> Similar problems have been faced in the relative literature regarding the international transmission of monetary policy shocks (Mumtaz and Surico 2009; Boivin and Giannoni 2008). Although the international dataset in both studies is less comprehensive for the non-UK variables and the non-US variables correspondingly, both studies agree that the FAVAR structure encompasses extensive international macroeconomic information. Data availability in China is limited, due to the country's rapid struc-

<sup>9</sup> The University of Michigan Inflation Expectation index represents the median expected price change in the next 12 months, according to the Survey Research Center, Thompson Reuters/University of Michigan. The index is extracted by the FRED. The next two inflation indices are extracted by the Survey of Professional Forecasts. Both these indices represent the median forecast for one-year-ahead annual average inflation.

<sup>10</sup> Some variables are also not available from the starting date (i.e. 1986). Government consumption, GDP deflator and investment are not available for some EU countries; long-term government bonds are not available for all EA countries, with the exception of Japan; terms of trade are only available for six countries, namely Hong Kong, Japan Singapore, Germany, Spain and the UK; balance of payments is available only for Korea, Japan Singapore, Germany, Spain and the UK.

**Table 1** Description of the variables

| Transformation        | Real activity and inflation variables   | Trade activity variables   | Asset prices and monetary aggregates   | US additional variables  |
|-----------------------|---|--|--|--|
| Levels                | Unemployment  |  | Short-term interest rate<br><br>Long-term government bonds   | Mid-term rate (12-month)<br><br>Spread between: Moody's AAA and 3 m rate<br><br>Spread between: Moody's AAA and 12 m rate<br><br>Inflation expectations (University of Michigan)     |
| First differences     |   | Balance of payments (current account)<br>Trade balance (TB)  |  |  |
| Log first differences | Gross domestic product<br><br>Government consumption<br><br>Employment<br><br><br>Industrial production (IP)<br><br>Private consumption<br><br>Consumer price index (CPI)<br><br>Investment<br><br>Producer price index (PPI)<br><br>GDP deflator | Exports imports<br><br>Terms of trade (ToT)<br><br>Import price<br><br><br>Export price<br><br><br><br>Exchange rates (\$ in terms of foreign currencies)<br><br>Effective exchange rate | Money supply (M0, M1 and M2)<br><br><br><br><br><br>Stock market index<br><br>Domestic credit<br><br><br>Consumer credit | House price<br><br><br><br>Expectation of CPI inflation (survey of professional forecasters)<br><br><br><br><br><br>Expectation of GDP deflator (survey of professional forecasters) |

The table presents the data variables. The variables are divided in four different dimensions of the country's economy, namely the real activity and the inflation (denoted in the second column), the trade activity (denoted in the third column) and the asset prices together with monetary aggregates (denoted in the fourth column). The sample consists of quarterly data for a period spanning from the first quarter of 1986 to the last quarter of 2014, for all the three counterparts: the USA, the European Union (EU) and the South East Asian (SEA). We do not report a full list of the series for each country, but it is available to the reader upon request. Finally, the last column presents the additional US domestic variables. In the first column, we indicate the stationary transformations, derived for the variables. The 'level' indicates that there is no transformation for the variables as they are already stationary, while all the non-stationary series are considered to be either the first-differenced or the first-differenced logarithmic values to be approximately stationary (column one). The ADF test is used to examine the stationarity of all the variables for 5% level of significance

tural transformation (Fernald et al. 2014). We consider the Chinese GDP, inflation measures and trade variables with the potential drawback of losing important information derived from other variables (e.g. investment, private consumption) so that can describe in a better way the transmission channels of the US shock to the Chinese economy. In the case of Taiwan, we obtain the imports, the exports and the bilateral exchange rate. In the case of Malaysia, we draw on the imports, exports, stock market index, money supply and bilateral exchange rate. On the other hand, not all variables are available at a quarterly frequency, but only on an annual basis for some of the countries in the sample. This is the case for the domestic credit series obtained from the World Bank and the Chinese series, which are both only available on an annual basis; we convert annual to quarterly data using a cubic spline interpolation.<sup>11</sup>

## 4 The channels of monetary transmission in the USA

This section presents the empirical results of our TVP-FAVAR model. It discusses the implications that rely on the policy questions with respect to the transmission channels over time. Finally, we conclude with some major arguments arising from the findings.

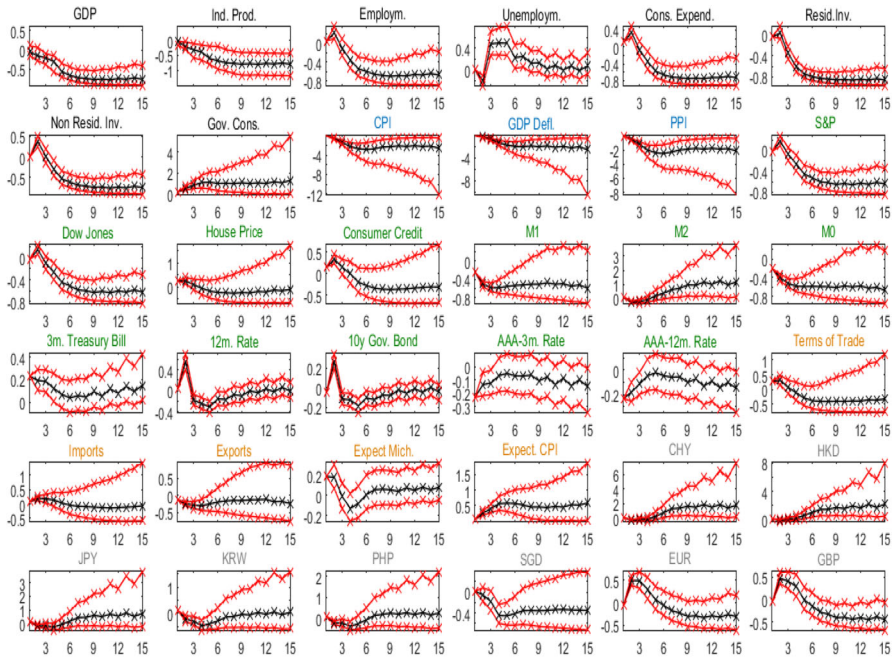
### 4.1 The US policy shock transmission into the US economy

We start the empirical analysis by setting the effect of the policy shock in the US economy itself. The first policy question that arises is whether the propagation of a US policy shock exerts its influence in the US economy through the transmission channels. Figure 1 illustrates the estimated effects of a US policy shock on its sovereign variables within a horizon of fifteen quarters ahead ( $h = 15$ ). We draw some interesting findings from these results by comparing the behaviour of the impulse responses (IRFs) under a contractionary policy shock.

As Fig. 1 demonstrates, the responses for the majority of the variables are consistent with the theoretical predictions formulated in the relative literature. In particular, we observe that output decreases gradually, inflation prices go down and monetary aggregates decline. The negative correlation between nominal interest rates and inflation suggests that our model properly manages to deal with the price puzzle observed in small-scale VAR models. Similarly, the negative relationship between interest rates and the money stock reveals that the liquidity effect observed elsewhere in the VAR literature is absent. In terms of transmission channels, the effect on the trade balance and the fall observed in imports and exports denote the functional efficiency of the MFD model and the channel described under the Redux model, respectively. In the

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<sup>11</sup> A common way to transform economic series from quarterly to monthly frequency is the cubic spline interpolation approach (Miranda and Fackler 2002). The spline interpolation has an advantage over others (e.g. polynomial interpolation methods) in that there is a narrow support among the splines functions and it can contain the effects of any discontinuities in the first or second derivatives. Therefore, cubic splines tend to be more stable and have less possibility of high oscillations between the data points.

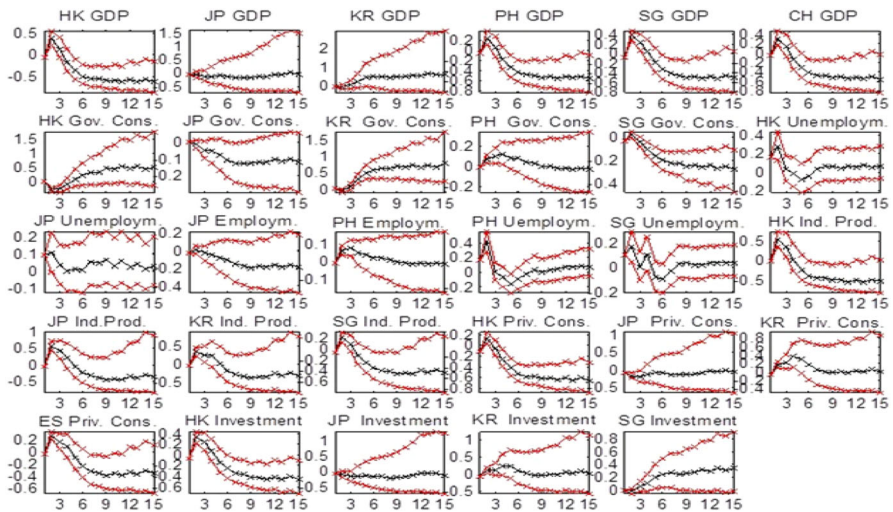


**Fig. 1** Responses of US macroeconomic and financial variables. *Note:* The figure illustrates impulse responses of US variables to a contractionary US monetary policy shock. The estimation period is spanning from the first quarter of 1986 to the end of 2014. The forecasting horizon is 15 quarters ahead. The variables are ordered as follows: real activity variables in black, inflation variables in blue, asset prices and monetary aggregates in green, trade variables and inflation expectations in orange, and last, bilateral exchange rates against the USD in grey. The currency symbols are as follows: CHY for China Yuan, HKD for Hong-Kong dollar, JPY for Japanese Yen, KRW for South Korea Won, PHP for Philippines Peso, SGD for Singapore Dollar, EUR for euro and GBP for British pound. The black line presents the posterior median of responses, while the red lines are the 32th and 68th percentiles. (Color figure online)

same manner, the fall in stock prices and consumer credit reveals the importance of the balance sheet channel. Finally, the results indicate that the exchange rate and forward discount puzzle under Dornbusch’s overshooting hypothesis is not present in the FAVAR model, since the shock leads to an initial depreciation for all foreign exchange rates and a gradual appreciation afterwards.<sup>12</sup>

We turn next to the analysis of impulse responses to a positive US policy shock during the global integration and the US financial crisis in 2007. We draw the importance of the findings by comparing the magnitude and the sign of the impulse responses estimates. Table 2 depicts the posterior medians of impulse responses four quarters ahead. The global integration is examined from 1987 to 1999, since this period gauges the impacts of the deepening of globalization. The pre- and post-US financial crisis periods are considered with the break year 2007 as denoted in Sect. 3. A point estimate

<sup>12</sup> The hypothesis states that an increase in interest rates should cause the nominal exchange rate to appreciate instantaneously and then depreciate according to uncovered interest parity (UIP).



**Fig. 2** Responses of real activity variables (SEA). *Note:* The figure illustrates selected impulse responses of South East Asian real activity variables to a US policy shock. The countries considered in the sample are: South Korea (KR), Japan (JP), China (CH), Hong Kong (HK), Philippines (PH) and Singapore (SG). The estimation period is spanning from the first quarter of 1986 to the end of 2014. The forecasting horizon is 15 quarters ahead. The black line presents the posterior median of responses, while the red lines are the 32th and 68th percentiles. (Color figure online)

close to zero that is associated with a variable in Table 2 implies a weak significant effect of the US policy shock.

As Table 2 shows, the effects of the US policy shock on the majority of the variables are bigger in 1999 compared to 1987. Taking into account some sovereign contextual factors (e.g. the magnitude of domestic changes or the efficiency of the transmission mechanisms involved), the resulting behaviour of the variables is consistent with the period of global integration which justifies the lower perceived volatility of domestic imbalances, higher liquidity and credit accessibility, and reduction of liquidity constraints among others. Regarding the pre-and post-crisis period, the variables that cover the real activity, inflation and asset prices, are positive before the outbreak of the crisis and are highly negative in its aftermath; what is more, the effect is stronger for real activity and inflation variables in the post-crisis period compared to the pre-crisis period. In summary, the results reveal a more intense effect of the shock on core macroeconomic variables and show a worsened condition of the US economy, which justifies the implementation of unconventional policies taken by US policymakers.

#### 4.2 The US policy shock transmission in the SEA economies

To further investigate the evolution of monetary policy, this subsection discusses the implications arising from the transmission of a US policy shock to the SEA and the EU economies. The impulse responses that generate the transmission mechanism of the US policy shock to SEA can be seen in Figs. 2, 3 and 4.

**Table 2** Posterior medians of responses for the US economy

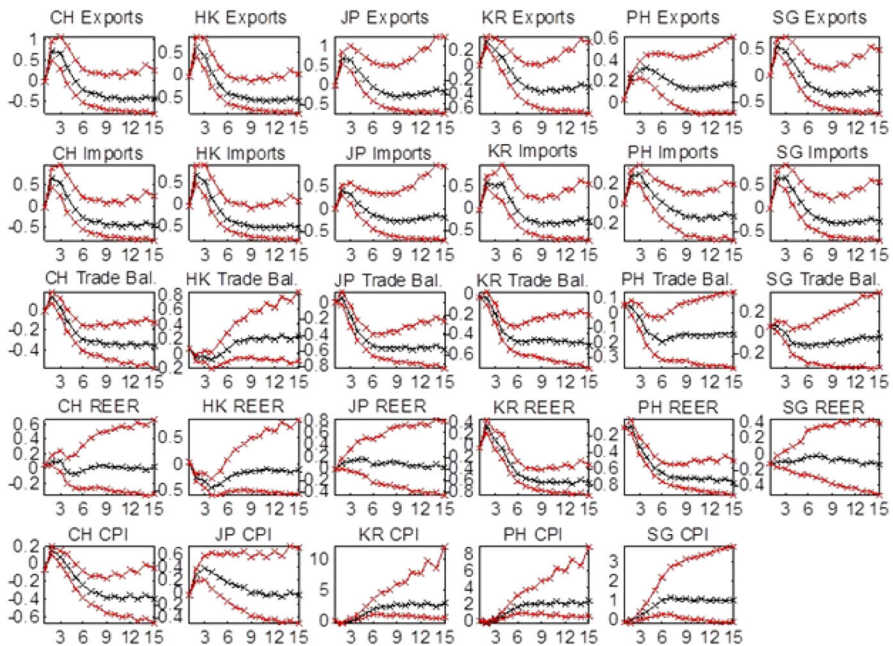
|   | 1987  | 1999  | 2007  | 2014  | 1987             | 1999  | 2007  | 2014  |
|---|-------|-------|-------|-------|------------------|-------|-------|-------|
| <b>Real activity</b>                        |       |       |       |       |                  |       |       |       |
| GDP   | 0.41  | 0.66  | 0.31  | -0.30 | -0.05            | -0.11 | -0.24 | -0.16 |
| IP  | 0.38  | 0.44  | 0.14  | -0.39 | 0.09             | 0.46  | 0.07  | 0.19  |
| Employment                                  | 0.33  | 0.47  | 0.22  | -0.35 | -0.23            | 0.19  | -0.13 | -0.28 |
| Unemployment                                | -0.09 | -0.20 | -0.06 | 0.86  | -0.22            | 0.19  | -0.21 | -0.47 |
| Pers. cons.                                 | 0.39  | 0.60  | 0.28  | -0.34 | -0.42            | 0.00  | -0.22 | -0.35 |
| Resid. inv.                                 | -0.18 | -0.07 | -0.16 | -0.60 | -0.28            | 0.13  | -0.18 | -0.45 |
| Gov. cons.                                  | 1.12  | 1.23  | 0.72  | 1.06  | 0.12             | 0.44  | 0.32  | 0.29  |
|   |       |       |       |       | -0.03            | 0.16  | 0.29  | 0.29  |
| <b>Asset prices and monetary aggregates</b> |       |       |       |       |                  |       |       |       |
| S&P   | 0.02  | 0.07  | 0.09  | -0.26 | 0.31             | -0.14 | -0.13 | -0.43 |
| DJ Ind. Index                               | 0.07  | 0.08  | 0.08  | -0.26 | 0.70             | 1.03  | 0.41  | -0.12 |
| House price                                 | 0.70  | 1.04  | 0.40  | -0.05 | -0.33            | 0.08  | -0.22 | -0.51 |
| Consumer credit                             | 0.39  | 0.71  | 0.42  | 0.00  | 1.03             | 0.67  | 0.45  | 0.14  |
| 3 m rate                                    | 1.57  | 1.61  | 1.06  | 0.92  | -0.55            | -0.49 | -0.40 | -0.30 |
| 12 m rate                                   | 0.05  | 0.54  | 0.42  | -0.04 | <b>Inflation</b> |       |       |       |
| 10y Gov. bond                               | -0.02 | 0.06  | 0.09  | -0.08 | 0.44             | 0.73  | 0.92  | 2.29  |
| M0  | -0.51 | -0.61 | -0.52 | -0.58 | 0.58             | 0.68  | 0.66  | 1.33  |

Table 2 continued

|                              | 1987  | 1999  | 2007  | 2014  | 1987           | 1999 | 2007 | 2014 |
|------------------------------|-------|-------|-------|-------|----------------|------|------|------|
| M1                           | -0.45 | -0.69 | -0.57 | -0.58 |                |      |      |      |
| M2                           | -0.02 | 0.10  | -0.15 | -0.09 | PPI Fin. goods |      |      |      |
| <i>Miscellaneous</i>         |       |       |       |       |                |      |      |      |
| Consumer expectations Mich.  | -0.30 | 0.46  | 0.21  | 0.17  |                |      |      |      |
| Expectation of CPI inflation | 0.27  | 0.43  | 0.35  | 0.56  |                |      |      |      |
| Expectation of GDP deflator  | -0.40 | -0.07 | -0.12 | -0.32 |                |      |      |      |
| Spread: Moody's AAA-3 m      | -0.43 | -0.60 | -0.49 | -0.44 |                |      |      |      |

Posterior medians of—1 year after—impulse responses for the US variables, by four factors. The responses referred to four representative years: 1987, 1999, 2007 and 2014. The year 1987 signs the beginning of global integration, the year 1999 is chosen to gauge the impact of the gradual deepening of financial integration, the year 2007 represents the US pre-crisis period, and, finally, the year 2014 is indicative of the US post-crisis period. The names of different categories are noted in bold and italics.

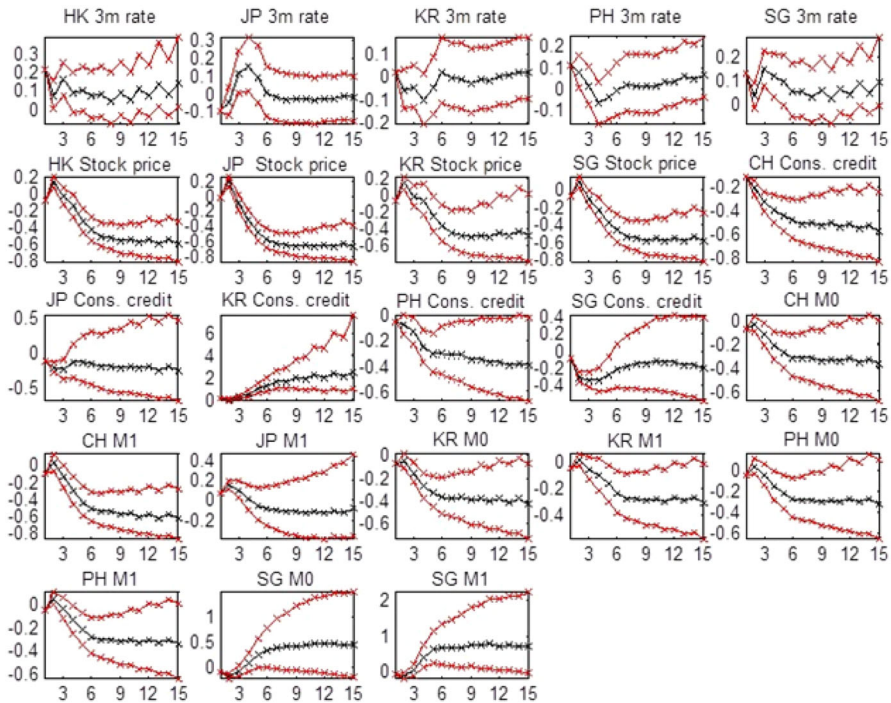




**Fig. 3** Responses of trade and inflation variables (SEA). *Note:* The figure illustrates selected impulse responses of South East Asian trade and inflation variables to a US policy shock. The countries considered in the sample are: South Korea (KR), Japan (JP), China (CH), Hong Kong (HK), Philippines (PH) and Singapore (SG). The estimation period is spanning from the first quarter of 1986 to the end of 2014. The forecasting horizon is 15 quarters ahead. The black line presents the posterior median of responses, while the red lines are the 32th and 68th percentiles. (Color figure online)

Before we move on to the description of the four transmission channels, we analyse the impact of the shock on two core macroeconomic indicators, GDP and unemployment. As shown in Fig. 2, a US policy shock lowers GDP after a short initial increase observed in Hong Kong, Philippines, China and Singapore, while the responses for South Korea and Japan are insignificant. A more careful inspection of Fig. 2 reveals that GDP responses of consumption, investment and employment show an initial hike in response to the shock, which later either dies out or becomes negative. This implies that the initial increase in output and the subsequent decrease are driven by consumption, investment and employment. Concerning labour markets, we notice that immediately after the shock there is an increase in unemployment in all countries in this region, which dies out after 2–3 months.

To dig further into the dynamics that move consumption, investment, employment and therefore, output, we should explore the role played by the trade balance in the region. Figure 3 shows that there is an immediate hike in trade balance in almost all SEA economies following the shock, which then becomes negative. This finding explains why we observe these behaviours in the macroeconomic variables. In particular, it seems that the expenditure switching effect, which is indicated by the small, initial improvement of the foreign trade balances, dominates in the first 2 months; this is why we observe these hikes in consumption, investment and employment. After that point, the income absorption effect dominates the system, particularly for China, Singapore



**Fig. 4** Responses of asset prices (SEA). *Note:* The figure illustrates selected impulse responses of South East Asian asset price variables to a US policy shock. The countries considered in the sample are: South Korea (KR), Japan (JP), China (CH), Hong Kong (HK), Philippines (PH) and Singapore (SG). The estimation period is spanning from the first quarter of 1986 to the end of 2014. The forecasting horizon is 15 quarters ahead. The black line presents the posterior median of responses, while the red lines are the 32th and 68th percentiles. (Color figure online)

and the Philippines, as indicated by the strong and significant worsening of their trade balances, which justifies the fall in output.

Our results are in line with former empirical studies that found the income absorption effect to be more important than the expenditure switching effect in the international transmission of monetary policy shocks (Janssen and Klein 2011). In terms of trade balance, there is an interesting difference between Kim's (2001) results for non-US G-7 countries and this paper's results. In particular, Kim finds that changes in foreign trade balance as a response to the US shock seem to play a minor role. This view accords well with the idea that emerging markets are more vulnerable to external shocks than are large and developed economies. Our findings are consistent with Canova (2005), who estimates the effects of US monetary policy shocks on emerging markets in Latin America and finds that, a US monetary policy shock does have an important effect in foreign trade balance.

Continuing with our analysis, we explore the role of wealth effects in the international transmission mechanism. Figure 3 points out the importance of this transmission channel for the majority of SEA countries (except China and Japan, for which a minor effect is observed). The reason is that there is significant depreciation in bilateral

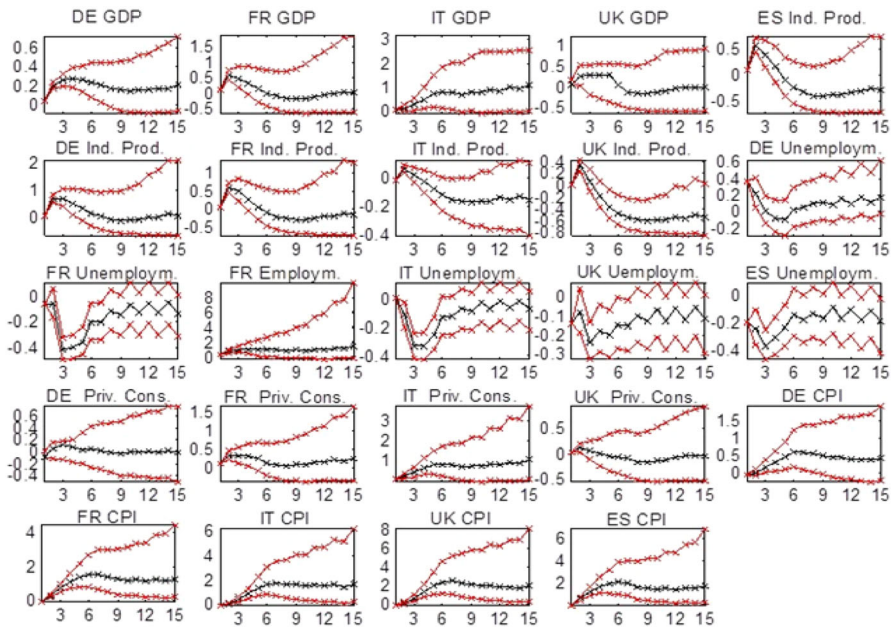
exchange rates and real effective exchange rates, followed by increases in inflation prices in these countries. Our results are consistent with Mackowiak (2007) who finds that US monetary policy shocks affect the exchange rate in a typical emerging market quickly and strongly and that the price level in emerging markets responds to US policy shocks by more than the price level in the USA itself.

Next, we investigate the importance of the channel under the Redux model as. Our empirical findings support the existence of this channel in the transmission mechanism. In particular, the results in Fig. 3 show that after an initial short rise in imports and exports, a strong and significant decrease follows in both variables as a result of the US monetary tightening. This final reduction in imports and exports in foreign economies may be due to the fact that residents in SEA economies decrease their demand for domestic and foreign goods and services, as evidenced by decreases in the responses of consumption for most of the these economies (Fig. 2).

Finally, Fig. 4 reports evidence in favour of the effectiveness of the balance sheet channel by revealing two main findings. The first one is that equity prices decline in all SEA countries. The second one is that there is a significant reduction in the responses of stock markets, consumer credit and/or bank lending in all SEA countries, except for South Korea, suggesting that the SEA consumers' access to credit is diminished as a result of the US monetary policy shock. In the case of South Korea, one possible explanation can be that the domestic banking sector of balance sheet activities (e.g. operating leases) insulates their loan supply against monetary policy shocks, thus creating a buffering effect on monetary transmission. Overall, the latter finding is consistent with the international credit channel recently discussed by Rey (2016), under which, a US contractionary monetary policy shock tightens credit conditions abroad. We provide empirical evidence that this channel does work for SEA economies.

Last, we assess the transmission of the US monetary policy in relation to the exchange rate regimes in the SEA economies. We would expect that a contractionary US monetary policy shock would depreciate the exchange rate of SEA currencies against the US dollar when a flexible exchange rate regime is allowed. However, Fig. 1 reveals that based on the error bands, the exchange rate depreciation in the short run is not significant for all countries, except for Korea. In particular, for China and Hong Kong, exchange rate movements are only significant on the medium and long horizon, while in Korea, there is a significant depreciation immediately after the shock.

The responses of the exchanges rates are quite interesting, given the exchange rate regimes that apply to these economies. In particular, the interest rates of the Philippines and Singapore, two countries that allow some exchange rate flexibility, exhibit a significant initial increase as a response to US policy rate increases, which can fully nullify the effects of the contractionary US monetary policy shock. The same behaviour is observed for Hong Kong, a country that adopted a fixed exchange rate regime. One can notice that interest rate reacts positively immediately after the shock to contribute to the exchange rate stability in response to the US monetary tightening. On the other hand, the insignificant response of the interest rate in Korea (a country with a relatively flexible exchange regime) shows that the Bank of Korea does not respond very much to the US interest rate changes. As a result, significant exchange rate depreciation is found in Korea. These results indicate that the conventional exchange



**Fig. 5** Responses of real activity and inflation variables (EU). *Note:* The figure illustrates selected impulse responses of EU real activity and inflation variables to a US policy shock. The countries considered in the sample are: Germany (DE), Italy (IT), France (FR), Spain (ES) and the UK. The estimation period is spanning from the first quarter of 1986 to the end of 2014. The forecasting horizon is 15 quarters ahead. The black line presents the posterior median of responses, while the red lines are the 32th and 68th percentiles. (Color figure online)

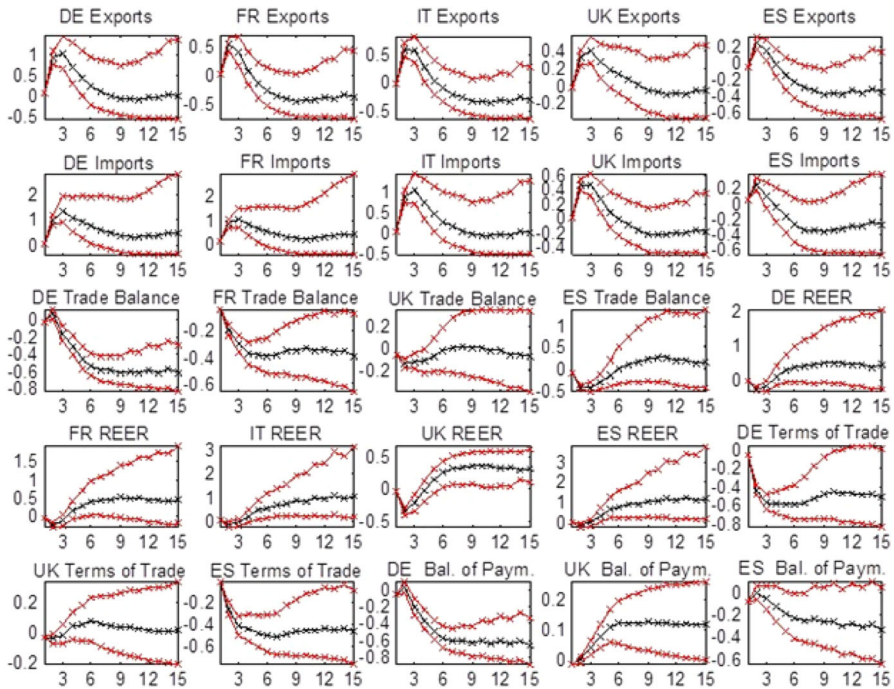
rate channel is unlikely to play much role in the transmission of a US interest rate hike to the SEA economies, excluding Korea, in the short run.

### 4.3 The US policy shock transmission in the EU

Figures 5, 6 and 7 show the responses of the EU economies under a US policy shock. A monetary tightening leads to a hike in economic activity (i.e. real GDP and industrial production indices) as shown in Fig. 5.

One possible explanation for this might be the role of exchange rates. Combining these results with the responses from the bilateral exchange rates shown in Fig. 1, we argue that the depreciation of both currencies (euro and pound) against the dollar may provide a good explanation for the rise observed in foreign output in the EU countries. Indeed, the importance of the exchange rate mechanism in raising the output in the EU as a result of the US monetary tightening is further enhanced by the fact that there is an initial short depreciation in the real effective exchange rates in all EU countries, as shown in Fig. 6. The responses of trade balance are both positive and insignificant (UK and Spain), or, they have the opposite signs of what would be expected under the MFD model. Taken together with the results, we conclude that the initial rise observed in economic activity in EU as a result of the shock is more driven by exchange rate





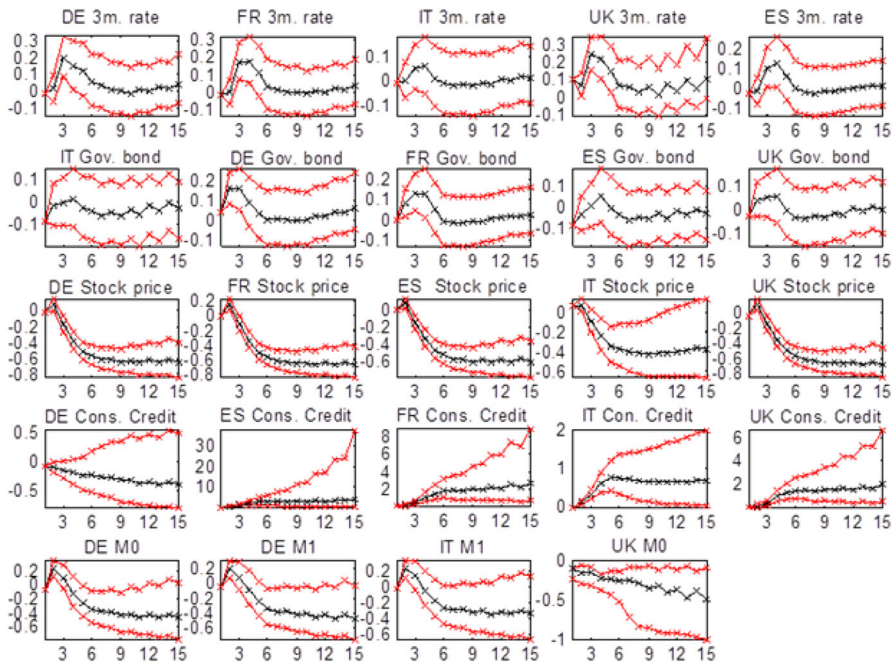
**Fig. 6** Responses of trade variables (EU). *Note:* The figure illustrates selected impulse responses of EU trade and inflation variables to a US policy shock. The countries considered in the sample are: Germany (DE), Italy (IT), France (FR), Spain (ES) and UK. The estimation period is spanning from the first quarter of 1986 to the end of 2014. The forecasting horizon is 15 quarters ahead. The black line presents the posterior median of responses, while the red lines are the 32th and 68th percentiles. (Color figure online)

changes rather than movements in the trade balance. These findings are in accordance with Kim (2001), who finds that the effect of US monetary policy on the foreign balance of developed economies is negligible.

Within this context, another interesting finding is the fact that the rise in foreign output produces a significant reduction in unemployment for all the countries, except for Germany. One possible explanation might be that the German economy has vast financial resources and high industrial production, allowing it to boost its output without necessarily showing significant reduction in unemployment. This can be explained by the high level of technology, new international trade partners or new investment opportunities.

Next, the transmission via wealth effects does play a significant role in the region. In particular, the effective exchange rates for most EU economies depreciate immediately after the shock, while the subsequent increase observed is insignificant. In addition, following the US monetary policy shock, inflation rises in all EU economies. Our findings are consistent with Neri and Nobili (2010) who find that an increase in the FFR causes the euro to immediately depreciate.

The transmission channel under the Redux model seems to be working via exports; since in response to the shock, exports fall for all countries after an initial short increase.



**Fig. 7** Responses of asset price variables (EU). *Note:* The figure illustrates selected impulse responses of EU asset price and monetary aggregates to a US policy shock. The countries considered in the sample are: Germany (DE), Italy (IT), France (FR), Spain (ES) and the UK. The estimation period is spanning from the first quarter of 1986 to the end of 2014. The forecasting horizon is 15 quarters ahead. The black line presents the posterior median of responses, while the red lines are the 32th and 68th percentiles. (Color figure online)

The same is not true for imports. The responses show that imports fall (following an initial short increase), with the exception of Germany, France and Italy, where imports rise in the first four quarters and then smoothly fade out. For these countries, the initial appreciation of the euro increases the purchasing power and private consumption of their residents (as shown in Figs. 1, 5) and in turn, may increase the imports from the domestic supply side (companies and micro-foundations) for foreign goods and services, functioning as a dynamic model of utility maximization.

Last, in contrast to SEA economies for which the balance sheet channel is found to have a pronounced impact, the results indicate that there is no strong evidence in favour of the existence of this channel in EU. In particular, although the consumer credit response for Germany is negative, it is insignificant. The effect on consumer credit variables for the other eurozone countries and the UK, although positive, is just on the verge of being insignificant; therefore no strong conclusions can be drawn from these responses.

#### 4.4 How has the US monetary policy transmission evolved over time?

In this section, we examine how has the international monetary transmission mechanism evolved over time. Tables 3, 4 and 5 depict the posterior medians of impulse

**Table 3** Posterior medians responses of the real activity

|                         | 1987  | 1999  | 2007  | 2014  |                              | 1987 | 1999 | 2007 | 2014  |
|-------------------------|-------|-------|-------|-------|------------------------------|------|------|------|-------|
| <i>GDP</i>              |       |       |       |       | <i>Private consumption</i>   |      |      |      |       |
| HK                      | 0.70  | 0.54  | 0.14  | -0.16 | HK                           | 0.43 | 0.11 | 0.00 | -0.24 |
| JP                      | 2.13  | 0.56  | 0.14  | -0.19 | JP                           | 1.11 | 0.12 | 0.04 | -0.11 |
| KR                      | 1.72  | 0.47  | 0.21  | 0.22  | KR                           | 1.47 | 0.49 | 0.35 | 0.36  |
| PH                      | 0.44  | 0.32  | 0.04  | -0.18 | SG                           | 1.04 | 0.51 | 0.30 | 0.09  |
| SG                      | 1.07  | 0.62  | 0.29  | 0.04  | DE                           | 0.60 | 0.12 | 0.03 | 0.00  |
| CH                      | 0.47  | 0.37  | 0.09  | -0.12 | FR                           | 1.47 | 1.21 | 0.56 | 0.33  |
| DE                      | 0.24  | 0.36  | 0.26  | 0.27  | IT                           | 2.10 | 1.30 | 0.67 | 0.67  |
| FR                      | 2.48  | 2.13  | 0.84  | 0.98  | UK                           | 1.27 | 0.78 | 0.36 | 0.01  |
| IT                      | 2.04  | 0.99  | 0.52  | 0.79  |                              |      |      |      |       |
| UK                      | 1.83  | 0.90  | 0.36  | -0.01 |                              |      |      |      |       |
| <i>Unemployment</i>     |       |       |       |       | <i>Industrial production</i> |      |      |      |       |
| HK                      | 0.01  | 0.57  | 0.27  | 0.46  | HK                           | 0.43 | 0.60 | 0.23 | 0.00  |
| JP                      | -0.14 | 0.25  | 0.05  | 0.22  | JP                           | 1.89 | 1.28 | 0.52 | 0.22  |
| PH                      | 0.50  | 0.94  | 0.62  | 0.46  | KR                           | 1.91 | 0.77 | 0.39 | 0.23  |
| SG                      | 0.64  | 0.45  | 0.32  | 0.39  | SG                           | 0.89 | 0.57 | 0.14 | -0.10 |
| DE                      | -0.05 | 1.19  | 0.67  | 0.46  | DE                           | 1.76 | 1.65 | 0.69 | 0.48  |
| FR                      | -0.28 | -0.23 | -0.28 | -0.69 | FR                           | 1.90 | 1.61 | 0.66 | 0.25  |
| IT                      | 0.00  | 0.00  | -0.16 | -0.60 | IT                           | 0.33 | 0.17 | 0.06 | -0.02 |
| SP                      | -0.29 | -0.55 | -0.47 | -0.72 | SP                           | 1.64 | 1.60 | 0.70 | 0.16  |
| UK                      | 0.14  | -0.32 | -0.21 | -0.49 | UK                           | 1.38 | 0.95 | 0.31 | -0.18 |
| <i>Gov. consumption</i> |       |       |       |       | <i>Investment</i>            |      |      |      |       |
| HK                      | 0.07  | -0.21 | -0.14 | -0.10 | HK                           | 0.24 | 0.24 | 0.17 | 0.07  |
| JP                      | 0.41  | 0.13  | 0.05  | -0.05 | JP                           | 1.21 | 0.26 | 0.07 | -0.14 |
| KR                      | 0.34  | 0.08  | 0.12  | 0.30  | KR                           | 1.53 | 0.41 | 0.25 | 0.24  |
| PH                      | -0.20 | -0.09 | 0.04  | 0.12  | SG                           | 0.22 | 0.16 | 0.07 | 0.10  |
| SG                      | 0.08  | 0.00  | -0.01 | -0.10 | FR                           | 1.83 | 1.89 | 0.82 | 0.35  |
| FR                      | 0.11  | -0.27 | -0.16 | -0.26 | UK                           | 0.42 | 0.23 | 0.06 | -0.26 |
| UK                      | 0.00  | 0.39  | 0.20  | 0.28  |                              |      |      |      |       |

Posterior medians of—1 year after—impulse responses of real activity variables to a US policy shock. The responses referred to four representative years: 1987, 1999, 2007 and 2014. The year 1987 signals the beginning of global integration, the year 1999 is chosen to gauge the impact of the gradual deepening of financial integration, the year 2007 represents the US pre-crisis period, and, finally, the year 2014 is indicative of the US post-crisis period

responses four quarters ahead. Table 3 depicts the effect of the policy shock on real activity and inflation variables, while Tables 4 and 5 illustrate the effect of the shock on trade variables and asset prices, respectively.

The findings are quite interesting when we compare the magnitude of these estimates for the EU and the SEA economies. The transmission mechanism of the policy shock shows a great heterogeneity during the global integration period. The results show that the deepening of global integration dampens the effect of the shock to the

**Table 4** Posterior medians responses of trade activity and inflation

|                      | 1987  | 1999  | 2007  | 2014  |                                | 1987  | 1999  | 2007  | 2014  |
|----------------------|-------|-------|-------|-------|--------------------------------|-------|-------|-------|-------|
| <i>Exports</i>       |       |       |       |       | <i>Effective exchange rate</i> |       |       |       |       |
| HK                   | 0.72  | 0.78  | 0.29  | 0.02  | HK                             | -0.37 | -0.14 | -0.25 | -0.45 |
| JP                   | 1.57  | 1.64  | 0.57  | 0.35  | JP                             | 0.41  | 0.12  | 0.04  | 0.14  |
| KR                   | 1.03  | 1.66  | 0.29  | 0.09  | KR                             | 0.40  | 0.14  | 0.21  | -0.04 |
| PH                   | 0.28  | 0.36  | 0.23  | 0.31  | PH                             | -0.22 | -0.36 | -0.22 | -0.45 |
| SG                   | 1.64  | 1.17  | 0.49  | 0.25  | SG                             | -0.37 | -0.33 | -0.18 | -0.10 |
| CH                   | 0.48  | 0.75  | 0.40  | 0.30  | CH                             | -0.28 | 0.10  | -0.01 | -0.04 |
| DE                   | 1.07  | 1.69  | 0.81  | 0.70  | DE                             | -0.21 | -0.44 | -0.17 | 0.06  |
| FR                   | 1.29  | 1.40  | 0.51  | 0.05  | FR                             | -0.30 | -0.39 | -0.12 | 0.16  |
| IT                   | 0.52  | 0.92  | 0.46  | 0.27  | IT                             | 0.33  | 0.10  | 0.08  | 0.24  |
| SP                   | 0.54  | 0.67  | 0.18  | -0.02 | SP                             | 0.67  | 0.19  | 0.14  | 0.35  |
| UK                   | 0.00  | 0.34  | 0.23  | 0.27  | UK                             | 0.62  | 0.67  | 0.30  | 0.02  |
| <i>Imports</i>       |       |       |       |       | <i>CPI</i>                     |       |       |       |       |
| HK                   | 0.74  | 0.80  | 0.34  | 0.12  | JP                             | 0.29  | 0.31  | 0.24  | 0.30  |
| JP                   | 1.50  | 1.16  | 0.40  | 0.09  | KR                             | -0.07 | 0.00  | 0.08  | 0.58  |
| KR                   | 1.60  | 0.73  | 0.54  | 0.51  | PH                             | 0.08  | 0.03  | 0.16  | 0.65  |
| PH                   | 0.19  | 0.35  | 0.20  | 0.17  | SG                             | -0.19 | -0.16 | -0.07 | 0.40  |
| SG                   | 1.22  | 1.27  | 0.53  | 0.38  | CH                             | 0.21  | 0.09  | 0.04  | 0.01  |
| DE                   | 0.84  | 1.82  | 0.90  | 1.08  | DE                             | -0.41 | -0.25 | 0.00  | 0.32  |
| FR                   | 1.21  | 2.07  | 0.93  | 0.82  | FR                             | 0.21  | 0.35  | 0.43  | 1.12  |
| IT                   | 0.81  | 1.52  | 0.78  | 0.72  | IT                             | 0.49  | 0.25  | 0.34  | 0.88  |
| SP                   | 1.68  | 0.98  | 0.36  | -0.04 | SP                             | 0.07  | 0.63  | 0.65  | 1.67  |
| UK                   | 0.36  | 0.70  | 0.39  | 0.26  | UK                             | -0.08 | 0.02  | 0.29  | 1.33  |
| <i>Trade balance</i> |       |       |       |       |                                |       |       |       |       |
| HK                   | 0.01  | 0.14  | -0.02 | -0.09 |                                |       |       |       |       |
| JP                   | 0.92  | 0.39  | 0.00  | -0.37 |                                |       |       |       |       |
| KR                   | -0.06 | -0.09 | -0.17 | -0.38 |                                |       |       |       |       |
| PH                   | 0.09  | 0.15  | 0.00  | -0.13 |                                |       |       |       |       |
| SG                   | 0.29  | 0.34  | 0.03  | -0.10 |                                |       |       |       |       |
| CH                   | 0.10  | 0.13  | 0.02  | -0.12 |                                |       |       |       |       |
| DE                   | 0.38  | 0.09  | -0.02 | -0.31 |                                |       |       |       |       |
| FR                   | 0.03  | -0.18 | -0.22 | -0.37 |                                |       |       |       |       |
| SP                   | -0.49 | -0.61 | -0.41 | -0.31 |                                |       |       |       |       |
| UK                   | -0.23 | -0.25 | -0.15 | -0.11 |                                |       |       |       |       |

Posterior medians of—1 year after—impulse responses of trade variables to a US policy shock. The responses referred to four representative periods: 1987, 1999, 2007 and 2014. The year 1987 signals the beginning of global integration, the year 1999 is chosen to gauge the impact of the gradual deepening of financial integration, the year 2007 represents the US pre-crisis period, and, finally, the year 2014 is indicative of the US post-crisis period



**Table 5** Posterior medians responses of asset prices

|                              | 1987  | 1999  | 2007  | 2014  |                        | 1987  | 1999  | 2007  | 2014  |
|------------------------------|-------|-------|-------|-------|------------------------|-------|-------|-------|-------|
| <i>3 month interest rate</i> |       |       |       |       | <i>Consumer credit</i> |       |       |       |       |
| HK                           | 1.22  | 1.29  | 0.80  | 0.62  | JP                     | 0.24  | -0.32 | -0.12 | -0.15 |
| JP                           | 0.59  | -0.09 | 0.04  | 0.13  | KR                     | 0.40  | 0.43  | 0.25  | 0.52  |
| KR                           | 0.05  | 0.00  | 0.05  | -0.18 | PH                     | -0.36 | -0.24 | -0.17 | -0.25 |
| PH                           | 0.54  | 0.60  | 0.40  | 0.12  | SG                     | -0.32 | -0.41 | -0.28 | -0.34 |
| SG                           | 0.88  | 0.68  | 0.55  | 0.48  | CH                     | 0.03  | -0.31 | -0.25 | -0.40 |
| DE                           | 0.16  | 0.00  | 0.16  | 0.38  | DE                     | -0.01 | -0.17 | -0.06 | -0.18 |
| FR                           | 0.48  | 0.07  | 0.22  | 0.37  | FR                     | 1.26  | 0.94  | 0.66  | 1.06  |
| IT                           | 0.48  | 0.08  | 0.18  | 0.11  | IT                     | 0.74  | 0.26  | 0.29  | 0.61  |
| SP                           | 0.67  | 0.10  | 0.20  | 0.20  | SP                     | 1.40  | 2.22  | 1.39  | 2.40  |
| UK                           | 0.93  | 0.62  | 0.58  | 0.77  | UK                     | 1.18  | 0.76  | 0.60  | 1.02  |
| <i>Stock market index</i>    |       |       |       |       | <i>M0</i>              |       |       |       |       |
| HK                           | 0.24  | 0.00  | 0.04  | -0.15 | JP                     | 0.34  | 0.14  | 0.02  | -0.06 |
| JP                           | 0.36  | 0.26  | 0.06  | -0.31 | KR                     | 0.17  | -0.02 | -0.11 | -0.27 |
| KR                           | 0.75  | 0.17  | 0.11  | -0.07 | PH                     | 0.41  | 0.16  | -0.01 | -0.15 |
| SG                           | 0.35  | 0.07  | 0.02  | -0.23 | SG                     | 0.11  | -0.19 | -0.13 | 0.06  |
| DE                           | -0.04 | 0.05  | -0.03 | -0.37 | CH                     | 0.36  | 0.04  | -0.07 | -0.22 |
| FR                           | 0.11  | 0.18  | 0.04  | -0.34 | DE                     | 0.32  | 0.29  | 0.05  | -0.12 |
| IT                           | 0.30  | 0.20  | 0.05  | -0.24 | UK                     | 0.23  | 0.40  | 0.05  | 0.00  |
| SP                           | 0.09  | 0.06  | -0.01 | -0.34 |                        |       |       |       |       |
| UK                           | 0.10  | 0.08  | -0.00 | -0.35 |                        |       |       |       |       |
| <i>MI</i>                    |       |       |       |       |                        |       |       |       |       |
| JP                           | 0.07  | 0.29  | 0.15  | 0.02  |                        |       |       |       |       |
| KR                           | 0.55  | 0.12  | 0.03  | -0.09 |                        |       |       |       |       |
| PH                           | 0.34  | 0.12  | 0.00  | -0.13 |                        |       |       |       |       |
| SG                           | 0.18  | -0.20 | -0.02 | 0.40  |                        |       |       |       |       |
| CH                           | 0.21  | -0.03 | -0.09 | -0.29 |                        |       |       |       |       |
| DE                           | 0.16  | 0.10  | 0.03  | -0.08 |                        |       |       |       |       |
| IT                           | 0.43  | 0.38  | 0.11  | -0.03 |                        |       |       |       |       |

Posterior medians of—1 year after—impulse responses of asset price variables to a US monetary policy shock. The responses referred to four representative periods, 1987, 1999, 2007 and 2014. The year 1987 signals the beginning of global integration, the year 1999 is chosen to gauge the impact of the gradual deepening of financial integration, the year 2007 represents the US pre-crisis period, and, finally, the year 2014 is indicative of the US post-crisis period

foreign economies in core macroeconomic and financial variables, e.g. GDP, industrial production, private consumption, investment, short-term rates and stock market. In contrast, globalization has increased the effect of the US policy shock to trade variables in foreign economies. This finding is as expected since the deepening of global integration resulted in the world network of the markets as an outcome of the increased trade exchange. In the period from 2007 to 2014, the magnitude of the effect on real activity variables (GDP, industrial production, consumption and investment)

is far lower than in the period from 1987 to 1999. It implies that the effect of a US policy shock on core foreign macroeconomic variables has diminished through time as a result of globalization. The change can be justified either by the decline in the role of the US as an international financial hub with the emergence of other large foreign economies through the years, and/or by the regime switches of domestic monetary and nominal exchange rate policies in the foreign countries. In the latter case, during the last two decades, the majority of advanced countries in the EU have adopted inflation targeting policies to stabilize inflation expectations, while some SEA countries have adopted both inflation targeting policies and float nominal exchange rate regimes, particularly after the South East Asian crisis in 1997. Due to the fact that the US policy shocks are sources of variations in terms of prices and exchange rates for all the world economies, the endogenous policy responses to these variations affect the magnitude of the transmission of the US policy shocks to the domestic economic activities in its counterparts.

Next, we find strong evidence that the magnitude of the effect of the shock is different in the pre- and post-US financial crisis period. The effect of the shock on the majority of the variables (GDP, inflation, unemployment, exchange rates, stock prices and consumer credit) has increased in the post-2007 period. The findings provide a novel insight herein, suggesting that in the aftermath of the financial crisis, both macroeconomic and financial variables are strongly reacting to policy changes originated in the USA. On the other hand, the magnitude of the transmission of the shock for a small number of variables, e.g. imports and exports, has decreased. The latter effect may be due to the fact that the financial crisis produced a severe worldwide drop in demand, which resulted in what Baldwin (2009) refers as the great trade collapse. In summary, the strong impact of the US monetary tightening in the EU and SEA suggests that in times of crisis, foreign central banks should follow a credible monetary policy in response to the US monetary policy shock in order to stabilize possible fluctuations in output and mitigate the negative effects in many other economic sectors.

Last, we wonder ourselves whether the FED still has the ability to majorly affect the global economy. In other words, has the monetary policy of *RoW* economies changed in such a way that they are able to efficiently insulate themselves from a US monetary policy shock? We investigate this issue by examining if foreign policy endogeneity is present in the SEA and EU countries. We observe that in response to rises in output, short-term rates (as denoted in Figs. 4, 7) increase in all countries (with the exception of South Korea). Moreover, we notice a significant reduction in the monetary aggregates, which further confirms the hypothesis that short-term rates in the EU respond endogenously to US monetary tightening. From a policymaking perspective, this means that the ECB and the Bank of England will respond to a US monetary tightening by increasing short-term rates in order to cool economy boost and inflationary pressures caused by the US policy. Indeed, the GDP responses in the long term (after the 4th horizon ahead) show that the initial increase in the level of economic activity has faded, which is the result of the policymaking intervention. In the case of SEA, the increases in central banks' interest rates are likely to nullify the effects of US policy shocks on the currencies' depreciation (as shown in Fig. 1). This can contribute to exchange rate stability and mitigate inflation in response to US monetary tightening, which further supports our hypothesis.

## 5 Conclusion

This paper uses a time-varying FAVAR model to provide novel insights that concern the transmission of US monetary policy to some key European and South East Asian economies. Impulse response analysis reveals that in the SEA economies, the income absorption effect is the most pronounced channel as indicated by the significant worsening of the trade balance of these countries. In addition, wealth effects and the balance sheet channel have an important contribution in the transmission of the US policy shock to these economies. In the EU, the initial rise observed in output as a result of the shock is driven more by exchange rate movements rather than movements in the trade balance. In terms of changes in the magnitude of the effect of the shock over time, our results indicate that the responses of foreign economic and financial variables to the shock are highly time-dependent, facing a great heterogeneity during the global integration period and the pre- and post-US financial crisis period. Finally, we argue that there is a homogeneous response of RoW's monetary stance to the US policy shock, such that the foreign central banks are acting as followers rather than being quasi-autonomous in relation to a US policy shock.

Extending the analysis to allow for feedback mechanisms from the RoW to the USA may generate interesting results regarding the appropriate monetary policy that foreign central banks should follow in response to a policy shock generated in the USA. In addition, within our modelling framework, it would be interesting to investigate the international transmission of unconventional monetary policy shocks such as a shock to central banks total assets or a yield spread compression. All of these extensions are left for future research.

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## Appendix

### A.1 Prior distributions

We begin by setting the priors of the factor equation. The prior for the factor loadings is:  $[\Lambda_i^f, \Lambda_i^R] \sim N(0_{1 \times K}, 4I_K)$ , while the prior of the diagonal elements of  $V_t$  follows the normal distribution  $v_{i0} \sim N(\mu_0, v_0)$  where  $\mu_0 = 0$  and  $v_0 = 4$ . The prior of the hyperparameter  $\xi_t$  is assumed to be inverse gamma:  $\xi_t \sim \text{IG}(0.01, 0.01)$ .

Next, we follow Primiceri (2005) to set the priors for the VAR coefficients. The first 10 years of the sample are used to calibrate the prior distributions. The prior of the VAR coefficients is  $B_0 \sim N(\widehat{B}_{OLS}, 4V(\widehat{B}_{OLS}))$ , where  $\widehat{B}_{OLS}$  is the OLS point estimate and  $V(\widehat{B}_{OLS})$  is its variance in a time invariant VAR, estimated on the 10-year subsample. In the same way, the prior of the off-diagonal elements of  $A_t$  is equal to:

$$A_0 \sim N(\widehat{A}_{OLS}, 4V(\widehat{A}_{OLS}))$$

The priors for the diagonal elements of the VAR covariance matrix are  $\log \sigma_0 \sim N(\log \widehat{\sigma}_{OLS}, I_K)$ . Turning to the hyperparameters of the VAR equation, the priors of  $Q$ ,  $W$ ,  $S$  follow the inverse Wishart distribution as:

$$Q_0 \sim IW(0.01^2 \cdot (\dim(B) + 1) \cdot V(\widehat{B}_{OLS}), (\dim(B) + 1))$$

$$W_0 \sim IW(0.01^2 \cdot (\dim(\alpha) + 1) \cdot I_K, (\dim(A) + 1))$$

$$S_0 \sim IW(0.1^2 \cdot (\dim(\sigma) + 1) \cdot I_K, (\dim(\sigma) + 1))$$

where  $\dim(B)$ ,  $\dim(A)$  and  $\dim(\sigma)$  are the dimensions of each of the three matrices, which can be found by stacking in vectors the parameters as follows:

$$B_t = (\text{vec}(B_{1t})', \dots, \text{vec}(B_{pt})')', \quad \sigma_t = (\log \sigma'_{1t} \dots \log \sigma'_{Kt}) \quad \text{and} \\ \alpha_t = (\alpha'_{j1,t}, \dots, \alpha'_{j(j-1),t}) \quad \text{for } j = 1, \dots, K + 1.$$

## A.2 Simulating the posterior distributions

### A.2.1 Factor and factor loadings

We first simulate the coefficients  $\Lambda_i$  and the variance elements  $v_{jj}$  from Eq. (2). Relevant studies in the FAVAR literature treat latent factors as unobserved and these factors are estimated along with other parameters of the model using Kalman filtering algorithms (Bernanke et al. 2005; Ellis et al. 2014). However, this method may suffer from a potential drawback since not only is computationally demanding, but also, there are identification issues that arise with Kalman filter estimation. Therefore, as initially proposed by Stock and Watson (2005), we estimate the parameters of the factor Eq. (2) conditional on the principal component estimates of the factors. In particular, following Bernanke et al. (2005), the factor loadings  $\Lambda_i$  are sampled from the normal distribution:  $\Lambda_i \sim N(\bar{\Lambda}_i, v_{ii} \bar{M}_i^{-1})$  where  $\bar{\Lambda}_i = \bar{M}_i^{-1} (F'_{it} F_{it}) \hat{\Lambda}_i$ , with  $\hat{\Lambda}_i$  being an OLS estimator and  $\bar{M}_i = \bar{M}_0 + (F'_{it} F_{it})$  with  $\bar{M}_0 = I_K$ , while the diagonal elements of  $V_t$  are drawn from the following inverse gamma distribution:  $v_{ii} \sim iG(\bar{v}_{ii}, T + v_0)$  where  $\bar{v}_{ii} = \mu_0 + \hat{e}'_i \hat{e}_i$  with  $\hat{e}_i$  denoting the residual  $X_{it} - \Lambda_i F_{it}$ ,

### A.2.2 Time-varying VAR parameters

Next, given a draw of the factor loadings, we simulate the parameters from the VAR equation. In particular, we first draw the coefficient states  $B_t$ , from the following distribution:

$$p(B^T | F^T, A^T, \Sigma^T, P) = p(B_T | F^T, A^T, \Sigma^T, P) \prod_{t=1}^{T-1} p(B_t | B_{t+1}, F^t, A^t, \Sigma^t, P)$$

with  $B_t | B_{t+1}, F^t, A^t, \Sigma^t, P \sim N(B_{t|t+1}, N_{t|t+1})$  where  $B_{t|t+1} = E(B_t | B_{t+1}, F^t, A^t, \Sigma^t, P)$  and  $N_{t|t+1} = \text{Var}(B_t | B_{t+1}, F^t, A^t, \Sigma^t, P)$ . To obtain  $B_{t|t+1}$  and  $N_{t|t+1}$ , note that the system of equations defined earlier as:

$$\begin{aligned} F_t &= X_t' B_t + A_t^{-1} \Sigma_t n_t, \\ B_t &= B_{t-1} + \eta_t \end{aligned}$$

is a linear and Gaussian state space form, thus, standard Kalman filter forward and backward recursions applied. Then, having  $B_t$  in hand, we draw the covariance states  $A_t$ . Note first that the observation equation can be written as:

$$A_t(F_t - X_t' B_t) = \Sigma_t n_t = A_t \hat{F}_t$$

where  $\hat{F}_t = F_t - X_t' B_t$  is observable since  $B^T$  is given from the previous step. Since  $A_t$  is a lower triangular matrix with ones in the main diagonal, this can be written as:

$$\hat{F}_t = Z_t a_t + \Sigma_t n_t,$$

where  $\alpha_t = \alpha_t - 1 + \rho_t$  as defined previously and  $Z_t$  is the following matrix:

$$Z_t = \begin{bmatrix} 0 & \dots & \dots & 0 \\ -\hat{F}_{1,t} & 0 & \dots & 0 \\ 0 & -\hat{F}_{(1,2),t} & \dots & \dots \\ \dots & \dots & 0 & 0 \\ 0 & \dots & 0 & -\hat{F}_{(1,\dots,K),t} \end{bmatrix}$$

with  $\hat{F}_{(1,\dots,K),t}$  denoting the row vector  $[\hat{F}_{1,t}, \hat{F}_{2,t}, \dots, \hat{F}_{K,t}]$ . The model has a non-linear form since  $\alpha_{i,t}$ 's cannot be drawn equation by equation using standard Kalman filter recursions. For this reason, we need to make the additional assumption that the covariance matrix of  $\alpha_{it}$ ,  $S$ , is block diagonal, where each block consists of the parameters  $\alpha_{ij,t}$  which are in the same row of  $A_t$ . For example, there are  $K$  blocks  $\alpha_t^{\text{block1}} = \{\alpha_{21,t}\}$ ,  $\alpha_t^{\text{block2}} = \{\alpha_{31,t}, \alpha_{32,t}\} \dots$  so that each block on the diagonal of  $S$  is of perspective dimensions. Then, we proceed exactly as in the previous step to draw recursively from:

$$p(\alpha_{i,t} | a_{i,t+1}, F^t, B^T, \Sigma^T, P) \sim N(a_{i,t|t+1}, \Gamma_{i,t|t+1})$$

where  $a_{i,t|t+1} = E(\alpha_{i,t} | a_{i,t+1}, F^t, B^T, \Sigma^T, P)$  and  $\Gamma_{i,t|t+1} = \text{Var}(\Gamma_{i,t} | \Gamma_{i,t+1}, F^t, B^T, \Sigma^T, P)$ .

In the third step, conditional on  $B^T$  and  $A^T$ , we draw the volatility states  $\log \sigma_t$  using Jacquier et al. (2002). Fourth, we draw the hyperparameters  $Q, S, W$  of the covariance matrix  $P$  conditional on  $F^t, B^T, \Sigma^T, A^T$ , where each hyperparameter follows the

inverse Wishart distribution. In the last step, the algorithm goes back to step one and repeats the process.

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