OESTERREICHISCHE NATIONALBANK
EUROSYSTEM

WORKING PAPER 195

The International Transmission of U.S. Structural Shocks – Evidence from Global Vector Autoregressions

Martin Feldkircher and Florian Huber

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Publisher and editor *Oesterreichische Nationalbank*
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Design *Communications and Publications Division*

DVR 0031577

ISSN 2310-5321 (Print)
ISSN 2310-533X (Online)

Editorial

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July 28, 2014

The International Transmission of U.S. Structural Shocks – Evidence from Global Vector Autoregressions*

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July 4, 2014

Abstract

In this paper we analyze the impact of three U.S. structural shocks on, and its transmission to, the world economy. For that purpose we use a Bayesian version of the global vector autoregressive (GVAR) model coupled with a prior specification that explicitly treats uncertainty regarding variable choice in the estimation stage of the model. Based on sign restrictions, we identify positive U.S. aggregate demand and supply shocks and a contractionary U.S. monetary policy shock. Our results are three-fold: First, we find significant spillovers of U.S. based shocks on the global economy. Responses of international output to a U.S. monetary policy shock are most pronounced, while those related to aggregate demand and supply shocks are more modest. Second, the dynamics of the receiving countries' responses depend on the structural interpretation of the respective shock. More specifically, whereas responses to the U.S. demand shock are rather short-lived, the remaining shocks produce spillovers that impact permanently on domestic output. Third, U.S. shocks tend to spread globally through interest rates which resembles the pivotal role of the economy in shaping international financial markets. Co-movements in output and indirect effects via the oil price are additional important channels through which U.S. shocks feed into the domestic economy.

Keywords: Transmission of external shocks, Global vector autoregressions, stochastic search variable selection, sign restrictions, model uncertainty.

JEL Codes: C30, E52, F41, E32.

*The views expressed in this paper are not necessarily those of the Oesterreichische Nationalbank. We would like to thank Jesús Crespo Cuaresma, Gernot Doppelhofer, participants of the annual meeting of the Austrian economic association (NOeG), the first annual conference of the International Association for Applied Econometrics, Queen Mary University, London, internal research seminars at the Vienna University of Economics and Business, the OeNB and the national bank of Slovakia for helpful comments. Email: `martin.feldkircher@oenb.at` and `fhuber@wu.ac.at`.

1 Introduction & Related Literature

The rise in international trade and cross-border financial flows over the last decades implies that countries are more than ever exposed to economic shocks from abroad. The global financial crisis has recently demonstrated how a local shock can spread out very quickly, ultimately engulfing the world economy. Certainly, the structural interpretation of such a shock is likely to determine the response of the policy maker and hence the domestic economy. It appears hence of ample importance to identify the nature of the underlying shock in order to assess its international transmission properly. In this paper we focus on three shocks emanating from the U.S. economy and ask the following research questions: First, which U.S. shocks have a larger impact on the global economy – aggregate demand, supply or monetary shocks? Second, are there differences in the transmission? More specifically, through which variables are the shocks likely to feed into the domestic economy and which of the domestic variables are more strongly linked to external events? Third, how much variation in key macroeconomic variables can be explained by foreign compared to domestic shocks? A thorough assessment of these questions seems essential to design adequate policy measures that can buffer shocks from abroad.

There is a long standing branch of the literature that employs small-scale, bilateral vector autoregressive (VAR) models to assess the impact of foreign shocks on the domestic economy. Due to its pivotal role in the world economy, the vast majority of the literature focuses on the international transmission of U.S. shocks. Kim (2001) examines the impact of U.S. monetary policy shocks on non-U.S. G-7 countries via VARs employing both different data frequencies and shock identification schemes. An unexpected U.S. monetary expansion triggers a fall in world real interest rates, which leads in turn to a rise in non-U.S. G-7 output. The transmission of the shock via the trade balance seems to play a minor role. In a related study Mackowiak (2007) finds a strong response to a U.S. monetary policy shock of both output and prices in 8 emerging economies. Strikingly, the effect is even larger in the receiving countries than in the U.S. economy itself. However, other 'external' shocks seem to be even more important in explaining output fluctuations in emerging markets. Canova (2005) analyses the response of 8 Latin American countries to three different U.S. shocks. The structural shocks are identified via sign restrictions and then treated as exogenous variables in the Latin American country VARs. He finds that U.S. aggregate demand and supply shocks have only little impact on Latin American domestic macrovariables, whereas responses to a U.S. monetary policy shock are typically large and significant. In line with Kim (2001) the transmission is rather driven via domestic interest rates responding strongly to the U.S. monetary expansion than via the trade balance. Looking at cross-country differences, Canova (2005) finds that the size of the response is independent of the bilateral trade ties with the U.S. as well as the size of the receiving economy. This finding is corroborated by Ehrmann & Fratzscher (2009), who show that U.S. monetary policy shocks impact strongly on short-term interest rates and ultimately on equity markets in 50 economies.[1] In line with Canova (2005) it is not the bilateral trade ties with the U.S. but the degree of global integration that determines the size of the response in the domestic economy.

More recently, Eickmeier (2007); Mumtaz & Surico (2009); Kazi *et al.* (2013) use factor augmented VARs (FAVAR) that allow to include information from vast data sets. These models thus account for a broad range of potential transmission channels such as contagion via stock

[1] See also Dovern & van Roye (2014) who examine U.S. financial stress shocks and report permanent negative effects on international economic activity. Their findings thus lend further support to the dominant position of the U.S. economy in the global financial system.

and asset markets, exposure in foreign direct investment, the international bank lending and the confidence channel. Eickmeier (2007) finds that U.S. supply and demand shocks affect the German and the U.S. economy symmetrically and that supply shocks tend to have medium-term effects, while demand shocks impact on the economies in the short-run only. Kazi *et al.* (2013) extend the FAVAR approach by allowing for time-varying parameters and analyze the effect of U.S. monetary policy shocks on 14 OECD countries. According to their results, responses are very country-specific. Moreover, the size of the effect is larger during turbulent times as experienced during the recent global financial crisis. Finally, Fukuda *et al.* (2013) show that the negative effect of a U.S. monetary policy contraction on domestic production in Asian and Latin American economies has weakened since the 2000s. Changes in the monetary policy stance and exchange rate regime in the domestic economies, as well as a decline in the relative importance of the U.S. economy for these markets have been found to explain the decrease in the spillovers' extent.

While the literature reviewed above has established the general importance of U.S. structural shocks and its bearings for the global economy, it is not able to take higher-order cross-country dynamics into account that can be analyzed in a multi-country framework. As such, global vector autoregressions allow to examine the spatial propagation and the time dynamics of external shocks jointly and have been recently become popular in applied counter-factual analysis. In a series of papers this framework has been successfully used to analyze the effects of U.S. macroeconomic shocks on selected foreign economies (Pesaran *et al.*, 2004; Dees *et al.*, 2007b,a). However, identification and assessment of structural shocks and spillovers thereof in the context of GVAR models has been rather limited.[2]

In this contribution we combine the virtues of the literature that draws on structural two-country VARs and the GVAR multicountry framework. We are the first ones to assess the worldwide transmission of three structural U.S. shocks: an aggregate demand, aggregate supply and a monetary policy shock. Each shock implies a distinct response of the U.S. economy and is thus likely to spread differently across the globe, depending both on the nature of the shock and the working of the macroeconomy and policy stance of the receiving economy. Following Crespo Cuaresma *et al.* (2014) we use a Bayesian version of the global VAR model coupled with a prior specification that allows country-specifics to play out more strongly and excels in forecasting. Our main findings are three-fold. First, we find positive spillover effects of all three U.S. based shocks on international output. That is, positive demand and supply shocks in the U.S.A. trigger a rise in international real output, while a contractionary monetary policy shock decreases output in most of the countries. International effects related to the U.S. monetary policy shock are most pronounced, while U.S. aggregate demand and supply shocks trigger more modest responses. Second, the shape of the responses depends on the structural interpretation of the specific shock. More specifically, while international responses to U.S. demand shocks are short-lived those to the remaining shocks are more permanent in nature. Finally, U.S. shocks spread globally through interest rates, co-movements in output and indirectly via movements in the oil price. These results are complemented by some systematic cross-regional differences that emerge from our analysis.

The paper is structured as follows: Section 2 introduces the global VAR model and Section 3 the data. Section 4 presents sign-restrictions to identify three U.S. structural shocks together with domestic impulse responses. Section 5 contains different methods to summarize the international transmission of U.S. based shocks that comprise specification of the country models,

[2] For a recent exception see Eickmeier & Ng (2011); Chudik & Fidora (2011).

impulse response analysis and structural generalized forecast error variance decompositions. Finally, Section 6 concludes.

2 Econometric Framework

2.1 Individual Country Models: VARX* Specification

The GVAR, originally proposed by Pesaran *et al.* (2004), is a compact representation of the world economy. In principle, it comprises *two layers* via which the model is able to capture cross-country spillovers. In the first layer, we estimate separate time series models for each country contained in the global model. This allows to take cross-country differences of the economies appropriately into account since we do not impose any kind of homogeneity as e.g., in a panel VAR. In the second layer, the country models are stacked to yield a global model that is able to trace the spatial propagation of a shock as well as its time dynamics.

The VARX* model for country $i \in i = 0, ..., N+1$ is given by

$$x_{i,t} = a_{i,0} + a_{i,1}t + \sum_{j=1}^{p} \psi_{i,j} x_{i,t-j} + \sum_{j^*=0}^{p^*} \Lambda_{i,j^*} x^*_{i,t-j^*} + \vartheta_{i,0} d_t + \vartheta_{i,1} d_{t-1} + \varepsilon_{i,t} \tag{1}$$

where $x_{i,t}$ is a $k_i \times 1$ matrix of endogenous variables in country i at time t, $a_{i,0}$ denotes the coefficient on the constant and $a_{i,1}$ is the coefficient on the deterministic time trend. The $k_i \times k_i$ matrix of dynamic coefficients for the lagged endogenous variables in country i are given by $\psi_{i,j}$. On top of that, the right hand side of Equation 1 features weakly exogenous and strictly exogenous variables. The weakly exogenous variables are defined as

$$x^*_{i,t} = \sum_{r \neq i}^{N+1} \omega_{i,r} x_{r,t} \tag{2}$$

where $x^*_{i,t}$ is of dimension $k^*_i \times 1$ and $\omega_{i,r}$ denotes bilateral weights between countries i and r. In empirical applications, these are most often based on trade or financial flows. The $k^{ex} \times 1$ matrix of global exogenous factors is given by d_t, with its corresponding coefficient matrix given by $\vartheta_{i,0}$. The usual vector white noise process is denoted by $\varepsilon_{i,t} \sim \mathcal{N}(0, \Sigma_{\varepsilon,i})$.

Several facts arise from Equation 1. First, note that the weakly exogenous and exogenous variables enter the model contemporaneously. Since bilateral weights $\omega_{i,r}$ are assumed to be exogenous and fixed, weakly exogenous variables simply resemble a function of x_t and are thus endogenously determined within the global system. This does not hold true for strictly exogenous variables, d_t, for which further assumptions about the underlying dynamics have to be fused into the model. Second, note that if $\Lambda_{i,j} = 0 \ \forall j \in \{0, p^*\}$ and $\vartheta_{i,0} = \vartheta_{i,1} = 0$, the VARX* collapses to a standard VAR(p) model.

2.2 Solving the global model

Solving for the global model is straightforward. We start by specifying a matrix $z_{i,t} = (x_{i,t}, x^*_{i,t})'$, which is of dimension $(k_i + k^*_i) \times 1$. For the sake of simplicity, we assume in the following discussion that $p = p^* = 1$ and $\vartheta_{i,0} = \vartheta_{i,1} = 0$. Equation (1) then simplifies to

$$x_{i,t} = a_{i,0} + a_{i,1}t + \psi_{i,1}x_{i,t-1} + \Lambda_{i,0}x^*_{i,t} + \Lambda_{i,1}x^*_{i,t-1} + \varepsilon_{i,t} \tag{3}$$

Collecting all contemporaneous terms on the left-hand side, we can rewrite the model in (3) as follows:

$$A_i z_{i,t} = a_{i,0} + a_{i,1}t + B_i z_{i,t-1} + \varepsilon_{i,t} \tag{4}$$

with $A_i := (I_{k_i} \;\; -\psi_{i,0})$ and $B_i := (\psi_{i,1} \;\; \Lambda_{i,1})$. Note that by using a suitable $(k_i + k_i^*) \times k$ linking matrix W_i, where $k = \sum_{i=1}^{N} k_i$ denotes the number of endogenous variables in the global system, we can easily rewrite $z_{i,t}$ in terms of a global vector. The global vector, $x_t = (x_{0,t}, ..., x_{N,t})'$ contains all endogenous variables in the system. Thus, it is easy to show that by using (2), $z_{i,t}$ can also be written as

$$z_{i,t} = W_i x_t \tag{5}$$

This allows us to re-express the country model in equation (3) in terms of the global vector,

$$A_i W_i x_t = a_{i,0} + a_{i,1}t + B_i W_i x_{t-1} + \varepsilon_{i,t} \tag{6}$$

Stacking the A_iW_i and B_iW_i matrices for all countries leads us to

$$G x_t = a_0 + a_1 t + H x_{t-1} + \varepsilon_t \tag{7}$$

where $a_0 := (a_{0,0}, ..., a_{N,0})$, $a_1 := (a_{0,1}, ..., a_{N,1})'$, $G := (A_0W_0, ..., A_NW_N)'$, $H := (B_0W_0, ..., B_NW_N)'$ and $\varepsilon_t := (\varepsilon_{0,t}, ..., \varepsilon_{N,t})'$. Premultiplying from left by G^{-1} yields the global vector autoregressive model:

$$\begin{aligned} x_t &= G^{-1}a_0 + G^{-1}a_1 t + G^{-1}Hx_{t-1} + G^{-1}\varepsilon_t & (8)\\ &= b_0 + b_1 t + F x_{t-1} + e_t, & (9) \end{aligned}$$

with F denoting the companion matrix. Note that Equation 9 resembles a simple VAR(1) with a deterministic trend term. This implies that we can employ standard methods such as impulse response analysis, forecasting and error variance decompositions in a straightforward fashion. To ensure stability of the model, the eigenvalues of the F-matrix lie within the unit circle, which implies that shocks have no permanent impact on the system in the very long-run.

2.3 Priors on the Parameters: The SSVS prior

The inclusion of weakly exogenous, foreign variables reduces the dimension of the underlying model to a large extent. However, the GVAR framework is still prone to the curse of dimensionality since the number of variables quickly grows through the inclusion of weakly exogenous variables and time lags. Hence, we are introducing a hierarchical prior structure on the coefficients and apply shrinkage on the parameters of the model. Since we are using a time series model with global coverage, country specifics should be properly taken into account. The GVAR framework builds on country-specific sub-models but the literature typically specifies each of them in a similar fashion with variable choice solely dictated by data availability. By contrast, we formally take uncertainty about variable choice into account by employing the so-called stochastic search variable selection prior (SSVS). This ensures country models that fully integrate the prevailing heterogeneity observed in the world economy.

For the subsequent discussion, it proves convenient to work with the stacked matrix of coefficients for country i, $\Xi_i = (a_{i,0}, a_{i,1}, \text{vec}(\psi_{i,1})', \text{vec}(\Lambda_{i,0})', \text{vec}(\Lambda_{i,1})')'$. The SSVS-prior assumes a mixture normal prior on each coefficient

$$\Xi_{i,j}|\delta_{i,j} \sim \delta_{i,j}\mathcal{N}(0, \tau_{i,0}^2) + (1 - \delta_{i,j})\mathcal{N}(0, \tau_{i,1}^2) \tag{10}$$

where $\delta_{i,j}$ is a binary random variable which equals 1 if variables j is included in country model i and zero otherwise. The above mixture prior belongs to the class of 'spike and slab' priors which are frequently used for Bayesian variable selection. Here, we follow George *et al.* (2008) and choose a hierarchical setting in which $\delta_{i,j}$ is a random variable that has to be estimated. Typically, $\tau_{i,0} >> \tau_{i,1}$, which implies that the 'spike' is tightly centered at zero. Variable selection is based on the probability of assigning the corresponding regression effect to the 'slab' component. That is, for small coefficients the 'spike' component applies, pushing the associated posterior estimate more strongly towards zero. For the remaining coefficients, the slab component resembles a non-informative prior that has little impact on the posterior. Following George *et al.* (2008) we set the prior variances for the normal distributions in a semi-automatic fashion. This implies scaling the mixture normal with the OLS standard errors of the coefficients for the full model. We choose $\tau_{i,0} = 0.01, \tau_{i,1} = 3$. Under this setting, the prior standard deviation on coefficient j in country i is then given by $\tilde{\tau}_{i,j} = 0.01\ \hat{\sigma}_{i,j}$ if $\delta_{i,j}$ equals zero and $\tilde{\tau}_{i,j} = 3\ \hat{\sigma}_{i,j}$ otherwise. In what follows, posterior results per country are based on 10,000 posterior draws after a burn-in phase of 5,000 iterations.[3]

As a byproduct of the SSVS prior, we can compute posterior inclusion probabilities (PIPs) for each coefficient j in country i based on posterior draws of $\delta_{i,j}$. These serve as a measure of the variable's importance in explaining variation in the respective dependent variable. Finally, we base our inference on the posterior draws of Ξ_i. That is, we average over model specifications that are characterized by different degrees of shrinkage applied to the coefficients instead of picking the variables with highest posterior inclusion probabilities only. Furthermore note that since the SSVS prior is based on a continuous distribution for the spike component, small coefficients are effectively shrunk to zero but never excluded from the model. This is in contrast to other model averaging techniques from the class of MC^3 algorithms put forward e.g., in Fernandez *et al.* (2001); Ley & Steel (2012) where averaging is carried out over different model specifications which are characterized by different zero restrictions on the coefficients.

For the country specific variance-covariance matrix Σ_i, we use the following factorization:

$$\Sigma_i = P_i^{-1'} P_i^{-1} \tag{11}$$

where $P_i^{-1'}$ denotes the lower Cholesky factor of Σ_i. For prior implementation it is more convenient to work with the precision matrix $\Sigma_i^{-1} = P_i' P_i$.

For the k_i main diagonal elements of P_i denoted by $\eta_{i,j}$ we impose a gamma prior, given by

$$\eta_{i,j} \sim \mathcal{G}(\underline{a_1}, \underline{a_2}) \ \ \forall i = j \tag{12}$$

where a_1 and a_2 are set such that the prior information is effectively rendered noninfluential. Furthermore we impose a normal prior on the remaining $\frac{k_i(k_i-1)}{2}$ free elements of P_i, denoted

[3] In a prior sensitivity analysis we have experimented with additional specifications for $\tau_{i,0}$ and $\tau_{i,1}$. Our results remain qualitatively unchanged.

by $\rho_{i,j}$. Formally,

$$\rho_{i,j} \sim \mathcal{N}(0, \underline{V}) \tag{13}$$

where we set $\underline{V}$ equal to 10, implying a non-informative prior on the off-diagonal elements of P_i. In principle, it would be possible to do a stochastic restriction search on the elements of Ψ_i. However, due to the fact that our identification routine is based on sign restrictions we leave that possibility aside and focus exclusively on a restrictions search on the dynamic coefficients of the model in Equation 3.

Estimation of the model with the SSVS specification can be done using a simple Gibbs sampling scheme which draws iteratively from the conditional posteriors of $p(\Xi_{i,j}|\mathcal{D}, \eta_{i,j}, \rho_{i,j}, \delta_{i,j})$, $p(\eta_{i,j}|\mathcal{D}, \Xi_{i,j}, \rho_{i,j}, \delta_i)$, $p(\rho_{i,j}|\mathcal{D}, \Xi_{i,j}, \eta_{i,j}, \delta_i)$, $p(\delta_{i,j}|\Xi_{i,j}, \eta_{i,j}, \rho_{i,j})$, where $\mathcal{D}$ denotes the data.

By this we retrieve posterior estimates of Ξ_i, Σ_i and δ_i.[4] However, the quantity of interest is not the posterior of the coefficients in the country model but posterior estimates of coefficients in the global model, outlined in Equation 9. We denote the posterior for the coefficients of the global model by $p(\Psi|\mathcal{D}, \Omega)$, where $\Psi = (b_0', b_1', \text{vec}(F)')'$, $\mathcal{D}$ and Ω denotes the global coefficient vector, available data and global variance-covariance matrix, respectively. It is straightforward to sample from $p(\Psi|\mathcal{D}, \Omega)$ by drawing from the country specific posteriors, Ξ_i and Σ_i and applying the algebra outlined in the previous subsection to generate valid draws from the global posterior. In this vein we can then compute the quantities of interest, like forecasts or impulse-responses.

3 Data

We use the data set put forward in Feldkircher (2013), which contains quarterly observations for 43 countries and 1 regional aggregate, the euro area (EA)[5]. Table A1 in the appendix provides the country coverage of our sample, which includes emerging economies, advanced economies and the most important oil producers and consumers representing more than 90% of the global economy in terms of GDP in 2010.[6]

We have 72 quarterly observations by country spanning the period 1995Q1 to 2012Q4 and cover data on real activity (y), change in prices (Δp), the real exchange rate (e), short-term interest rates (i_s), long-term interest rates (i_l) and the ratio of real exports to real imports (tb). On top of that we include oil prices ($poil$) as a global control variable. The variables are briefly described in Table A2 in the appendix. With the exception of government yields all of them are available with wide country coverage. We construct foreign counterparts for all domestic variables except for the export to import ratio.[7] In deviation to the bulk of the literature, we opt to control for co-movements of currencies, which has recently demonstrated to improve

[4] Σ_i is constructed by using the draws from $p(\eta_{i,j}|\mathcal{D}, \Xi_{i,j}, \rho_{i,j}, \delta_i)$ and $p(\rho_{i,j}|\mathcal{D}, \Xi_{i,j}, \eta_{i,j}, \delta_i)$, respectively.

[5] The country composition on which the data on the euro area is based changes with time. While historical time series are based on data of the ten original euro area countries, the most recent data are based on 17 countries. The results of our analysis remain qualitatively unchanged if we use a consistent set of 14 euro area member states throughout the sample period instead of the rolling country composition for the data on the euro area, as the relative economic size of these three countries is quite small.

[6] These figures are based on nominal GDP and are taken from the IMF's World Economic Outlook database, April 2012.

[7] See Greenwood-Nimmo *et al.* (2012) for theoretical reasons why not to include foreign counterparts of trade-related domestic variables.

forecasts (Carriero *et al.*, 2009).[8] In the early literature on GVARs, weakly exogenous variables have been exclusively constructed based on bilateral trade flows (Pesaran *et al.*, 2004, 2009; Dees *et al.*, 2007b). More recent contributions suggest using trade flows to calculate foreign variables related to the real side of the economy (e.g., output and inflation) and financial flows for variables related to the financial side of the economy (e.g., interest rates, credit volumes), while other weighting schemes, such as distance based weights, have been broadly overlooked so far.[9] In this paper we account for uncertainty about the type of weights by examining 9 distinct matrices comprising bilateral trade flows, distance based measures, banking exposures and foreign direct investment positions. In what follows, results are based on a marginal-likelihood-weighted average of the top 3 matrices that together receive most of the posterior support. This implies taking either bilateral banking sector exposure, foreign direct investment positions or trade weights to construct i_s^*, i_l^*, while $y^*, \Delta p^*, e^*$ are always based on bilateral trade weights. See the appendix for a detailed description on the matrices and the way we account for uncertainty about their specification.

The U.S. model deviates from the other country models in the sense that the global control variable, the oil price, is determined within that country model. The dominance of the U.S. economy on the financial markets is often accounted for by including only a limited set of weakly exogenous variables. Since our modeling approach entails variable selection, we let the data decide which variables to include in the U.S. model and do not restrict the range of variables a priori. Due to the rather short time span of the data, untreated outliers can have a serious impact on the overall stability and the results of the model. We therefore follow Crespo Cuaresma *et al.* (2014) and introduce a set of dummy variables in the country-specific specifications to control for outliers. These account for the fact that some countries witnessed extraordinarily high interest rates at the beginning of the sample period (which returned steadily to 'normal' levels) and that some economies (Russia or Argentina, for instance) were exposed to one-off crisis events. The largest deviations from 'normal' times per country are identified based on country-expert information and periods are listed in Table A3. By introducing one-off dummies coupled with linear interaction terms of the relevant variables we then take care of unusually large historical observations. While identification of the time periods characterized by deviations from the norm are based on judgment, inclusion of these dummy variables is subject to the SSVS prior and thus finally data-driven. The full set of a priori specification of the country models are provided in the Appendix, Table A3.

4 Identification and Domestic Response of U.S. Structural Shocks

We follow Dees *et al.* (2007b) and identify the shocks locally in the U.S. country model which is indexed by $i = 0$:

$$x_{0,t} = \psi_{0,1} x_{0,t-1} + \Lambda_{0,0} x_{0,t}^* + \Lambda_{0,1} x_{0,t-1}^* + \varepsilon_{0,t} \tag{14}$$

[8] In this paper we abstain from formally testing the assumption of whether foreign variables can be treated as weakly exogenous taking a purely empirical stance. Since the majority of the economies can be safely regarded as small compared to the global system, treating foreign variables as weakly exogenous seems appropriate. See also results on classical tests provided in Feldkircher (2013), which ensures weak exogeneity also partially for larger countries such as the U.S.A. and the euro area.

[9] See LeSage & Pace (2009) for an introduction to spatial econometrics for which distance based weight matrices are frequently used.

Without loss of generality, we omit the deterministic part of our model. To back out the structural form of the model we premultiply Equation 15 by Q_0

$$Q_0 x_{0,t} = Q_0 \psi_{0,1} x_{0,t-1} + Q_0 \Lambda_{0,0} x^*_{0,t} + Q_0 \Lambda_{0,1} x^*_{0,t-1} + Q_0 \varepsilon_{0,t} \tag{15}$$

where $Q_0 = R_0 P_0^{-1'}$. The structural errors are now given by $v_{0,t} = Q_0 \varepsilon_{0,t}$, with R_0 being a $k_i \times k_i$ matrix chosen by the researcher and $P_0^{-1'}$ denoting the lower cholesky factor of $\Sigma_{\varepsilon,0}$. The variance-covariance structure of $\varepsilon_{0,t}$ is given by $\Sigma_0 = P_0^{-1'} P_0^{-1}$. In the present application we find R_0 by relying on sign restrictions. That is, we search for an orthonormal $k_0 \times k_0$ rotation matrix R_0 that satisfies $R_0 R_0' = I_{k_0}$. Given R_0, we can use the following decomposition of the structural variance covariance matrix

$$\Sigma_v = R_0 P_0^{-1'} P_0^{-1} R_0' = Q_0 Q_0' \tag{16}$$

This implies that, conditional on using a suitable rotation matrix R_0, we can back out the structural shocks. To obtain a candidate rotation matrix we draw R_0 using the algorithm outlined in Rubio-Ramírez *et al.* (2010). We then proceed by constructing a $k \times k$ matrix Q, where the first k_0 rows and columns correspond to R_0.

Formally, Q looks like

$$Q = \begin{pmatrix} Q_0 & 0 & \cdots & 0 \\ 0 & I_{k_1} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & I_{k_N} \end{pmatrix} \tag{17}$$

Premultiplication of the GVAR with Q leads to

$$Q x_t = Q b_0 + Q b_1 t + Q F x_{t-1} + Q e_t \tag{18}$$

Equation 18 can be used to obtain the h-step impulse response function with respect to the structural errors, denoted by $\varphi(Q)^h$. In case responses fulfill the set of sign restrictions we keep the candidate rotation matrix. We proceed sampling rotation matrices until we have 10 matrices that fulfill the restrictions. Finally we select between the successful rotation matrices as outlined in Fry & Pagan (2011). That is, we choose the rotation matrix that yields impulse responses most similar to the median responses over the successful matrices. This is done for each of the 1,000 draws that we have randomly selected from the full set of 10,000 posterior draws due to computational reasons. Hence our results are implicitly based on $1,000 \times 10$ rotation matrices with the accompanying credible sets of impulse responses reflecting both parameter uncertainty and uncertainty with respect to identification of the structural shocks.

Note that we rely on structural generalized impulse responses advocated in Dees *et al.* (2007b,a) that take the historical correlation among cross-country residuals into account. We furthermore rely on a block diagonal structure of Σ_e as proposed in Eickmeier & Ng (2011). Setting the off-diagonal elements to zero restricts cross-country spillovers and can thus be seen as a further assumption about the transmission of shocks. More specifically, the assumption implies that immediate spillovers across countries are modest[10] which might be justified when using quarterly data.

[10] Note that we do not restrict immediate spillovers to be exactly zero since Σ_e is pre-multiplied by G^{-1} for the global model.

4.1 Identification Scheme

We follow Peersman (2005) and impose the restrictions provided in Table 1 on the impulse response functions of the U.S. country model.

Table 1: Sign restrictions.

Shock	y	Δp	i_s
Aggregate demand	↑	↑	↑
Aggregate supply	↑	↓	↓
Monetary policy	↓	↓	↑

Notes: The restrictions are imposed as $\geq$ / $\leq$. Constraints on output (y) and price dynamics (Δp) are binding for 1 quarter, while the restrictions on the short term interest rate (i_s) are imposed on impact only.

The constraints above are based on a typical aggregate demand and supply diagram and consistent with most dynamic general equilibrium models. Restrictions on output and price dynamics are imposed on impact and the following quarter. Since interest rates are more flexible and typically adjust faster to external shocks, the respective constraints are binding on impact only (Peersman, 2005). First, a positive demand shock triggers an increase in real output and prices and no immediate fall of the short-term interest rate. This pattern is consistent with a shift of the aggregate spending / IS curve (Peersman, 2005). In contrast, an aggregate supply shock is characterized by an increase in output, while prices decline. Finally, an unexpected increase in the U.S. federal funds rate, is assumed to trigger a contraction in real output. The increase in the policy rate is further assumed to contain price dynamics. Unlike Peersman (2005) we abstain from analyzing the effect of an unexpected increase in the oil price since it is very similar to an aggregate supply shock and can be hardly isolated within the present framework.[11]

4.2 Measuring U.S. Shocks

We first investigate the dynamics of the U.S. variables' responses to the three structural shocks. The results are depicted in Figures A2 and A3. The first two panels of Figure A2 show the median response along with 25th and 75th percentiles for the aggregate demand shock. On impact, real output increases by 0.8%.In general, responses are short-lived and the economy adjusts gradually within the first 5 quarters. Inflation and short-term interest rates both respond positively and pronounced in the short-run. The initially positive response of the oil price converges to zero after about 10 quarters, but responses are accompanied by wide credible sets throughout the horizon. Figure A2 bottom two panels show the results for the aggregate supply shock. In line with our expectations, the supply shock has a more long-lasting effect on real output. Initially, real GDP increases by about 0.8%. While the effect gradually declines, it is still significant up to 15 quarters. Similar to the aggregate demand shock, the reaction of inflation and short-term interest rates is pronounced in the short-run, but effects are petering out very quickly. By contrast, responses of the export to import ratio, the oil price and long-term interest rates are moderate and accompanied by large credible sets. Finally, we illustrate the results for the monetary policy shock in Figure A3. The unexpected increase in the U.S.

[11] In fact Peersman (2005) separates the aggregate supply from the oil price shock by assuming the latter causes a stronger initial response in the oil price only.

federal funds rate deters real output significantly up to 8 quarters after which credible sets contain the zero response. We thus cannot reject long-run neutrality of the monetary policy shock with respect to output which is in line with findings provided by Peersman (2005) and implicitly Uhlig (2005) who finds evidence for output neutrality even in the short-run.[12] On impact, real GDP declines by 1.5%. The increase in U.S. short-term interest rates converges to zero after about 5 quarters, while the response of inflation adjusts more quickly. Responses of U.S. long-term interest rates, the trade balance and the oil price are accompanied by wide credible sets.

5 The International Transmission of U.S. Structural Shocks

Our framework allows for three different assessments of U.S. structural shocks and their transmission to the global economy. First, we analyze the country models. This is done by examining posterior inclusion probabilities that are obtained as a by-product of the SSVS prior in the estimation step. Foreign variables that receive strong support in the data might be considered as shock transmitters. Moreover, examining which domestic equations are most strongly linked to foreign factors might yield further insights about the transmission mechanism. Second, we assess the effect of U.S. shocks on the global economy by reporting the structural impulse responses of real output, inflation, the export to import ratio and short-term interest rates to the three structural shocks. By this we aim to assess which regions are most strongly affected by what kind of shock. Finally, forecast error variance decompositions yield another angle on the importance of U.S. shocks in explaining movements in domestic variables. Note that while the assessment of posterior inclusion probabilities is purely empirical and regards the reduced form estimation stage of the model, structural impulse response functions and error variance decompositions yield insights about the dynamics of the global structural model, which we have pinned down via sign restrictions.

5.1 Reduced Form Comparison of Individual Country Models

Posterior inclusion probabilities for each of the six domestic equations are provided in Table A4 as simple averages per region. For the sake of brevity we concentrate on those variables that receive PIPs ≥ 0.5, which compose the so-called median model that can be shown to posses excellent forecasting features (Barbieri & Berger, 2004). First, posterior inclusion probabilities attached to *domestic variables* reveal strong support for the first own lag in all equations but long-term interest rates and the trade balance. In these two equations, the importance of domestic variables is more broadly based. On top of that, in all regions the export to import ratio appears as an important determinant for real output, while short-term interest rates are included in the equation for domestic inflation. The inclusion of other domestic variables varies strongly with the region under consideration.

[12] There is a substantial literature asking whether monetary policy shocks can be considered neutral with respect to output. In fact, it appears that more traditional, recursive schemes for identification find significant, long-run effects of monetary policy shocks, while they are transitory when identification is done via placing restrictions on the signs of impulse responses (see results provided in e.g., Uhlig, 2005; Peersman, 2005). Among other factors this might be driven by the assumption implied by traditional recursive schemes that restrict the initial response of output to zero (Uhlig, 2005).

Posterior inclusion probabilities attached to *foreign variables* reveal strong support for oil prices and foreign inflation as control variables. This holds true throughout the regions for nearly all equations hinting at international inflation linkages as an important channel to pass on external shocks to the domestic economy. The inclusion of other foreign factors turns out to be region-specific. In general, *advanced economies* are strongly integrated with the global economy and among themselves. This can be seen by the average PIPs associated to foreign variables per domestic equation, which ranges from 0.56 (**e**) to 0.71 (**tb**). More specifically, foreign inflation, the oil price and – to a lesser extent – foreign output are the most important external factors in advanced economies that explain movements in real GDP, domestic inflation, the trade balance and interest rates. In a similar fashion, these factors appear as important determinants of domestic variables in *Asia*. However, movements in domestic Asian variables are also strongly influenced by foreign long-term interest rates. For *Emerging Europe*, the SSVS prior reveals rather parsimonious models for the six equations in terms of both foreign and domestic factors. Co-movements in foreign output are by far the most important determinant of real activity, while the oil price plays a more prominent role for domestic inflation and the trade balance. Finally note the particular strong support for foreign interest rates in the equation for domestic long-term interest rates. This might be partially explained by the low coverage of domestic long-term interest rates in emerging Europe. Devoid of domestic long-term interest rates, foreign interest rates are likely to absorb variation that would otherwise be soaked up by domestic financial variables (Feldkircher, 2013). Lastly, in *Latin America* foreign price dynamics and the oil price are important determinants of most equations, while foreign output receives strong posterior support in the domestic output equation only. Latin America is the only region, where exchange rates are explained solely by foreign prices, while no support for co-movements of exchange rates appears in the data (Carriero *et al.*, 2009). Similar to economies in emerging Europe, the coverage of domestic long-term interest rates is low which might explain the particularly strong role of foreign long-term interest rates in the respective domestic equation. In general, these first cross-country differences suggest that shocks are transmitted differently across the regions. They do not, however, yield insights about the extent to which a particular region is exposed to a foreign shock, which is analyzed by means of impulse response functions in the next section.

5.2 Impulse Response Analysis

Hitherto, the empirical literature has established significant spillovers that emanate from the U.S. economy to emerging (Latin American) and developed (non-U.S. G7) countries using mostly two-country VAR models. In what follows, we concentrate on the response of four key macroeconomic variables to the U.S. based shocks: output, price dynamics, short-term interest rates and the export to import ratio. These responses are illustrated in Figures A4 to A6, which show the median responses along with the 25th and 75th percentiles. Responses are shown as simple averages per region, since purchasing power parity (PPP) weighted responses would limit the responses to those of one or two dominant countries per region only. [13]

First, we examine the transmission of aggregate supply and demand shocks that emanate from the U.S. economy. Galesi & M. J. Lombardi (2013) examine the international transmission of oil and food price shocks and find considerable linkages through which inflationary pressures are transmitted. Moreover, a considerable part of fluctuations in domestic headline inflation can be attributed to foreign sources. Since the aggregate demand and supply shocks are separated by

[13] Results for single countries and PPP-weighted regional averages are made available upon request.

opposite movements in prices, we expect countries to respond differently to the two shocks. As such, all regions respond with an increase of real output to the U.S. expansion that is driven by demand side disturbances. In line with our expectations this effect is, however, only transitory. Throughout the regions, positive spillovers are present within the first five to ten quarters after which the effect on real output becomes insignificant. The peak of the real output responses lies in the range of 0.08 to 0.13% which is about 6 to 10 times smaller compared to the immediate reaction of U.S. real GDP itself. These rather homogeneous responses regarding the magnitudes are not contradicting the results based on the analysis of posterior inclusion probabilities, which revealed rather parsimonious models for emerging Europe in terms of foreign factors. Dynamic responses depend rather on the magnitude of estimated coefficients and not on the number of foreign factors included in the respective country models. While real output responses are close in magnitude across the regions, their shapes differ. In advanced and Asian economies the responses peak within the first three quarters. In emerging Europe and Latin America the peaks are more delayed. The response of domestic inflation is hump-shaped and credible sets are large. With the exception of Latin America, responses of short-term interest rates are accompanied by large credible sets. In Latin America, the response of domestic interest rates is pronounced and about one-fourth of the size of the initial reaction of U.S. short-term interest rates. Throughout the regions, the response of the trade balance is non-significant.

Second, we analyze the consequences of an U.S. aggregate supply shock. The U.S. expansion affects real output positively throughout the regions. Rather than short-lived, responses on output are significant up to 20 quarters in advanced economies, Asia and emerging Europe and up to 15 quarters in Latin America. This is in contrast to responses to aggregated U.S. demand disturbances. Responses reach their peaks within the first five quarters for advanced and Asian economies and within 8 quarters for emerging Europe and Latin America. These peaks amount to 0.09 to 0.12% which is close to the responses related to the aggregate demand shock. Inflation adjusts gradually but responses are accompanied by large credible sets throughout the regions. Similar to the demand shock, the reaction of short-term interest rates is most pronounced in Latin America (one third of the initial decrease in U.S. rates). The remaining regions show a pronounced reaction in the very short-run that is accompanied by tight credible sets in emerging Europe and Asia. The response of the trade balances dies out very quickly and is not significant across the regions.

Last, we analyze the transmission of U.S. monetary policy shocks. As outlined in Kim (2001); Canova (2005) the basic versions of the Mundell-Flemming-Dornbusch theorem proposes at least two ways of how shocks to the interest rate can affect foreign economies. First, an increase in the U.S. federal funds rate and an accompanied appreciation of the U.S. dollar could increase foreign output due to a shift of domestic expenditures toward now comparably cheaper imports (expenditure switching). This effect might be offset by reduced domestic spending – and thus import demand – triggered by the increase in the monetary policy rate (income effect). These two effects resemble the trade channel. Second, since the U.S.A. inherits a pivotal role in global financial markets, an increase in the U.S. federal funds rates is likely to trigger movements in foreign interest rates (financial channel). Kim (2001) and Canova (2005) find strong evidence for the financial channel and less for the trade channel. Our results show that cross-country responses of real output to the U.S. monetary policy shock are negative, permanent and mostly significant. This is in contrast to the domestic response of U.S. output to the monetary policy disturbance, which was rather short-lived. More specifically, minima of output responses are reached within the first three quarters in advanced economies, while they are more delayed for the remaining regions. Minima of output responses lie in the range of -0.2 to -0.25% with

Latin American output showing the largest response. Here, the response of output levels out very quickly where it stays even after 20 quarters. This finding generalizes results provided in Willems (2013) who reports permanent output responses for Latin American economies not covered in this analysis (Ecuador, Panama and El Salvador). Similar to before, responses of inflation are hump-shaped but accompanied by wide credible sets. Furthermore, domestic interest rates respond strongly in the short-run in all regions but advanced economies where credible sets are large. In line with previous results, the reaction of Latin American interest rates is most pronounced (about one third of the initial increase in U.S. rates). Finally, responses for the trade balance are non-significant.

5.3 Forecast Error Variance Decompositions

We finally assess the importance of foreign versus domestic factors in explaining domestic key macroeconomic variables. This is done by means of a forecast error variance decomposition. Usually, forecast error variance decompositions are computed using orthogonalized shocks. However, in the presence of cross-country correlation this assumption is no longer valid. Hence, we have to follow Dees *et al.* (2007b) and compute a Structural Generalized Forecast Error Variance Decomposition (SGFEVD), which is given by

$$\mathcal{SGFEVD}(x_{(h),t}; v_{(j)t}, h) = \frac{\sigma_{jj}^{-1} \sum_{l=0}^{h} \{\mathfrak{e}_{\mathfrak{l}}' F^l (RG)^{-1} \Sigma_v \mathfrak{e}_{\mathfrak{j}}\}^2}{\sum_{l=0}^{h} \{\mathfrak{e}_{\mathfrak{l}}' F^l (RG)^{-1} \Sigma_v (RG)^{-1'} F^{l'} \mathfrak{e}_{\mathfrak{j}}\}}, \text{ for } h = 0, 1, 2, ... \tag{19}$$

where $\mathfrak{e}_{\mathfrak{l}}$ denotes a $k \times 1$ selection vector and Σ_v denotes the variance structure of the structural shocks. This expression measures the influence of elements of v_t on x_{t+h}. To compute quantities of interest like the posterior mean of S., we sample from the global posterior and use those draws together with (19) and the draws of R. As a point estimate we rely on the posterior mean of the SGFEVDs. Note that numbers above 100 % arise because of non-zero cross-country correlations (Galesi & Sgherri, 2013). These are, however, rather small.[14]

Figures A7 to A9 present the average forecast error variance decomposition of shocks to real GDP, inflation and short-term interest rates emanating in the domestic economy. Note that these compositions are based on the structural errors identified via the set of sign restrictions provided in Table 1. Assessing the relative importance of domestic and foreign / U.S. variables allows to identify the equation in the domestic economy that is most exposed to shocks from abroad. Put differently, this yields insights about the receiving end of the transmission of foreign shocks. This assessment is complemented by identifying the variables that transmit a shock to the domestic economy. Regional results for advanced economies, Asia, Latin America and emerging Europe are calculated by computing averages of the single countries' forecast error variance decompositions.

On impact, domestic factors explain most of the forecast error variance associated to real output, inflation and short-term interest rates. This finding holds equally true for all four regions under consideration. As the forecast horizon expands, and through the lag structure in the system, the contributions of the foreign variables increase considerably. This increase is region-specific and depends on the variable under consideration. Compared to domestic factors, foreign variables play a particularly pronounced role in explaining real output. In all four regions, foreign factors explain about the same share of forecast error variance as their domestic counterparts in the

[14] Averages of pair-wise cross-country residuals based on the posterior median are available from the authors upon request.

medium-term (20 quarters). This emphasizes the importance of international co-movements in business cycles for developments in the domestic economy throughout the globe. By contrast, movements in inflation are driven more strongly by domestics factors. This holds in particular true in advanced economies and Asia, while foreign factors explain about one-third of forecast error variance in emerging Europe and Latin America. Finally, Figure A9 shows the results for domestic short-term interest rates. Similar to real output, domestic factors explain most of the variance on impact, while this share decreases with the forecast horizon. In the medium term, foreign factors account for about one third of the variance in advanced economies, Asia and emerging Europe. In Latin America, foreign factors account for even slightly more variance than domestic variables in the medium-term.

Next, we examine which particular foreign variables can explain significant shares in forecast error variances. Throughout the regions, foreign factors from leading industrialized economies such as the euro area, the U.S.A. and Japan can explain large shares of forecast error variance. This list of global players is complemented by China, whose economy has grown rapidly during the period covered in our sample.[15] Last, oil prices appear as important control variable which can explain significant shares of forecast error variance in all regions. This set of variables is complemented by variables from additional, local key players which differ with the region under consideration.

In *advanced economies*, that comprise the U.S. itself, the analysis reveals variables related to Mexico, Canada and the U.K. on top of the aforementioned global key players as important foreign factors. While forecast error variances related to inflation and short-term interest rates are frequently explained by foreign exchange rates and inflation, a large fraction of variance attributed to real output is explained by its foreign counterparts. Looking at U.S. related variables, U.S. inflation, short-term interest rates and output explain significant shares of forecast error variance. Similar to advanced economies, factors explaining forecast error variance in *Asia* are related to leading industrialized economies. On top of that, Korea and Indonesia are important local drivers of Asian domestic economies. Foreign interest rates, inflation and exchange rates account for most of the forecast error variance that is explained by foreign factors. For *Emerging Europe*, variables related to the euro area appear frequently among the most important foreign factors. This holds especially true for interest rates and inflation, which might be partially driven by the fact that some of the countries peg their currencies in one way or the other to the euro. Finally, for *Latin America* foreign factors from the U.S.A resurface frequently among the most important foreign factors. In addition to variables from the leading industrialized countries, variables from regional key players such as Brazil and Argentina explain significant shares of forecast error variance related to short-term interest rates. U.S. variables appear frequently as important foreign factors emphasizing the pivotal role the U.S. economy plays in shaping Latin America's business cycles. These comprise U.S. inflation, short- and long-term interest rates. On top of that the U.S. trade balance explains significant shares of variances related to Latin American inflation. This implies that U.S. based shocks are likely to feed via both the trade and the financial channel into Latin America's domestic economy.

[15]See Feldkircher & Korhonen (2014); Cesa-Bianchi *et al.* (2012) for recent contributions examining the importance of China for the global economy.

6 Conclusions

In this paper we examine the international transmission of aggregate demand, supply and monetary policy shocks emanating from the U.S. economy using a multi-country model. The global vector autoregressive model allows for a coherent assessment of the international transmission of these shocks by taking cross-country higher order effects into account. We identify the structural shocks via constraints put on the impulse response functions in the U.S. country model, while the transmission is assessed in a empirical manner by means of the global model. Following Fry & Pagan (2011) we pick the rotation matrix for identification that minimizes the distance to the median response over a set of different matrices. In deviation from existing work we estimate the global model employing Bayesian techniques that allow for variable selection at the country level. More specifically, the stochastic search variable selection prior proposed by George *et al.* (2008) is placed on the coefficients, while uncertainty about the choice of cross-country linkages is accounted for by averaging results over the three weight matrices that receive strongest posterior support. Our results are thus robust to a wide range of potential misspecifications and can be summarized as follows:

First, we assess the *international effects* triggered by U.S. based shocks and find positive spillovers from the U.S. on the global economy. For all three shocks, international real output responds in parallel with its U.S. counterpart. That is, positive demand and supply shocks trigger a rise in real output, while a contractionary monetary policy shock decreases output throughout the regions. Moreover, we find most pronounced effects to a monetary policy shocks, while responses of real output to shocks originating from aggregate demand and supply are more modest. Our analysis thus generalizes findings provided in Canova (2005) for Latin America. Furthermore, the shape of international responses depends on the nature of the shocks. In line with expectations, international responses to U.S. demand shocks are rather short-lived while responses to the U.S. supply and monetary policy shocks tend to be permanent and significant. With respect to the latter, we reject long-run neutrality of domestic output to a monetary policy shock for the U.S. economy itself. Our analysis shows, however, that spillovers generated from this monetary policy shock tend to impact permanently on international output (Kim, 2001; Willems, 2013).

Second, we examine the *transmission channel* through which U.S. shocks spread internationally. We find evidence for several facets of the transmission mechanism, of which the financial channel appears as most essential. Responses of domestic interest rates tend to be strong in the short-run – in particular so to U.S. aggregate supply and monetary policy disturbances. A forecast error variance decomposition lends further support to the financial channel: U.S. interest rates appear systematically as important factor explaining forecast error variances related to domestic output, short-term interest rates and inflation. This emphasizes the pivotal role of the U.S.A. in shaping global financial markets. In this vein we confirm findings provided in Canova (2005) for Latin America and Kim (2001) for non-U.S. G7 countries and indirectly Ehrmann & Fratzscher (2009) who demonstrate how contagion through interest rates affect international equity markets. While we do not find evidence for the trade channel, other mechanisms through which U.S. shocks spill over can be recovered from our analysis. As such, we find evidence for international price linkages, either directly or indirectly via movements in the oil price, which appear as important control variables in the reduced form of nearly all domestic equations and throughout the regions. This finding is corroborated by forecast error variance decompositions which reveal U.S. inflation and the oil price to account for significant shares of forecast error variance. Evidence for international inflation linkages is in line with findings in Galesi &

M. J. Lombardi (2013). The transmission channel is complemented by direct co-movements in output, which can be evidenced by the associated forecast error variance decompositions.

Third, some systematic *cross-regional differences* emerged from the analysis. As such, the U.S. shocks trigger more immediate responses of real output in advanced economies, while reactions tend to be more delayed in emerging economies in Europe and Latin America. Also, these economies are modeled more parsimoniously in terms of foreign factors, which might hint at a more simple mechanism through which external shocks are fed into the respective domestic economies. While we have found evidence for spillovers via domestic interest rates in all regions, the responses in Latin America are particularly pronounced. This might be explained by the fact that Latin American economies tend to peg their domestic currencies in one way or the other to the U.S. dollar. Looking at the foreign factors that account for large shares of forecast error variance in domestic output, short-term interest rates and inflation, variables from leading industrialized economies and China appear frequently in the data. Depending on the region under consideration, additional local specifics emerge. As such, variables from the euro area resurface most frequently as determinants of forecast error variance in emerging Europe, and U.S. related variables in Latin America respectively. Also Korea and Indonesia explain significant shares of forecast error variance in Asia. These determinants thus resemble international patterns in trade and financial flows.

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A Appendix

A.1 Tables & Data Overview

Table A1: Country coverage

Advanced Economies (11):	U.S.A., EA, UK, CA, AU, NZ, CH, NO, SE, DK, IS
Emerging Europe (18):	CZ, HU, PL, SK, SI, BG, RO, HR, AL, RS, TR, LT, LV, EE, RU, UA, BY, GE
Asia (9):	CN, KR, JP, PH, SG, TH, ID, IN, MY
Latin America (5):	AR, BR, CL, MX, PE

Abbreviations refer to the two-digit ISO country code.

Table A2: Data description

Variable	Description	Min.	Mean	Max.	Coverage
y	Real GDP, average of 2005=100. Seasonally adjusted, in logarithms.	3.682	4.527	5.332	100%
Δp	Consumer price inflation. CPI seasonally adjusted, in logarithms.	-0.213	0.020	1.215	100%
e	Nominal exchange rate vis-à-vis the U.S. dollar, deflated by national price levels (CPI).	-5.699	-2.308	5.459	97.8%
i_S	Typically 3-months-market rates, rates per annum.	-0.001	0.097	4.332	95.6%
i_L	Typically government bond yields, rates per annum.	0.006	0.060	0.777	43.2%
tb	Ratio of real exports to real imports. Seasonally adjusted, in logarithms.	-0.315	-0.006	0.106	97.7%
$poil$	Price of oil, seasonally adjusted, in logarithms.	-	-	-	-
Trade flows	Bilateral data on exports and imports of goods and services, annual data.	-	-	-	-
Banking exposure	Bilateral outstanding assets and liabilities of banking offices located in BIS reporting countries and Russia. Annual data.	- -	- -	- -	- -
FDI	Bilateral foreign direct investment positions, annual data.	-	-	-	-

Summary statistics pooled over countries and time.

The coverage refers to the cross-country availability per country, in %. Data are from the IMF's IFS data base and national sources. Trade flows stem from the IMF's DOTS data base, data on banking exposure from the BIS and foreign direct investment positions from the IMF's CDIS data base. For more details see Feldkircher (2013).

A.2 Uncertainty about the Linkages

Since foreign variables play a vital role in GVAR modeling, taking uncertainty about the specification thereof is essential to assess the robustness of empirical results. In what follows, we examine both the marginal likelihood of the country models and the overall global model for different specifications of W. Note that we do not mix specifications, i.e., for each W we assume the same specification across countries. To simplify notation, we denote a generic global weighting matrix as W, with the different types of matrices denoted by $W^{(q)}$, $q = 1, ..., Q$. Formally, the global marginal likelihood conditional on $W^{(q)}$ is given by

$$p(x_t|W^{(q)}) = \int p(x_t|\Psi, W^{(q)})p(\Psi|x_t, W^{(q)})d\Psi \tag{20}$$

Normalizing yields marginal-likelihood based weights:

$$p(W^{(q)}|x_t) = \frac{p(x_t|W^{(q)})}{\sum_{q=1}^{Q} p(x_t|W^{(q)})} \tag{21}$$

We integrate out uncertainty attached to the specification of W by computing weighted averages of any quantity of interest (e.g., impulse responses, forecast error variance decompositions etc.) denoted by Θ. This implies that the posterior of Θ is given by

$$p(\Theta|y) = \sum_{q=1}^{Q} p(\Theta|y, W^{(q)})p(W^{(q)}|x_t) \tag{22}$$

Note that as mentioned above, in our application $Q = 9$ rendering the summation in Equation 22 feasible. The marginal likelihood has been computed using the Bayesian Information Criterion (BIC) approximation.

We use the following types of weights:

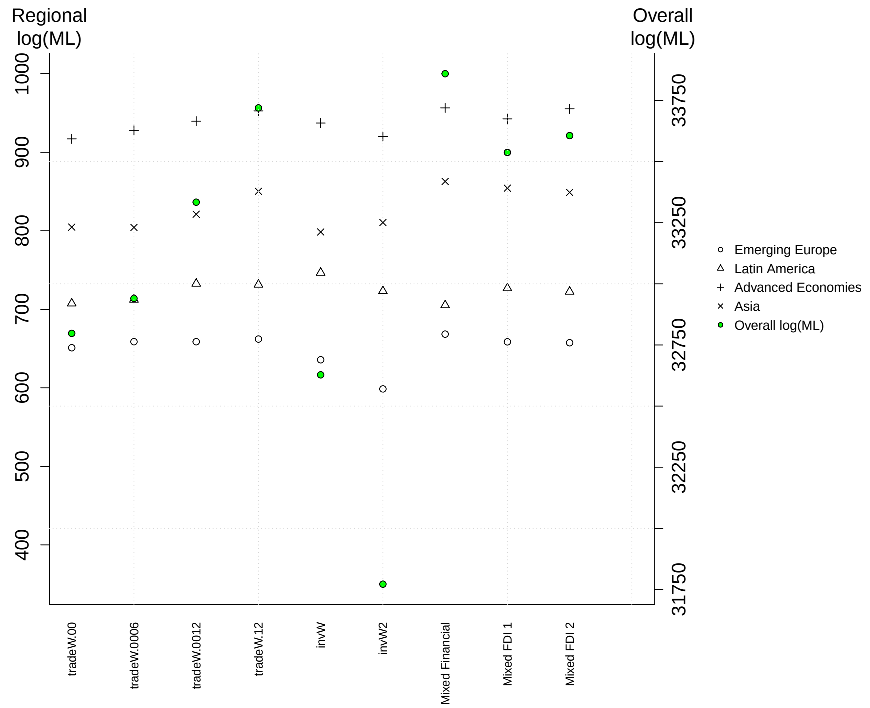
1. Trade flows from 2000 (**tradeW.00**).
2. Trade flows averaged over the pre-crisis period from 2000 to 2006 (**tradeW.0006**).
3. Trade flows averaged over the period from 2000 to 2012 (**tradeW.0012**).
4. Trade flows in 2012 (**tradeW.12**).
5. Inverse distances measured in km between capital cities (**invW**).
6. Inverse distances between capital cities squared (**invW2**).
7. Outstanding assets and liabilities of mainly BIS reporting banks[16], averaged over the period from 2007 to 2008 to weight i_l and i_s, **tradeW.0012** for y, Δp and e (**MixedFinancial**).
8. Foreign direct investment positions averaged over the period from 2009-2012, asset side, to weight i_l and i_s, and trade flows averaged over the period from 2000 to 2012 for y,Δp and e (**MixedFDI1**).

[16] A thorough description is included in Backé *et al.* (2013).

9. Foreign direct investment positions averaged over the period from 2009-2012, liability side, to weight i_l and i_s, and trade flows averaged over the period from 2000 to 2012 for y, Δp and e (**MixedFDI2**).

Trade flows entail exports and imports of goods and services, data on FDI is taken from the IMF Foreign Direct Investment Survey (CDIS) database. For the latter we distinguish asset side and liability side channels by reversing the assignment of claims by country. The results are summarized in Figure A1 below:

Figure A1: Regional and Overall Marginal Likelihoods for Different Weight Matrices



Notes: The left-hand axis plots the marginal likelihood for different regions, the right-hand axis the overall marginal likelihood.

The plot shows the cross-country marginal likelihoods on the left-hand axis and the overall marginal likelihoods on the right-hand axis. It reveals the mixed weighting approach using bank exposures for financial variables and trade flows for real variables as the one which receives by far the strongest overall posterior support in the data. With the exception of Latin America, this holds also true across countries. Other matrices that are supported by the data are trade weights in 2012 (**tradeW.12**) and a variant employing FDI positions (**MixedFDI2**). These three link matrices account for almost 99% of the posterior support of the weights calculated as in Equation 22. Consequently, we account for uncertainty regarding the choice of W by basing the following inference on a weighted average of the matrices **MixedFinancial**, **tradeW.12** and **MixedFDI2**.

Table A3: Specification of the country models

Countries	Domestic Variables	Foreign Variables	Dummy Variables
EA	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$Dp \times$ eaD$_{(07Q4-08Q4)}$, eaD$_{(07Q4-08Q4)}$
US	y, Δp, i_s, i_l, tb, $poil$	y^*, Δp^*,e^*, i_s^*, i_l^*	$Dp \times$ usD$_{(07Q4-08Q4)}$, usD$_{(07Q4-08Q4)}$
UK	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
JP	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
CN	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
CZ	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ czD$_{(97Q1-97Q2)}$, czD$_{(97Q1-97Q2)}$
HU	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
PL	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
SI	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ siD$_{(95Q1-96Q4)}$, siD$_{(95Q1-96Q4)}$
SK	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
BG	y, Δp, e, i_s, tb, i_l	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ bgD$_{(95Q1-97Q2)}$, $Dp \times$ bgD$_{(95Q1-97Q2)}$ bgD$_{(95Q1-97Q2)}$
RO	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ roD$_{(96Q4-97Q3,98Q1,98Q4-99Q2)}$, $Dp \times$ roD$_{(96Q4-97Q3,98Q1,98Q4-99Q2)}$, $e \times$ roD$_{(96Q4-97Q3,98Q1,98Q4-99Q2)}$, roD$_{(96Q4-97Q3,98Q1,98Q4-99Q2)}$
EE	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ eeD$_{(97Q4-99Q1)}$, eeD$_{(97Q4-99Q1)}$
LT	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ ltD$_{(95Q1-96Q4)}$, ltD$_{(95Q1-96Q4)}$
LV	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ lvD$_{(95Q1-96Q4)}$, lvD$_{(95Q1-96Q4)}$
HR	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ hrD$_{(95Q1-96Q2)}$, hrD$_{(95Q1-96Q2)}$
AL	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ alD$_{(97Q1-98Q3)}$, alD$_{(97Q1-98Q3)}$
RS	y, Δp, e	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ rsD$_{(98Q4-00Q4)}$, rsD$_{(98Q4-00Q4)}$
RU	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ ruD$_{(95Q1-95Q3,98Q3)}$, ruD$_{(95Q1-95Q3,98Q3)}$
UA	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ uaD$_{(98Q3-99Q4)}$, uaD$_{(98Q3-99Q4)}$
BY	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
GE	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ geD$_{(95Q1-96Q4)}$, geD$_{(95Q1-96Q4)}$
KG	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
AR	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ arD$_{(01Q4-02Q3)}$, $e \times$ arD$_{(01Q4-02Q3)}$, arD$_{(01Q4-02Q3)}$
BR	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ brD$_{(95Q1-95Q4)}$,$Dp \times$ brD$_{(95Q1-95Q4)}$, brD$_{(95Q1-95Q4)}$
CL	y, Δp, e, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
MX	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$Dp \times$ mxD$_{(95Q1-98Q4)}$, mxD$_{(95Q1-98Q4)}$
PE	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	peD$_{(98Q3)}$
KR	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ krD$_{(97Q4-98Q2)}$, $Dp \times$ krD$_{(97Q4-98Q2)}$, krD$_{(97Q4-98Q2)}$
PH	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
SG	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
TH	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ thD$_{(97Q3-98Q2)}$, thD$_{(97Q3-98Q2)}$, $e \times$ thD2$_{(95Q1-98Q3)}$, thD2$_{(95Q1-98Q3)}$
IN	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$Dp \times$ inD$_{(98Q4-99Q4)}$, inD$_{(98Q4-99Q4)}$
ID	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ idD$_{(97Q3-98Q2)}$, $e \times$ idD$_{(97Q3-98Q2)}$, $Dp \times$ idD$_{(97Q3-98Q2)}$ idD$_{(97Q3-99Q2)}$
MY	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$e \times$ myD$_{(95Q1-97Q4)}$, eD$_{(95Q1-97Q4)}$
AU	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
NZ	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
TR	y, Δp, e, i_s, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	$i_s \times$ trD$_{(00Q4-01Q1)}$, trD$_{(00Q4-01Q1)}$
CA	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
CH	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
NO	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
SE	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
DK	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-
IS	y, Δp, e, i_s, i_l, tb	y^*, Δp^*, e^*, i_s^*, i_l^*, $poil^{**}$	-

Notes: The table represents the general specification and variable cross-country variable coverage of our GVAR model. Throughout the paper we have used 1 lag for endogenous, weakly exogenous and strictly exogenous variables only.

Table A4: Posterior Inclusion Probabilities across Countries

	y	Δp	e	i_s	i_l	tb
Cons	0.660	0.850	0.517	0.720	0.711	0.859
Trend	0.993	0.982	0.979	0.992	0.996	0.990
y_t^*	0.872	0.618	0.593	0.479	0.546	0.561
Δp_t^*	0.807	0.910	0.437	0.886	0.865	0.913
e_t^*	0.472	0.584	0.961	0.476	0.541	0.647
$i_{s,t}^*$	0.468	0.467	0.395	0.595	0.670	0.595
$i_{l,t}^*$	0.567	0.698	0.465	0.653	0.574	0.706
$poil_t$	0.839	0.958	0.433	0.891	0.989	0.989
y_{t-1}^*	0.693	0.630	0.587	0.484	0.665	0.520
Δp_{t-1}^*	0.783	0.893	0.639	0.900	0.877	0.922
e_{t-1}^*	0.455	0.496	0.856	0.522	0.566	0.589
$i_{s,t-1}^*$	0.439	0.553	0.511	0.601	0.509	0.420
$i_{l,t-1}^*$	0.637	0.610	0.481	0.650	0.720	0.685
$poil_{t-1}$	0.788	0.988	0.397	0.940	0.988	0.989
Ø	0.652	0.701	0.563	0.673	0.709	0.711
y_{t-1}	0.940	0.341	0.438	0.426	0.412	0.484
Δp_{t-1}	0.789	0.906	0.594	0.872	0.927	0.944
e_{t-1}	0.574	0.822	1.000	0.592	0.767	0.950
$i_{s,t-1}$	0.542	0.560	0.438	0.889	0.702	0.589
$i_{l,t-1}$	0.491	0.597	0.453	0.627	0.554	0.619
tb_{t-1}	0.600	0.718	0.501	0.767	0.575	0.817
Ø	0.656	0.658	0.571	0.696	0.656	0.734

Advanced Economies

	y	Δp	e	i_s	i_l	tb
Cons	0.716	0.940	0.479	0.725	0.858	0.929
Trend	0.988	0.967	0.983	0.986	0.994	0.988
y_t^*	0.776	0.313	0.493	0.367	0.611	0.512
Δp_t^*	0.792	0.959	0.458	0.623	0.848	0.866
e_t^*	0.400	0.411	0.864	0.509	0.423	0.540
$i_{s,t}^*$	0.400	0.499	0.520	0.573	0.801	0.556
$i_{l,t}^*$	0.717	0.723	0.587	0.611	0.834	0.867
$poil_t$	0.709	0.688	0.379	0.517	0.814	0.890
y_{t-1}^*	0.585	0.387	0.587	0.506	0.589	0.668
Δp_{t-1}^*	0.792	0.921	0.476	0.711	0.717	0.904
e_{t-1}^*	0.421	0.370	0.769	0.363	0.546	0.485
$i_{s,t-1}^*$	0.461	0.504	0.530	0.551	0.422	0.449
$i_{l,t-1}^*$	0.579	0.778	0.486	0.495	0.958	0.809
$poil_{t-1}$	0.674	0.660	0.395	0.592	0.821	0.891
Ø	0.609	0.601	0.545	0.535	0.699	0.703
y_{t-1}	1.000	0.186	0.511	0.384	0.360	0.447
Δp_{t-1}	0.515	0.773	0.541	0.504	0.758	0.654
e_{t-1}	0.566	0.561	1.000	0.379	0.741	0.788
$i_{s,t-1}$	0.501	0.513	0.460	0.803	0.826	0.622
$i_{l,t-1}$	0.492	0.761	0.658	0.668	0.919	0.705
tb_{t-1}	0.753	0.671	0.553	0.591	0.817	0.789
Ø	0.638	0.577	0.621	0.555	0.737	0.668

Asia

	y	Δp	e	i_s	i_l	tb
Cons	0.676	0.643	0.459	0.409	0.144	0.806
Trend	0.989	0.976	0.982	0.973	0.974	0.989
y_t^*	0.852	0.431	0.391	0.283	0.146	0.666
Δp_t^*	0.523	0.647	0.478	0.515	0.716	0.598
e_t^*	0.439	0.448	0.937	0.294	0.158	0.600
$i_{s,t}^*$	0.363	0.328	0.356	0.451	0.604	0.479
$i_{l,t}^*$	0.477	0.585	0.520	0.578	0.786	0.509
$poil_t$	0.725	0.805	0.342	0.419	0.138	0.943
y_{t-1}^*	0.657	0.384	0.464	0.180	0.004	0.608
Δp_{t-1}^*	0.589	0.723	0.399	0.480	0.684	0.672
e_{t-1}^*	0.336	0.320	0.757	0.232	0.178	0.472
$i_{s,t-1}^*$	0.520	0.445	0.486	0.531	0.346	0.473
$i_{l,t-1}^*$	0.522	0.475	0.511	0.498	0.708	0.534
$poil_{t-1}$	0.653	0.730	0.383	0.477	0.502	0.953
Ø	0.554	0.527	0.502	0.411	0.414	0.626
y_{t-1}	1.000	0.241	0.353	0.231	0.120	0.550
Δp_{t-1}	0.469	0.732	0.549	0.548	0.016	0.546
e_{t-1}	0.544	0.571	1.000	0.326	0.244	0.720
$i_{s,t-1}$	0.520	0.759	0.431	0.961	0.850	0.743
$i_{l,t-1}$	0.516	0.430	0.502	0.427	1.000	0.653
tb_{t-1}	1.000	0.372	0.398	0.438	0.268	0.544
Ø	0.675	0.518	0.539	0.488	0.416	0.626

Emerging Europe

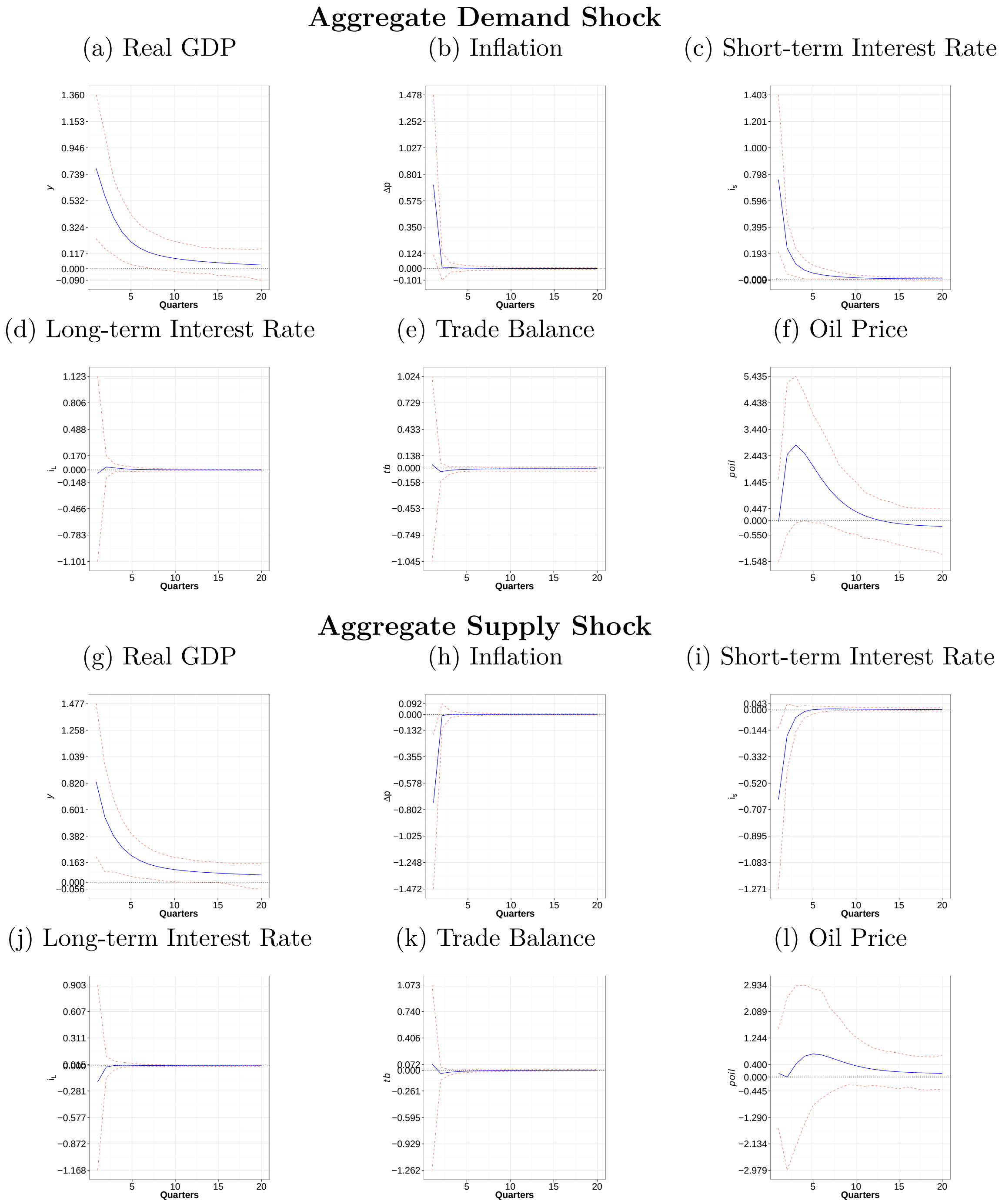
	y	Δp	e	i_s	i_l	tb
Cons	0.692	0.759	0.488	0.524	0.014	0.940
Trend	0.992	0.980	0.984	0.988	0.956	0.986
y_t^*	0.741	0.547	0.395	0.204	0.130	0.945
Δp_t^*	0.846	0.789	0.609	0.469	0.324	0.853
e_t^*	0.339	0.330	0.564	0.409	0.016	0.734
$i_{s,t}^*$	0.390	0.514	0.507	0.700	0.378	0.649
$i_{l,t}^*$	0.594	0.901	0.345	0.410	1.000	0.940
$poil_t$	0.961	0.988	0.599	0.408	0.124	0.988
y_{t-1}^*	0.578	0.763	0.558	0.252	0.142	0.912
Δp_{t-1}^*	0.822	0.844	0.666	0.371	0.214	0.874
e_{t-1}^*	0.404	0.333	0.560	0.207	0.084	0.592
$i_{s,t-1}^*$	0.600	0.563	0.418	0.446	0.238	0.635
$i_{l,t-1}^*$	0.592	0.664	0.542	0.590	0.808	0.832
$poil_{t-1}$	0.909	0.992	0.389	0.383	0.080	0.986
Ø	0.648	0.686	0.513	0.404	0.295	0.828
y_{t-1}	1.000	0.301	0.682	0.272	0.010	0.574
Δp_{t-1}	0.821	0.485	0.548	0.471	0.196	0.602
e_{t-1}	0.710	0.944	1.000	0.515	0.140	0.901
$i_{s,t-1}$	0.782	0.758	0.395	0.955	1.000	0.919
$i_{l,t-1}$	0.275	0.423	0.502	0.604	0.380	0.998
tb_{t-1}	0.986	0.996	0.542	0.376	0.834	0.996
Ø	0.762	0.651	0.612	0.532	0.427	0.832

Latin America

Notes: The table shows averages of posterior inclusion probabilities across per country group. Note that due to data availability, the average PIPs explaining domestic long-term interest rates might be composed of only a limited set of countries. Averages of PIPs shown for foreign variables (excluding the constant and the trend term) and domestic variables.

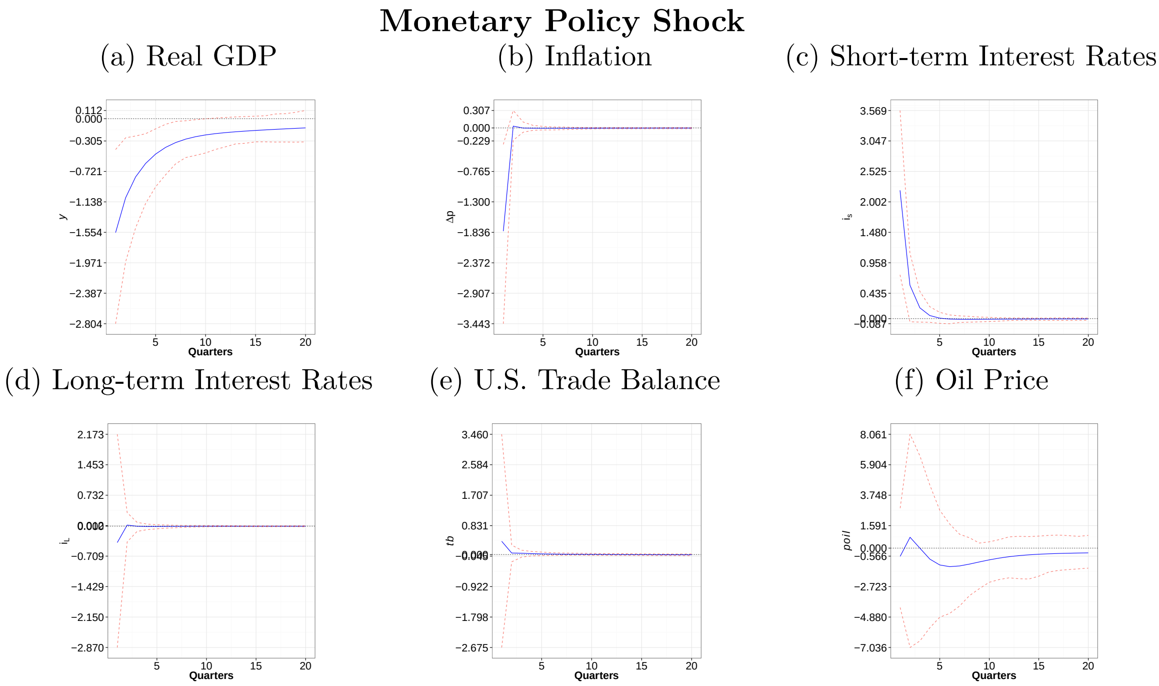
A.3 U.S. Responses

Figure A2: U.S. Response to positive Aggregate Supply and Demand Shocks (1.s.e)



Notes: Median impulse response in blue (solid line) along with 25th and 75th percentiles in red (dashed line). Results in percentages and based on 1000 iterations that are randomly extracted from the full set of posterior draws.

Figure A3: U.S. Response to a contractionary Monetary Policy Shock (1 s.e.)



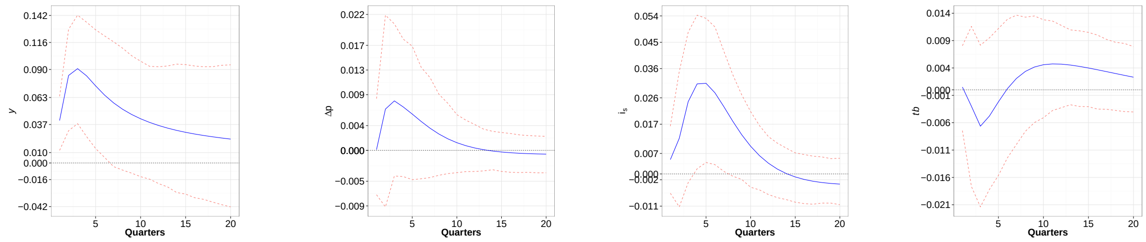
Notes: Median impulse response in blue (solid line) along with 25th and 75th percentiles in red (dashed line). Results in percentages and based on 1000 iterations that are randomly extracted from the full set of posterior draws.

A.4 International Responses

Figure A4: Positive U.S. Aggregate Demand Shock (1 s.e.)

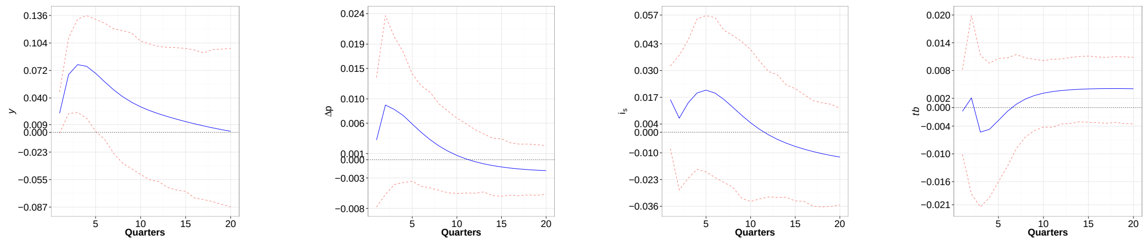
Advanced Economies

(a) Real GDP (b) Inflation (c) Interest rates (d) Trade Balance



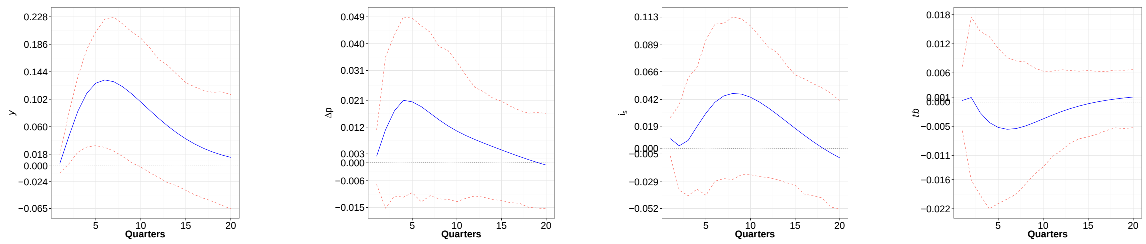
Asia

(e) Real GDP (f) Inflation (g) Interest rates (h) Trade Balance



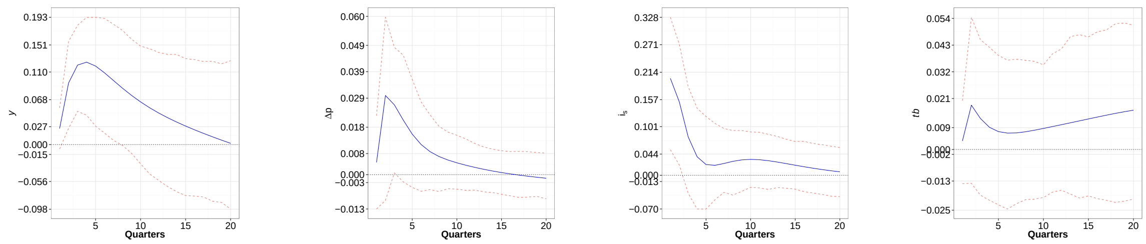
Emerging Europe

(i) Real GDP (j) Inflation (k) Interest rates (l) Trade Balance



Latin America

(m) Real GDP (n) Inflation (o) Interest rates (p) Trade Balance

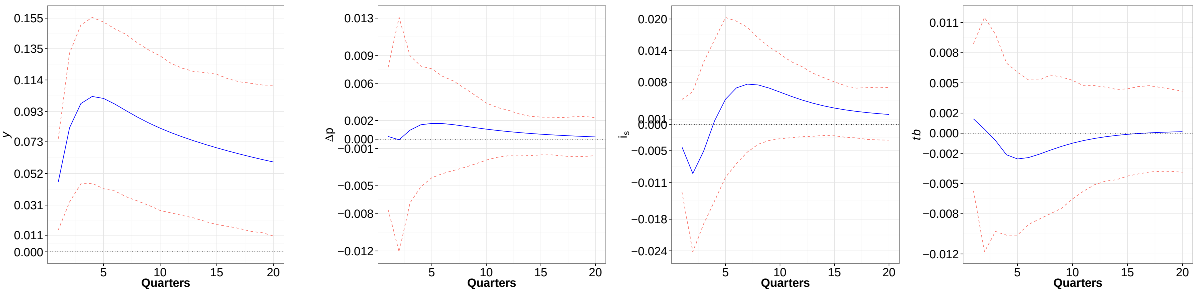


Notes: Median impulse response in blue (solid line) along with 25th and 75th percentiles in red (dashed line). Results in percentages and based on 1000 iterations that are randomly extracted from the full set of posterior draws. Unweighted responses per region reported. U.S. responses excluded from advanced economies.

Figure A5: Positive U.S. Aggregate Supply Shock (1 s.e.)

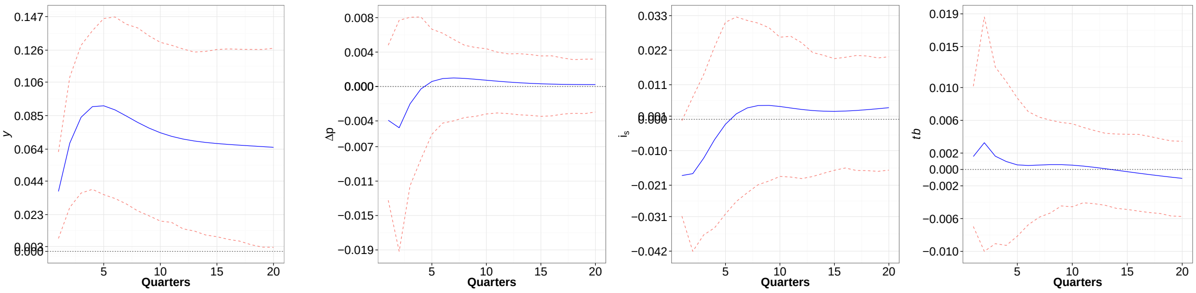
Advanced Economies

(a) Real GDP (b) Inflation (c) Interest rates (d) Trade Balance



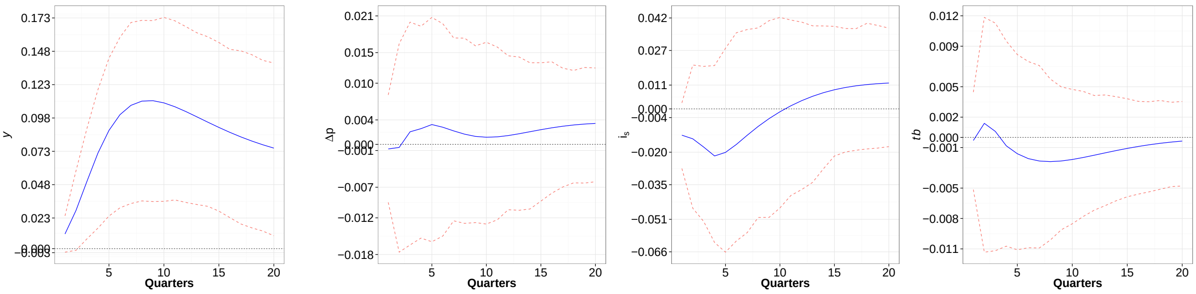
Asia

(e) Real GDP (f) Inflation (g) Interest rates (h) Trade Balance



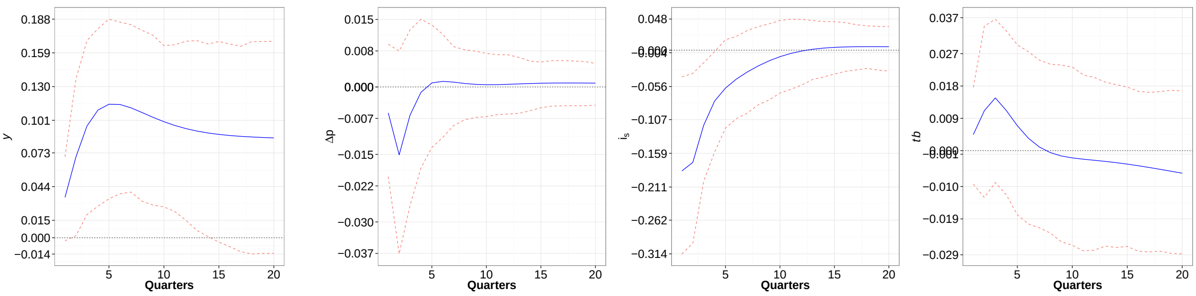
Emerging Europe

(i) Real GDP (j) Inflation (k) Interest rates (l) Trade Balance



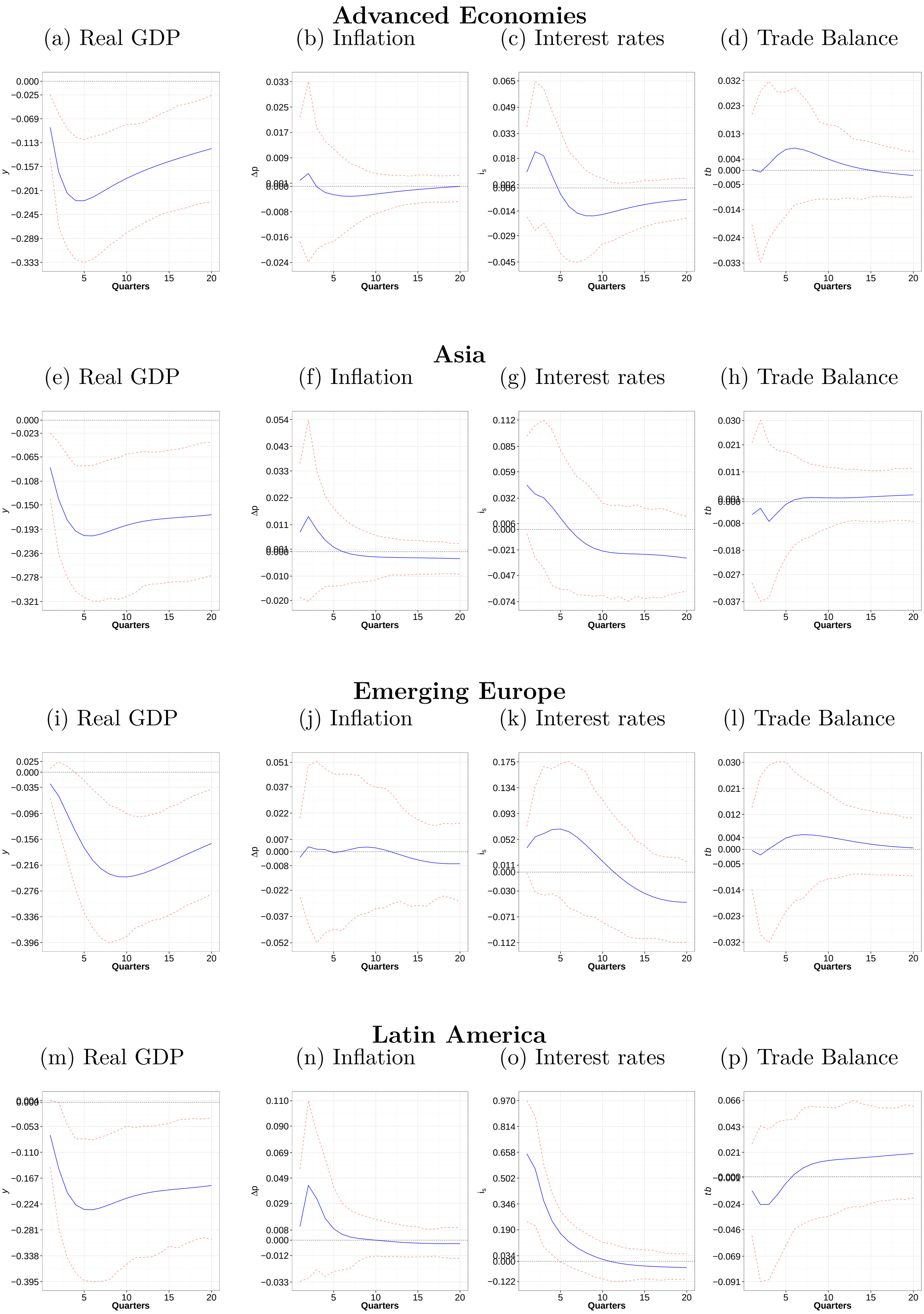
Latin America

(m) Real GDP (n) Inflation (o) Interest rates (p) Trade Balance



Notes: Median impulse response in blue (solid line) along with 25th and 75th percentiles in red (dashed line). Results in percentages and based on 1000 iterations that are randomly extracted from the full set of posterior draws. Unweighted responses per region reported. U.S. responses excluded from advanced economies.

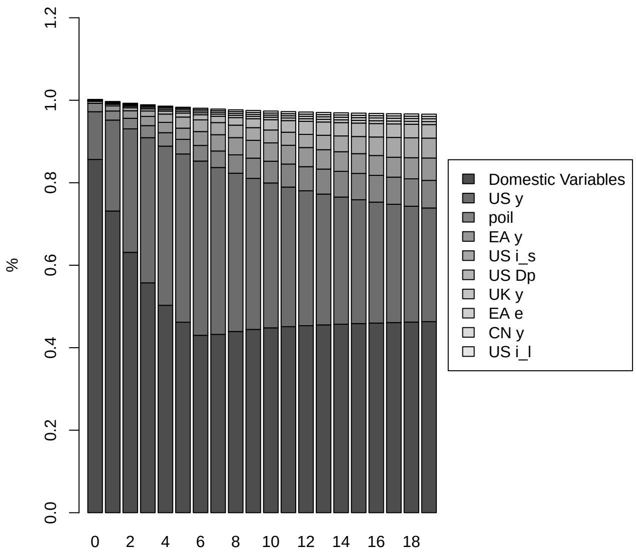
Figure A6: Contractionary U.S. Monetary Policy Shock (1 s.e.)



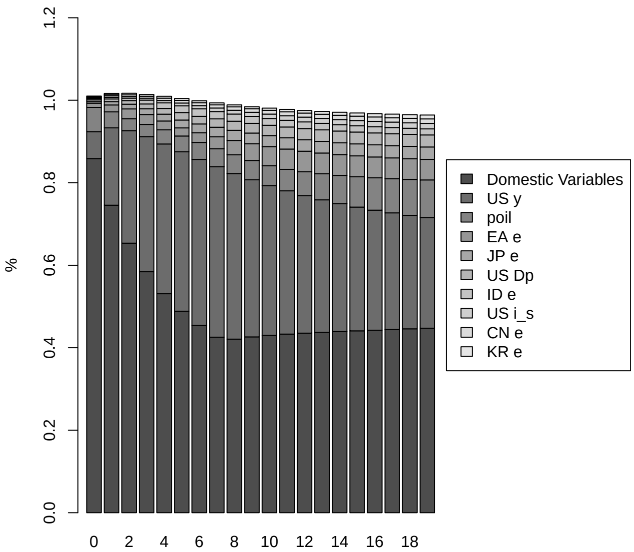
Notes: Median impulse response in blue (solid line) along with 25th and 75th percentiles in red (dashed line). Results in percentages and based on 1000 iterations that are randomly extracted from the full set of posterior draws. Unweighted responses per region reported. U.S. responses excluded from advanced economies.

Figure A7: Average Forecast Error Variance Decompositions of real Output across Regions.

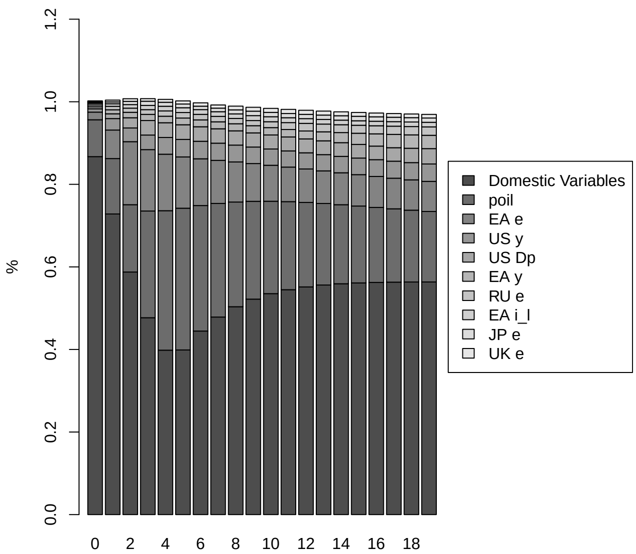
(a) Shock to real GDP in Advanced Economies



(b) Shock to real GDP in Asia



(c) Shock to real GDP in Emerging Europe



(d) Shock to real GDP in Latin America

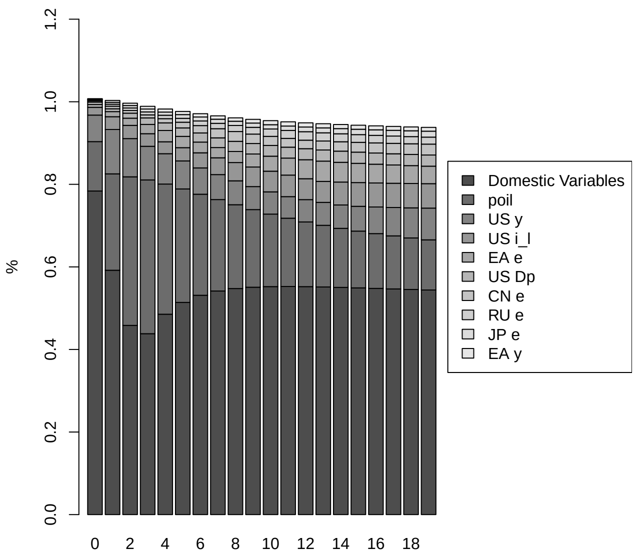
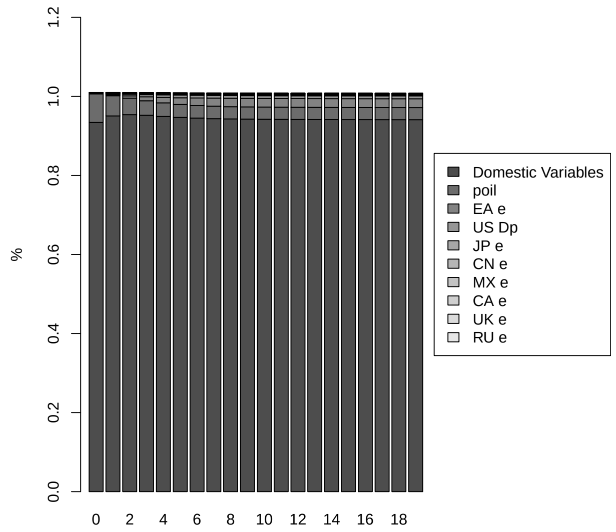
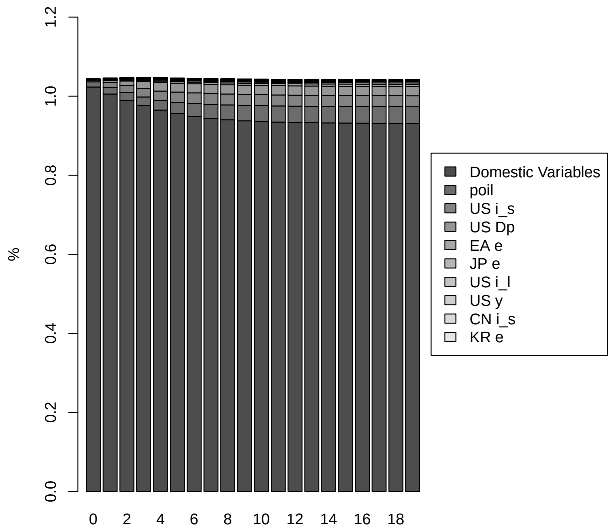


Figure A8: Average Forecast Error Variance Decompositions of Inflation across Regions.

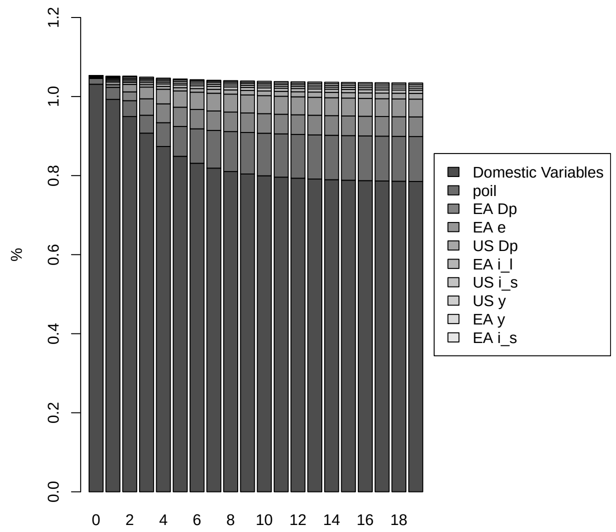
(a) Shock to Inflation in Advanced Economies



(b) Shock to Inflation in Asia



(c) Shock to Inflation in Emerging Europe



(d) Shock to Inflation in Latin America

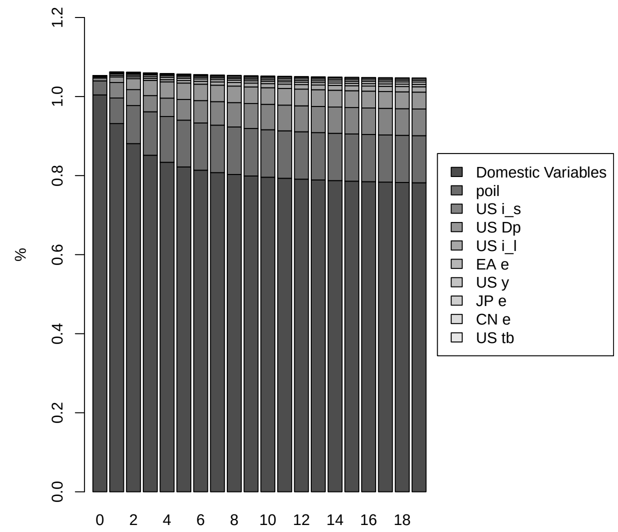
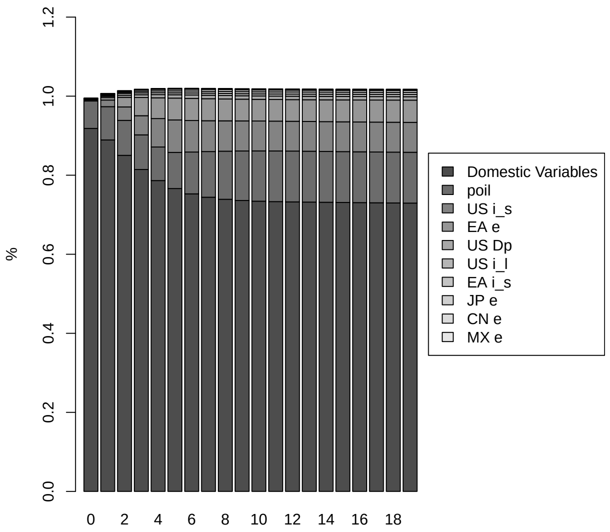
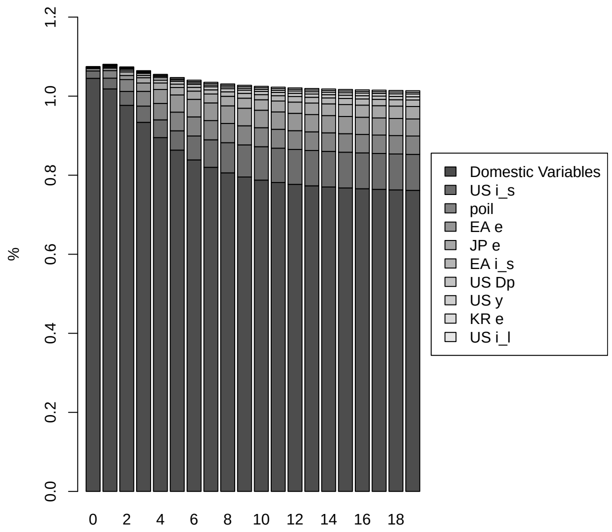


Figure A9: Average Forecast Error Variance Decompositions of short-term interest rates across Regions.

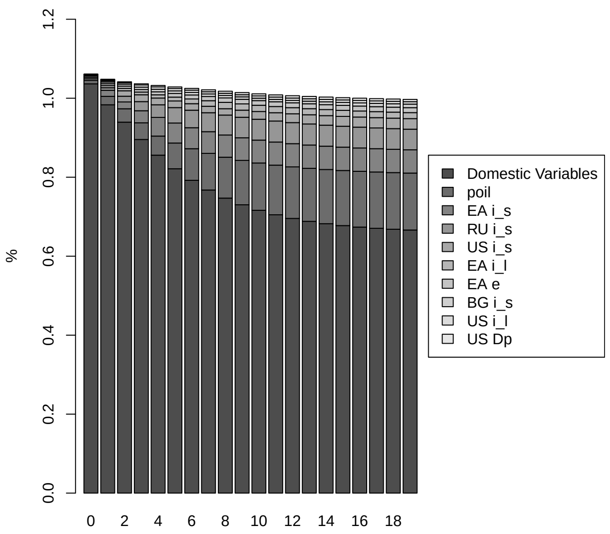
(a) Shock to interest rates in Advanced Economies



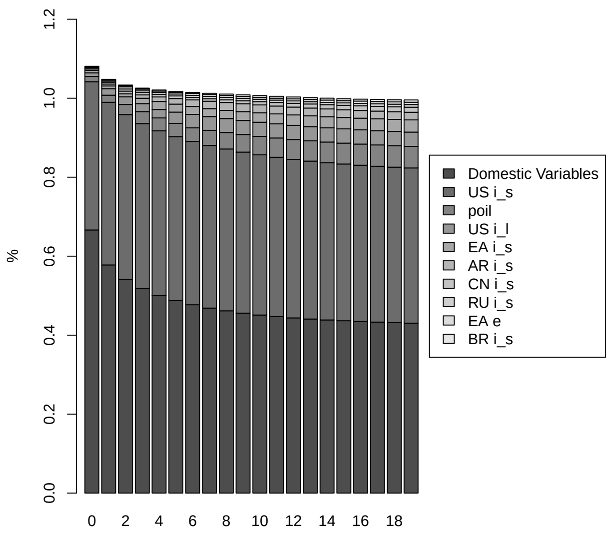
(b) Shock to interest rates in Asia



(c) Shock to interest rates in Emerging Europe



(d) Shock to interest rates in Latin America



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Visiting Research Program

The Oesterreichische Nationalbank (OeNB) invites applications from external researchers for participation in a Visiting Research Program established by the OeNB's Economic Analysis and Research Department. The purpose of this program is to enhance cooperation with members of academic and research institutions (preferably post-doc) who work in the fields of macroeconomics, international economics or financial economics and/or with a regional focus on Central, Eastern and Southeastern Europe.

The OeNB offers a stimulating and professional research environment in close proximity to the policymaking process. Visiting researchers are expected to collaborate with the OeNB's research staff on a prespecified topic and to participate actively in the department's internal seminars and other research activities. They will be provided with accommodation on demand and will, as a rule, have access to the department's computer resources. Their research output may be published in one of the department's publication outlets or as an OeNB Working Paper. Research visits should ideally last between 3 and 6 months, but timing is flexible.

Applications (in English) should include

- a curriculum vitae,
- a research proposal that motivates and clearly describes the envisaged research project,
- an indication of the period envisaged for the research visit, and
- information on previous scientific work.

Applications for 2014 should be e-mailed to *eva.gehringer-wasserbauer@oenb.at* by November 1, 2014.

Applicants will be notified of the jury's decision by mid-December. The following round of applications will close on May 1, 2015.